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EDITORIAL

Impactul Domeniilor de Specializare Inteligentă în Fluid Power

Dr. Ing. **Gabriela Matache**
REDACTOR ȘEF

Odată cu accelerarea evoluției tehnologice, specializarea inteligentă în domeniul Fluid Power se dovedește a fi o oportunitate esențială pentru îmbunătățirea eficienței și sustenabilității în industrie. Această ramură, care utilizează fluide sub presiune pentru generarea și controlul puterii, are un impact semnificativ în sectoare variate, inclusiv construcții, agricultură și producție.

Un aspect remarcabil al specializării inteligente în Fluid Power este potențialul de a optimiza eficiența energetică. Tehnologii avansate, cum ar fi senzorii IoT și algoritmii de optimizare, facilitează monitorizarea în timp real a consumului de energie, permițând ajustări care reduc pierderile. De exemplu, optimizarea presiunii fluidului în funcție de sarcini permite companiilor să scadă costurile și să limiteze impactul asupra mediului, contribuind astfel la atingerea obiectivelor de dezvoltare durabilă.

Inovația reprezintă o altă oportunitate importantă. Prin utilizarea inteligenței artificiale și a analizei datelor, se pot dezvolta soluții personalizate care răspund nevoilor specifice ale clienților. Această capacitate nu numai că îmbunătățește experiența utilizatorului, dar și consolidează competitivitatea pe piață. Sistemele de Fluid Power care își extrag lecții din datele istorice pot anticipa cerințele viitoare, promovând astfel o gestionare mai eficientă a resurselor.

În plus, specializarea inteligentă contribuie la tranziția către economii circulare prin optimizarea proceselor și reducerea risipei. Implementarea soluțiilor durabile permite companiilor să reducă emisiile de carbon și să încurajeze utilizarea eficientă a resurselor, demonstrând astfel un angajament față de responsabilitatea socială și ecologică în fața provocărilor globale.

Totuși, această specializare nu este lipsită de provocări, cum ar fi necesitatea formării continue a personalului și integrarea noilor tehnologii în infrastructurile existente. Colaborarea între universități, institute de cercetare și sectorul industrial devine crucială pentru a depăși aceste obstacole și pentru a stimula inovația.

În concluzie, specializările inteligente în Fluid Power oferă oportunități semnificative pentru creșterea eficienței energetice, stimularea inovației și promovarea sustenabilității. Prin adoptarea de tehnologii moderne și practici inovatoare, acest sector are potențialul de a transforma modul în care gestionăm și utilizăm energia. Investiția în specializare, alături de colaborarea între diverse entități, va fi esențială pentru un viitor sustenabil și inovator.

EDITORIAL

The Impact of Intelligent Specialization Domains in Fluid Power

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EDITOR-IN-CHIEF

With the rapid advancement of technology, smart specialization in the field of Fluid Power proves to be an essential opportunity for improving efficiency and sustainability in industry. This branch, which utilizes pressurized fluids for power generation and control, has a significant impact across various sectors, including construction, agriculture, and manufacturing.

A remarkable aspect of smart specialization in Fluid Power is its potential to optimize energy efficiency. Advanced technologies, such as IoT sensors and optimization algorithms, facilitate real-time monitoring of energy consumption, allowing for adjustments that reduce losses. For example, optimizing fluid pressure based on loads enables companies to lower costs and minimize environmental impact, thereby contributing to the achievement of sustainable development goals.

Innovation represents another important opportunity. By using artificial intelligence and data analytics, customized solutions can be developed that meet specific customer needs. This capability not only enhances user experience but also strengthens market competitiveness. Fluid Power systems that learn from historical data can anticipate future demands, thus promoting more efficient resource management.

In addition, smart specialization contributes to the transition towards circular economies by optimizing processes and reducing waste. Implementing sustainable solutions allows companies to reduce carbon emissions and encourage efficient resource use, thereby demonstrating a commitment to social and ecological responsibility in the face of global challenges.

However, this specialization is not without its challenges, such as the need for continuous staff training and the integration of new technologies into existing infrastructures. Collaboration between universities, research institutes, and the industrial sector becomes crucial to overcoming these obstacles and stimulating innovation.

In conclusion, smart specializations in Fluid Power offer significant opportunities for enhancing energy efficiency, stimulating innovation, and promoting sustainability. By adopting modern technologies and innovative practices, this sector has the potential to transform how we manage and use energy. Investment in specialization, along with collaboration between diverse entities, will be essential for a sustainable and innovative future.

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Assessing the Remaining Useful Life of Hydraulic Pumps: A Review

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Abstract: *Predicting the remaining useful life of hydraulic pumps is critical for ensuring their optimal performance and extending their operational lifespan. Accurate remaining useful life predictions enable timely adjustments to the pump's working conditions, thus enhancing maintenance strategies and preventing unexpected failures. This review comprehensively examines the two primary categories of remaining useful life prediction methods for hydraulic pumps: data-driven and model-driven methods. Data-driven approaches leverage historical and real-time operational data, employing machine learning and statistical analysis techniques to forecast remaining useful life. In contrast, model-driven methods utilize physical models and failure mechanisms to predict the remaining lifespan based on the pump's working conditions and inherent characteristics. By evaluating the strengths and limitations of these methods, this review aims to offer insights into their practical applications and future research directions in the field of hydraulic pump prognostics.*

Keywords: *Hydraulic pumps, data-driven methods, model-driven methods, predictive maintenance, prognostics, remaining useful life*

1. Introduction

Hydraulic systems are fundamental elements in essential mechanical apparatus and are crucial contributors to industrial production and manufacturing operations owing to a multitude of advantages. Hydraulic systems utilize pumps to pressurize fluid, which is then transmitted through tubes to actuators (hydraulic motors and cylinders) for movement or stabilization, before being cycled back through a filter and re-pressurized, offering compactness and efficiency as key advantages [1-5]. These systems utilize fluid power to perform a wide range of functions, from simple mechanical movements to complex automated tasks [1, 2]. Research has extensively explored the impact of fluid properties such as density and viscosity on hydraulic performance [3], and studies on the design and optimization of hydraulic systems have highlighted the importance of precise modeling and simulation [5, 6]. The mathematical modeling and simulation of hydraulic systems facilitate a comprehensive understanding of their operational dynamics and performance characteristics [6-8]. Advancements in computer tools for dynamic analysis [7] and strategies to reduce energy losses in hydraulic installations [8] underscore the ongoing efforts to enhance the efficiency and reliability of hydraulic systems.

The hydraulic pump is the vital converter of mechanical energy to hydraulic energy, essential for supplying pressurized oil throughout the hydraulic system [1]. Modeling and simulating the operation of hydraulic tool holder systems [9], analyzing vibrations in centrifugal pumps for predictive maintenance [10], and determining optimal curves for hydraulic pump profiles [11] are a few examples of the comprehensive research being conducted. Studies have also examined cavitation in centrifugal pumps [12], the influence of fluid nature on driving power in volumetric pumps [13], and dynamic analysis using CFD and FEM methods [14]. Additional research includes testing digital hydraulic cylinders [15], assessing pressure variation effects on gear pump lifespan [16], reviewing progress on digital hydraulic pumps and valves [17], and simulating electro-hydraulic systems for waste baling presses [18]. Investigations into rotating piston shape [19], operating equations of rotating machines [20], and the use of pressure intensifiers in hydraulic units [21] further illustrate the diverse scope of hydraulic system research. Distributed hardware and software architectures for hydraulic drive monitoring [22], technical solutions for digital hydraulic cylinders [23], and the dynamics of hydraulic cylinders [24] continue to advance the field. Design details and fluid flow analysis for centrifugal pumps [25], best maintenance strategies for hydraulic systems [26], and energy use in hydraulic drive systems [27] also contribute significantly to the ongoing development and refinement of hydraulic technologies.

As the hydraulic industry evolves, the complexity of hydraulic pump designs increases, leading to a higher probability of malfunctions. When these pumps fail, it can result in extended downtime for the equipment they control, which negatively impacts production efficiency, creates economic and safety concerns, and can even cause severe injuries in extreme cases. Therefore, it is essential to perform precise and timely fault diagnoses for hydraulic pumps. Accurate fault diagnosis, along with predictions of potential failures, estimates of remaining service life, and ongoing health monitoring, is crucial for ensuring the safety and reliability of hydraulic pumps [28].

Hydraulic pumps faults in engineering equipment are often hidden and complex, making them difficult to detect. This necessitates researching advanced technologies and methods for effective fault diagnosis. The fault diagnosis method for hydraulic pumps involves deploying various sensors to monitor key performance indicators such as pressure, temperature, vibration, and flow. These sensors collect real-time data, known as state monitoring signals, reflecting the pump's operating condition. Advanced software analyzes these signals to identify patterns and anomalies, indicating potential faults. By comparing real-time data with benchmarks, engineers can assess the pump's condition and detect issues early. This proactive approach allows for timely maintenance, preventing unexpected failures and extending the pump's lifespan [29-33].

Hydraulic pump fault diagnosis methods include signal processing, artificial intelligence, and mechanism analysis approaches. Building on fault diagnosis, suitable prediction and analysis methods enable fault forecasting. Additionally, for comprehensive health management throughout the hydraulic pump's life cycle, the remaining useful life (RUL) can be estimated, and continuous health status monitoring can be implemented [28]. Scientifically grounded predictions of the RUL are crucial for implementing Condition-Based Maintenance strategies for hydraulic pumps. The prediction of RUL depends on two key factors: the characterization of the degradation process with a robust health indicator (*HI*), and the application of advanced prediction methodologies to forecast the degradation trajectory. This review aims to investigate the two primary methodologies for forecasting the RUL of hydraulic pumps: data-driven and model-driven methods.

2. Research methodology

A survey was conducted to assess the growing research interest in the RUL of hydraulic pumps. Given the practical significance of this field, the investigation spans from 2012 to 2024. The study reviews a range of journal articles focused on RUL concepts and their applications.

2.1 The common mathematical formulations for predicting RUL of hydraulic pumps

1) Statistical models

a) Linear regression.

$$RUL(t) = [L - D(t)]/k \tag{1}$$

where: *L* - threshold value of the degradation measure (units depend on *D(t)*), e.g., mm for wear); *D(t)* - current degradation measure at time *t* (units depend on the degradation measure, e.g., mm for wear); *k* - degradation rate (units of *D(t)* per unit time, e.g., mm/hour).

b) Polynomial regression.

$$D(t) = \sum_{i=0}^{n} \beta_i t^i \tag{2}$$

where: β_i - regression coefficients (units depend on *D(t)*); *t* - time (hours); D(t) - degradation measure at time *t* (units depend on the degradation measure, e.g., mm for wear).

c) Proportional hazards model (PHM).

$$\lambda(t) = \lambda_0(t)\exp\left(\sum_{i=1}^{n} \beta_i x_i(t)\right) \tag{3}$$

where: *λ(t)* - hazard function at time *t* (failure rate, e.g., failures per hour); $\lambda_0(t)$ - baseline hazard function (failure rate, e.g., failures per hour); β_i - coefficients for covariates; $x_i(t)$ - covariates (e.g., temperature in °C, pressure in pounds per square inch (psi), vibration in units of gravitational force (g)).

d) Weibull distribution.

$$f(t;\lambda,k) = \frac{k}{\lambda}\left(\frac{t}{\lambda}\right)^{k-1} e^{-\left(\frac{t}{\lambda}\right)^k} \tag{4}$$

where: *t* – time, *λ* (scale parameter) characterizes the life scale; *k* (shape parameter) indicates the failure rate behavior.

2) Time series models

a) Autoregressive integrated moving average (ARIMA). $$X(t) = c + \sum_{i=1}^{p} \varphi_i X(t-i) + \sum_{j=1}^{q} \theta_j \varepsilon(t-j) + \varepsilon(t) \quad (5)$$

where: *X(t)* - value of the time series at time *t* (e.g., a sensor reading in appropriate units); c - constant term; φ_i - auto-regressive parameters; θ_j - moving average parameters; *ϵ(t)* - error term at time t.
b) Exponential smoothing (ETS). $$S(t) = \alpha X(t) + (1-\alpha) S(t-1) \quad (6)$$
where: *S(t)* - smoothed value at time *t* (units depend on *X(t)*); *X(t)* - observed value at time *t* (units depend on the measurement, e.g., psi for pressure); *α* - smoothing parameter (unitless).

3) Machine learning models

a) Support vector regression (SVR). $$f(x(t)) = \sum_{i=1}^{n} \left(\alpha_i - \alpha_i^*\right) K\left(x_i(t), x(t)\right) + b \quad (7)$$

where: α_i, α_i^* − Lagrange multipliers; $K(x_i(t),x(t))$ - Kernel function; *b* - bias term.
b) Neural networks. $$y(t) = f\left(Wx(t) + b)\right) \quad (8)$$
where: *W* - weight matrix; *x(t)* - input vector at time *t* (e.g., features like vibration in g, temperature in °C); *b* - bias vector; *f* - activation function.

c) Random Forests. $$RUL(t) = \frac{1}{n} \sum_{i=1}^{n} \left(Tree_i(x(t))\right) \quad (9)$$

where: *n* - number of trees; $Tree_i(x(t))$ - prediction from the *i*-th tree.

4) Stochastic models

a) Hidden Markov models. $$P(X(t)/X(t-1)) = \sum_{i=1}^{n} \left(P(X(t)/S(t)=s_i\right) P(S(t)=s_i / S(t-1)=s_j) \quad (10)$$

where: *P(X(t) /X(t−1))* - probability of *X(t)* given *X(t−1)*; *S(t)* - hidden state at time *t*; *P(X(t)|S(t))* - emission probability; *P(S(t)|S(t-1))* - transition probability.

b) Particle filtering. $$P(X(t)/Z_{1:t}) = \sum_{i=1}^{n} w(t)^i \, \delta\left(X(t) - X(t)^i\right) \quad (11)$$

where: $P(X(t)/Z_{1:t})$ - posterior distribution of the state; $w(t)^i$ - weight of the *i*-th particle; $X(t)^i$ - state of the *i*-th particle. *δ* - Dirac delta function.

5) Physics-based models

a) Physics-of-Failure (PoF) models. $$\frac{dD(t)}{dt} = f(D(t), t, \theta) \quad (12)$$

where: *D(t)* - damage state at time *t* (units depend on the type of damage, e.g., mm for wear); *t* - time (hours); *θ* - model parameters.

6) Bayesian networks. $$P(X_i(t)/Pa(X_i(t))) \quad (13)$$

Structure - directed acyclic graph where nodes represent variables (degradation indicators, operating conditions, health states, RUL) and edges represent dependencies.
Conditional probability tables (CPTs) - define the probability of each node given its parents.

Each of these models requires specific parameters, and the choice of the model depends on the available data, the complexity of the degradation process, and the computational resources.

2.2 Data-driven approach

In the last 12 years, the data-driven approach has gained significant traction in prognostics and health management (PHM) systems, particularly in predicting the RUL of hydraulic pumps. This section explores various data-driven methods, categorized into neural network and non-neural network approaches, employed for RUL prediction in hydraulic pumps.

a) Neural network methods
Neural networks are computational models inspired by the human brain, consisting of interconnected nodes (neurons) that can learn to recognize patterns and make predictions. Neural network-based approaches harness the capabilities of deep learning architectures, which are adept at discerning complex patterns from raw sensor data, thereby facilitating precise predictions of the RUL. This method capitalizes on the neural network's ability to extract and process intricate features from the data, allowing for a comprehensive understanding of the hydraulic pump's condition and performance over time.
Lee et al. [33] devised Health Indices (*HI*) by combining vibration (*v*) and pressure (*p*) signals to represent the health status of hydraulic pumps, by the following mathematical expression:

$$HI = f(v, p) \tag{14}$$

where *f* denotes the function combining *v* and *p*.
Subsequently, they employed a Bidirectional Long Short-Term Memory (Bi-LSTM) neural network to learn from these *HI* and predict the RUL of the hydraulic pumps, with a specific architecture of the Bi-LSTM network, which illustrates the network's layers, connections, and data flow [33].
The Bi-LSTM network is particularly adept at capturing temporal dependencies within the sensor data due to its recurrent structure. This is achieved through the incorporation of both forward and backward information flow in the network's hidden layers. Mathematically, the forward and backward hidden states in the Bi-LSTM cell are updated using the following equations:

$$i_t = \sigma(W_{xi}x_t + W_{hi}h_{t-1} + W_{ci}c_{t-1} + b_i);\ f_t = \sigma(W_{xf}x_t + W_{hf}h_{t-1} + W_{cf}c_{t-1} + b_f);$$
$$o_t = \sigma(W_{x0}x_t + W_{h0}h_{t-1} + W_{c0}c_t + b_0);\ g_t = \tanh(W_{xg}x_t + W_{hg}h_{t-1} + b_g);\ c_t = f_t \otimes c_{t-1} + i_t \otimes g_t; \tag{15}$$
$$h_t = o_t \otimes \tanh(c_t)$$

where i_t, f_t, o_t, g_t, c_t, and h_t represent the input gate, forget gate, output gate, cell gate, cell state, and hidden state at time step *t*, respectively. x_t is the input at time step *t*, and *W* and *b* are the weight matrices and bias vectors, respectively. The sigmoid function *σ* and hyperbolic tangent function *tanh* are used as activation functions, while $\otimes$ denote element-wise multiplication.
Lee et al. [33] utilized flow and pressure data from the gear pump to establish thresholds for different health states, integrated vibration signals with an extended Kalman filter for health index (HI) construction, and employed a BiLSTM neural network trained and analyzed with multiple performance indices for precise future RUL predictions.
Wang et al. [34] employed DCAE (Deep Convolutional Autoencoder) to process vibration data from hydraulic pumps, used the extracted features to construct a *HI* indicating the pump's degradation state, and integrated this *HI* into a Bi-LSTM-based RUL prediction model (fig. 1). Mathematically, the equations below described the DCAE used for vibration data characterization [34]:

$$h = \sigma(W_{conv} * x + b_{conv});\ h_{pool} = pooling(h);\ x' = \sigma(W_{deconv} * upsample(h_{pool}) + b_{deconv}); \tag{16}$$

where: for encoder (the convolutional layer applies filters W_{conv} to input *x*, then adds biases b_{conv}, followed by an activation function *σ* and pooling to extract features h_{pool}); and for decoder (upsamples h_{pool}, applies deconvolutional filters W_{deconv} and activation σ, then adds biases b_{deconv} to reconstruct *x'*).

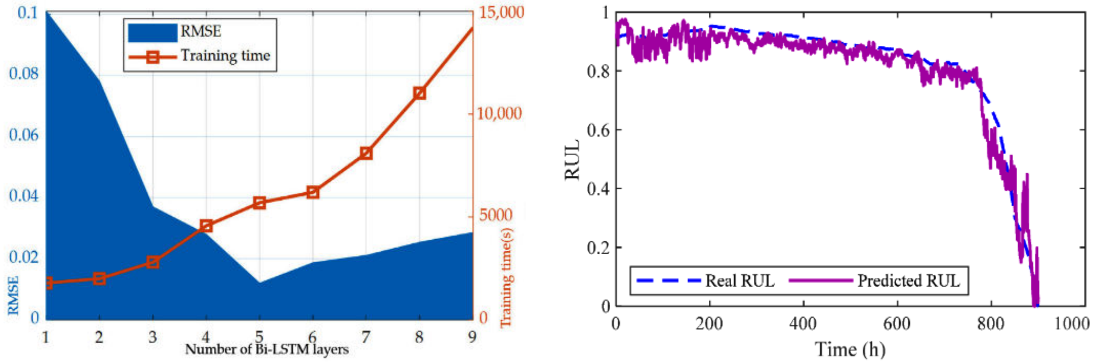

Fig. 1. a) Test results of the model with different Bi-LSTM layers; b) Life prediction results of gear pump). Reprinted from ref. [34] with permission of MDPI AG publisher.

This approach [34] leverages advanced neural network techniques to enhance the accuracy and reliability of predicting the RUL of hydraulic pumps based on their vibration characteristics.
Zhang et al. [35] focused on predicting the RUL of gear pumps using a deep sparse autoencoder for feature extraction and support vector data description for degradation degree calculation. Their method, validated on both public bearing and self-collected gear pump datasets, outperforms comparative algorithms and achieves improved RUL prediction accuracy, demonstrating its effectiveness for mechanical equipment maintenance and operation (fig. 2).

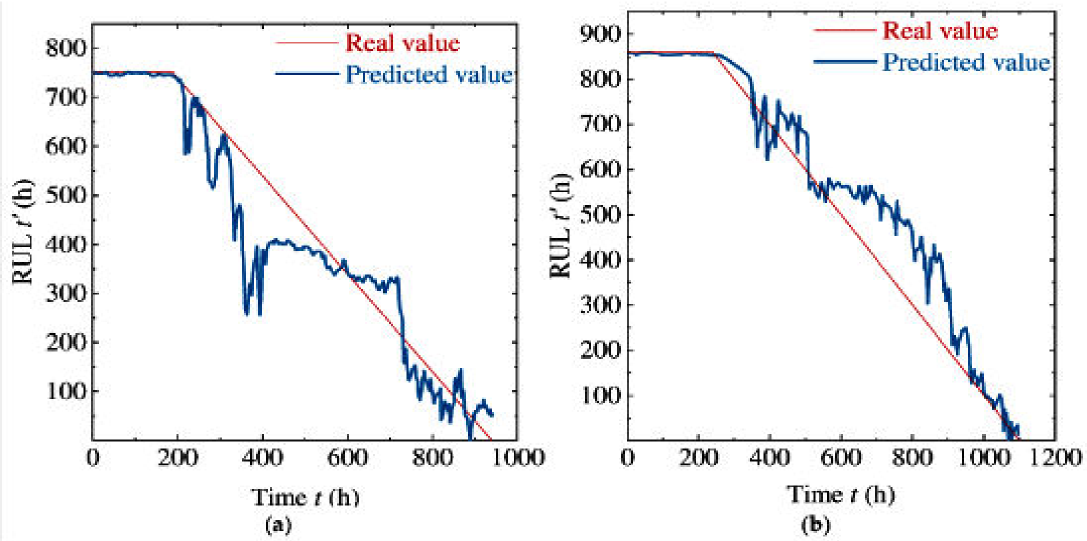

Fig. 2. Predicted and actual RUL curves. (a) Description of curves for pump 3; (b) description of curves for pump 4. Reprinted from ref. [35] with permission of MDPI AG publisher.

Guo et al. [36] proposed a method to predict the RUL of an external gear pump using a Bayesian regularized radial basis function neural network (Trainbr-RBFNN). The process involves denoising vibration data from accelerated degradation tests with variational mode decomposition (VMD) and using Hilbert modulation to demodulate the signal, comparing this to ensemble empirical mode decomposition (EEMD) and modified EEMD (MEEMD). Factor analysis (FA) combines different parameters to create a degradation evaluation index, which trains the Trainbr-RBFNN model.
Zhigang [37] proposed an artificial neural network (ANN) method for predicting the RUL of equipment based on condition monitoring. The ANN model used the equipment's age and multiple condition monitoring measurements from present and past inspections as inputs, predicting the life percentage as the output. To minimize noise and improve accuracy, the model fited condition monitoring data to a function derived from the Weibull failure rate. Additionally, a validation mechanism was employed during training to enhance performance. The method was validated with real-world vibration data from pump bearings, showing that it outperforms a previously reported method in predicting RUL accurately.
Zheng et al. [38] proposed a robust deep learning model, Robust-ResNet, for multi-channel health status management of internal gear pumps. Their model achieved high accuracies of 99.96% and 99.94% in classifying health status and 99.53% in predicting RUL, demonstrating superior performance and real-time monitoring capability for gear health management. The key equation for Robust-ResNet using the explicit Euler method, as applied to multi-channel is:

$$X_{k+1} = X_k + \mu\sigma(W_k X_k + b_k) \tag{17}$$

where: X_k is the concatenated feature vector from all channels at layer; W_k is the combined weight matrix for all channels, b_k is the combined bias vector for all channels; η represents the step size or learning rate; σ represents the activation function.
Ugochukwu and Jang-Wook [39] developed a data-driven model for predicting the RUL of solenoid pumps. Their approach utilizes stacked autoencoders for feature extraction from pressure signals decomposed with complementary ensemble empirical mode decomposition with adaptive noise,

feeding these features into a gated recurrent units (GRU) network for accurate RUL estimation, validated through empirical studies showcasing its effectiveness in prognostics (fig. 3).

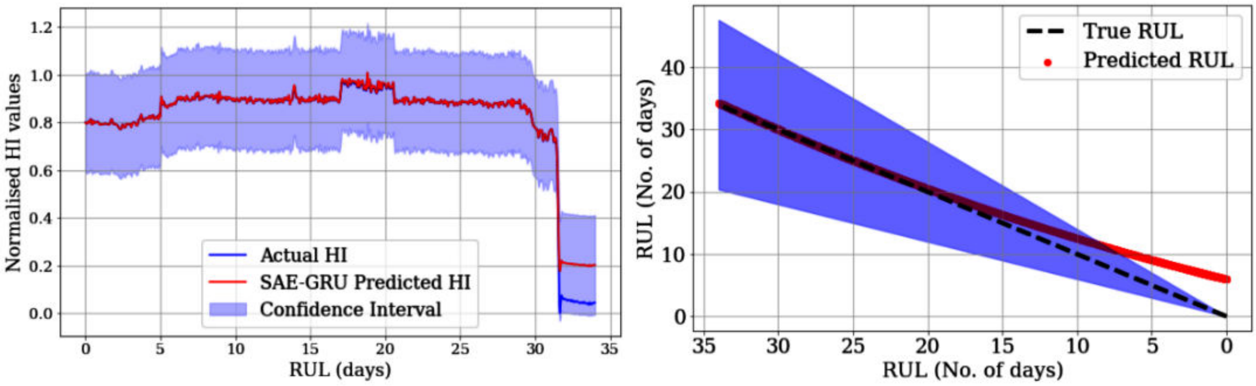

Fig. 3. a) One-step ahead prediction by GRU estimator; b) RUL prediction results by GRU at TSP (68th day). Reprinted from ref. [39] with permission of MDPI AG publisher.

Hongru et al. [40] proposed a novel fault prognosis methodology for hydraulic pumps integrating bispectrum entropy and Deep Belief Network (DBN). Their approach utilized bispectrum features of vibration signals with an entropy method based on energy distribution for effective feature extraction, and employs a DBN based on Restrict Boltzmann Machine (RBM) for prognostics. Experiment results demonstrated satisfactory performance, affirming its suitability for Condition-Based Maintenance (CBM) requirements.

Junyu et al. [41] proposed a novel method for predicting the Remaining Useful Life (RUL) of drilling pumps using a parallel channel approach integrating Convolutional Neural Network (CNN)-Convolutional Block Attention Module (CBAM) and Transformer network. This method independently extracts time-frequency domain and time-domain features from strain signals, integrates them for degradation estimation, and achieves higher prediction accuracy compared to existing approaches, validated with operational data from four drilling pumps.

Adil et al. [42] investigated fault detection in hydraulic pumps, focusing on the common issue of leakage due to wear over time. They employ the NARX neural network with various training algorithms to estimate the RUL of an axial pump used in hydraulic systems for sheet metal casting, demonstrating promising results for maintenance planning and operational efficiency improvements.

Jian et al. [43] introduced a novel prognostic method for hydraulic pumps, enhancing predictive performance by employing the DCT-composite spectrum (DCS) fusion algorithm to integrate multi-channel vibration signals. They extracted DCS composite spectrum entropy as a feature and utilized a modified echo state networks (ESN) model for prognostics, updating the reservoir and redefining neighboring matrix elements to improve prediction accuracy. Experimental analysis in hydraulic pump degradation experiments validates the feasibility and significance of the proposed algorithm for Condition-Based Maintenance (CBM).

Peng et al [44] introduced a novel framework for predicting the remaining service life of hydraulic pumps, emphasizing the importance of reliability and safety. They enhance traditional Long short-term memory (LSTM) networks with a dual self-attention mechanism to better capture temporal dependencies and feature importance levels in time series data. This approach integrated LSTM for sequence feature learning and Transformer for simultaneous learning of sequence and time step features, demonstrating improved performance in RUL prediction validated through simulation experiments.

b) Non-neural network methods

The non-neural network method can still achieve accurate RUL predictions for hydraulic pumps through various techniques such as statistical modeling, physical modeling, and machine learning algorithms that do not rely on neural networks.

Yu and Hongru [45] introduced a novel method for hydraulic pump RUL prediction, addressing challenges with insufficient degradation data and complex degradation mechanisms. Their approach integrated modified Auto-Associative Kernel Regression with multi-source fusion of vibration and return oil flow, modeled using a degree 3B-spline with monotonicity constraints. Additionally, they proposed monotonicity-constrained particle filtering to update coefficients monotonously, achieving accurate RUL predictions and confidence intervals, validated through experimental results showing superior performance over existing approaches.

Tongyang et al. [46] proposed an adaptive-order particle filter method for improving the long-term accuracy of RUL prediction in aviation piston pumps. Their approach combined model-based initialization with adaptive updates based on new observations, utilizing Monte Carlo simulation to estimate future degradation states effectively, demonstrating superior precision compared to traditional methods in experimental return oil flow data.

Li et al. [47] developed a novel method for predicting the remaining useful life (RUL) of gear pumps using kernel principal component analysis (KPCA) and just in time learning (JITL). By extracting characteristic indices from experiment pressure signals, applying KPCA for weighted fusion, and utilizing k-vector nearest neighbor (k-VNN) with JITL, their approach achieves higher prediction accuracy compared to traditional methods, demonstrating its feasibility and effectiveness for RUL prediction and condition monitoring in gear pumps (fig. 4).

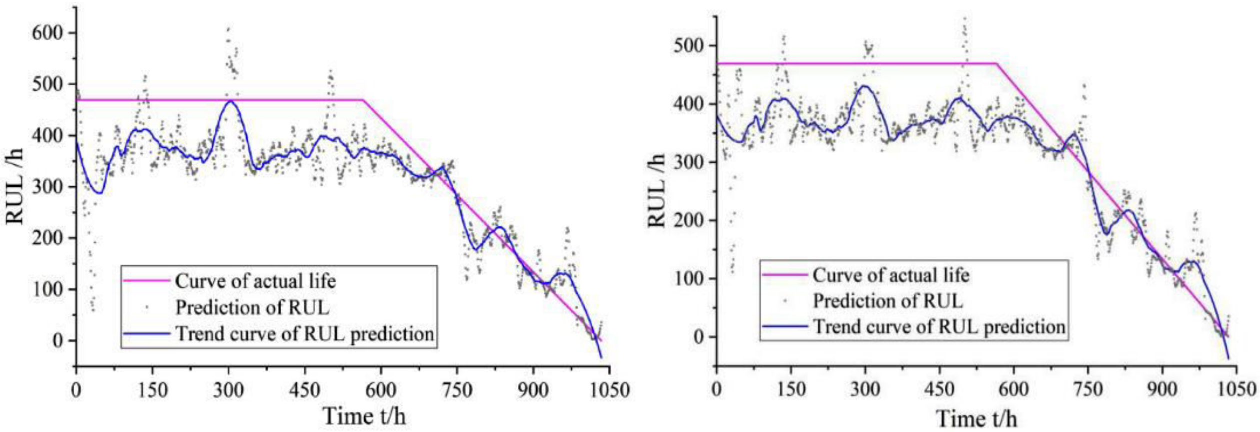

Fig. 4. a) RUL prediction of gear pump based on JITL method proposed in article; b) RUL prediction of gear pump predicted by JITL method based on k-NN. Reprinted from ref. [47] with permission of MDPI AG publisher.

Wu et al. [48] proposed a non-neural method for predicting the RUL of hydraulic pumps using limited degradation data. Their approach constructed a degradation trajectory model based on volumetric efficiency, achieving over 85% prediction accuracy. The study compared its method with traditional machine learning algorithms and introduced evaluation and verification techniques for robust RUL estimation (fig. 5).

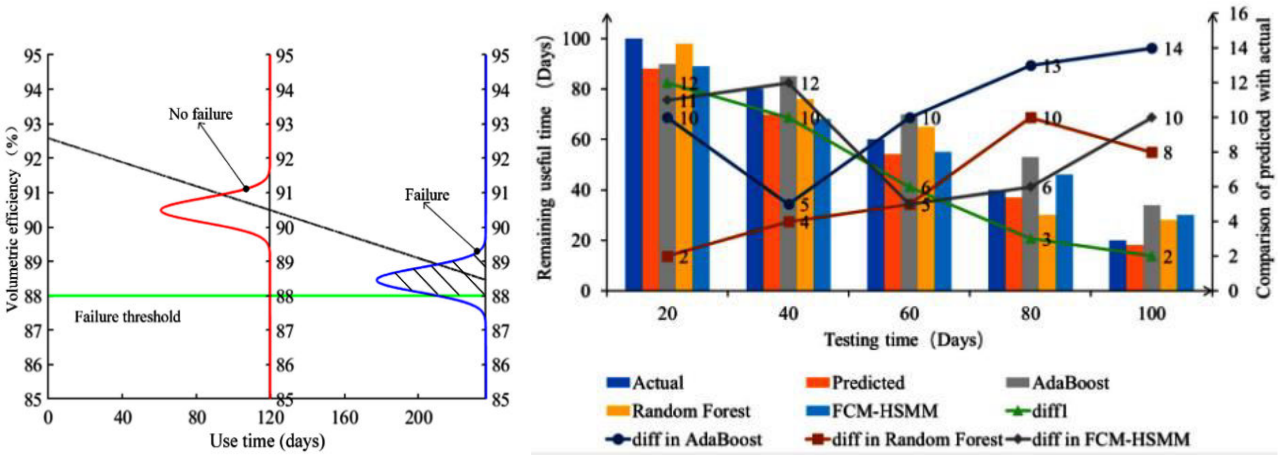

Fig. 5. a) RUL calculation schematic diagram; b) Comparison of actual RUL and predicted RUL. Reprinted from ref. [48] with permission of MDPI AG publisher.

2.3 Model-driven methods

Model-driven methods use the principles of physics, engineering, and domain-specific expertise to construct explicit mathematical models that describe the behavior and degradation processes of the hydraulic pump. The models offer transparency by providing clear insights into failure mechanisms and enabling detailed understanding and control, while also possessing strong predictive power to accurately forecast failures based on physical and operational conditions. However, their complexity demands significant expertise in pump mechanics, and their specificity to certain pump types and conditions limits their adaptability compared to data-driven methods.
Tongyang et al. [49] highlighted the critical link between the effective operation of aviation hydraulic pumps and passenger safety, emphasizing that accurate RUL prediction is crucial for establishing maintenance strategies to mitigate risks. They addressed the challenge of modeling pump degradation due to experimental complexity and data scarcity by proposing a numerical approach that incorporates uncertainty, utilizing Monte Carlo sampling to simulate wear debris and a partition-integration RUL prediction framework validated by experimental data, demonstrating effectiveness even under extreme conditions with limited data.
Xingjian et al. [50] developed a method for predicting the RUL of aviation hydraulic axial piston pumps, characterized by gradual wear. They utilized the Wiener process to model performance degradation based on return oil flow, applying maximum likelihood estimation (MLE) and Kalman filtering to estimate model parameters and drift coefficients, respectively. Experimental findings validated the efficacy of this approach in accurately forecasting pump RUL by leveraging internal wear indicators and statistical modeling techniques.
Xingjian et al. [51] addressed the need for condition-based maintenance in aircraft safety by developing a model to accurately predict the RUL of aviation hydraulic piston pumps. They focused on hydraulic oil contamination as the primary failure mode and establish a life prediction model based on contaminant sensitivity theory. By deducing a mathematical relationship between oil contamination levels and piston pump lifespan, they proposed an experimental method to measure contaminant sensitivity and validate their model's effectiveness through predictions based on experimental data.
Bo et al. [52] focused on enhancing the accuracy of remaining useful life (RUL) prediction for hydraulic piston pumps by proposing an improved inverse Gaussian (IG) process model. This model incorporated considerations for random effects and measurement errors, which are critical factors often overlooked in traditional approaches, leading to more precise predictions of wear degradation. They employed Monte Carlo integration and the expectation maximization (EM) algorithm to estimate model parameters, demonstrating the effectiveness of their approach through comprehensive case studies that validate the enhanced predictive capabilities of the proposed IG process model.
Zhonghai et al. [53] proposed a fault diagnosis method for intelligent hydraulic pump systems (IHPS) in aircraft, employing a nonlinear unknown input observer (NUIO). This method considers nonlinear factors specific to IHPS and utilizes output pressure and swashplate angle signals for real-time fault detection. The approach aims to enhance system reliability by accurately diagnosing and isolating typical failure modes through analysis and simulation, highlighting its significance in improving the operational reliability of IHPS in aircraft applications.
Yixuan et al [54] focused on developing a statistical method for aeronautics pumps under constraints of small test samples through re-sampling techniques. They integrated the Synthetic Minority Over-Sampling Technique (SMOTE) algorithm, Kolmogorov-Smirnov (KS) test, and accumulated damage theory to formulate a life evaluation approach using both limit accelerated life testing and regular life testing samples. The SMOTE algorithm addresses sample group imbalances, while the KS test ensures the goodness of fit. Maximum likelihood estimation demonstrates efficient expansion of sample groups while maintaining guaranteed goodness-of-fit criteria.
Kapuria et al. [55] highlighted the necessity to reduce operational costs in nuclear power plants by transitioning from scheduled-based maintenance to proactive strategies. They noted that operational costs comprise a substantial portion of a plant's annual budget due to the current maintenance methods. To address this, they proposed using Bayesian networks to forecast the remaining useful life of centrifugal pumps. Their research successfully applied this Bayesian network in a case study, demonstrating its effectiveness. This approach offers a probabilistic

method for predictive maintenance, optimizing maintenance schedules in real time. By forecasting equipment conditions, nuclear plants can achieve significant cost savings and enhanced operational efficiency (fig. 6).

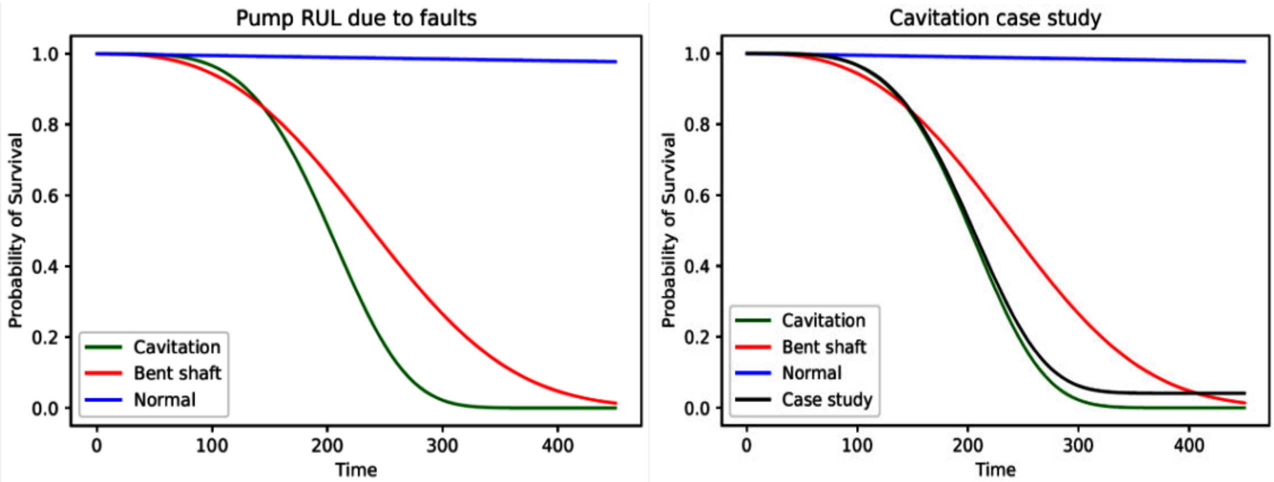

Fig. 6. a) The curves in this plot show the RUL forecast for a pump, if the Bayesian network estimates a 100% likelihood for each mode of operation. b) The forecasted RUL closely follows the cavitation curve, with some deviations due to the inherent uncertainty of probabilistic estimation. Reprinted from ref. [55] with permission of MDPI AG publisher.

Guolei et al. [56] investigated the impact of hydraulic pump wear on aircraft hydraulic systems, analyzing oil return flow changes due to slipper and cylinder bore wear. They analyzed the degradation mechanisms and establish a model using Simulink and AMESim co-simulation. Additionally, they employ a multi-step Support Vector Machine (SVM) algorithm to predict aero-hydraulic pump failures and estimate the RUL of the system, demonstrating the accuracy and effectiveness of their wear model.

3. Trends in predicting the remaining useful life of hydraulic pumps

In the last 12 years, there has been a notable research and development focused on predicting the RUL of hydraulic pumps. This trend reflects a growing recognition of the importance of predictive maintenance in optimizing operational efficiency, enhancing reliability, and reducing maintenance costs across various industries.

Khalid et al. [57] discussed the importance of predictive maintenance (PM) strategies, which rely on real-time data to diagnose potential failures and predict machine health. PM is proactive, using predictive modeling to alert maintenance activities and foresee failures before they occur. Various industries have adopted PM to enhance reliability and safety, but the aviation industry has higher safety expectations due to the high costs and risks to human life associated with aircraft failures. Although flight data monitoring systems with AI algorithms are commonly used in commercial operations, there is limited research on safety-critical systems like engines and hydraulic systems.

Approximately 40% of recent studies focus on integrating machine learning and artificial intelligence (AI) techniques, such as recurrent neural networks (RNNs) and Long Short-Term Memory (LSTM) networks, for RUL prediction. These models excel in analyzing time-series data and predicting future trends based on historical performance data with high accuracy.

Around 30% of recent research explores the application of deep learning architectures, including convolutional neural networks (CNNs) and transformers, for RUL prediction. CNNs are utilized to extract spatial and temporal features, while transformers capture long-range dependencies across sequences, aiming to enhance predictive accuracy and robustness.

Approximately 20% of literature emphasizes the development of hybrid models that combine physics-based modeling with data-driven approaches. These models describe degradation mechanisms based on fundamental principles and optimize parameters using historical operational data, aiming to improve prediction accuracy while maintaining interpretability.

Around 10% of recent studies highlight the adoption of real-time monitoring technologies integrated with Internet of Things (IoT) devices for continuous assessment of hydraulic pump health. IoT-enabled sensors and edge computing platforms are employed to collect and analyze real-time data, supporting proactive maintenance strategies and enhancing operational efficiency.

4. Future challenges in predicting the remaining useful life of hydraulic pumps

Despite advancements, challenges such as limited labeled data availability, complex system dynamics, and the need for scalable and interpretable models remain. Future research directions should encompass developing robust anomaly detection techniques, enhancing model interpretability through explainable AI methods, and integrating domain knowledge with advanced machine learning algorithms to improve RUL prediction accuracy. These efforts should prioritize overcoming existing challenges, refining predictive models, and integrating multidisciplinary knowledge to advance the field of hydraulic pump prognostics.

5. Conclusions

This review has highlighted the significance of accurate RUL predictions in enabling timely adjustments to maintenance strategies, thereby preventing unexpected failures and extending equipment lifespan. By examining data-driven and model-driven approaches comprehensively, this study underscores their respective strengths and limitations in the context of hydraulic pump prognostics. The ongoing evolution towards real-time monitoring using IoT technologies and edge computing will facilitate proactive maintenance strategies and enhance operational efficiency. However, challenges persist, including the scarcity of labeled data, the complexity of system dynamics, and the demand for scalable and interpretable models. By addressing these challenges, the industry can achieve greater reliability and efficiency in hydraulic system management in diverse industrial applications.

Conflicts of Interest: The author declares no conflict of interest.
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Considerations on Making Test Stands for Small Hydraulic Turbines

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Abstract: *Hydraulic turbine test stands represent an important link in the efficient utilization of the energy potential of water flows. The realization of these turbines begins with an approximate design, based on the differential equations of motion of ideal fluids, and continues with successive stages of performance testing in the laboratory, on small-scale models. Using different similarity criteria based on geometric, kinematic and dynamic similarities, the conclusions drawn from the operation of the model will also be valid for the real machine. The purpose of the paper is to present some points of view on the realization of three types of stands for small hydraulic turbines, of which two are patented and one is a patent application. These stands simulate real operating conditions on permanent flowing water with velocities, flows and falls for small hydraulic turbines that can be installed on the water line, in locations that do not use dams or other expensive water storage facilities. The main author of the patent documentation makes a synthesis of the constructive-functional characteristics of the respective stands through this article.*

Keywords: *Test stands, small hydraulic turbines, permanent flowing waters, velocities, flows and water falls*

1. Introduction

The role of a test stand is to reproduce in total geometric similarity the physical phenomena that take place in an industrial turbine. The experimental research of hydropower aggregates is carried out in the laboratories of universities and institutes with concerns in the field, on experimental stands that simulate the real operating conditions of hydraulic turbines. Function of the type of hydraulic energy converted into electrical energy, hydraulic turbines are divided into two categories: "**flow (speed) turbines**", which harness the kinetic energy, respectively the flow rate Q [m^3/s] or the speed v [m/s] of the water and "**fall turbines",** which exploit the potential energy, respectively the fall H [m] of the water. Therefore, the experimental test stands for hydraulic turbines will be "flow (velocity) stands" [1,2], with larger horizontal dimensions and "drop stands" [3,4], with larger vertical dimensions.

The load of the hydraulic turbine mounted on the experimental test stand can be achieved with an electric generator, with the shaft coupled to the turbine rotor shaft, or simulated, with a mechanical / hydraulic braking system, which replaces the electric generator. Three constructive solutions of stands for small hydraulic turbines are presented below; two from the first category [5,6] and one from the second category [7].

2. Constructive stand solutions for testing small flow hydraulic turbines

This chapter presents the constructive solutions for two means of testing small hydraulic turbines, which differ from each other in the water flow (speed) regulation mode and the load simulation system, respectively:

- *a stand for the optimization of the hydrodynamic profile of the blades and functional tests of the rotors of hydraulic turbines*, with which the speed distribution on the rotor blades of axial hydraulic turbines of reduced dimensions and masses can be determined experimentally, successively in two stages, in order to optimize their hydrodynamic profile, in the first stage, as well as the mechanical parameters, speed and moment, of the hydraulic turbine rotors, with the previously experimentally optimized blade profile, in the second stage;
- *a stand with a tilting water ford*, for the experimental testing of scale models, with reduced dimensions and masses, of axial hydraulic turbine rotors, with a vertical or horizontal shaft.

2.1. Stand for optimizing the hydrodynamic profile of blades and functional tests of hydraulic turbine rotors

Constructive solution for this stand is shown in figures 1, 2 and 3.

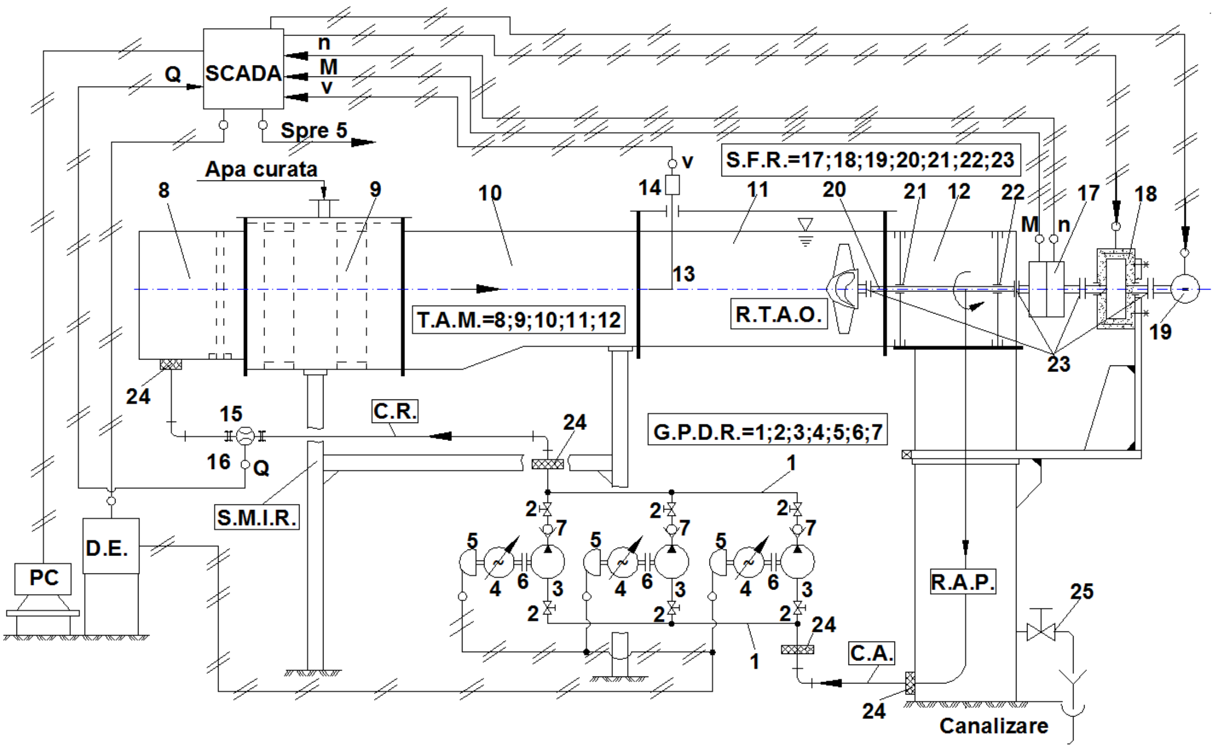

Fig. 1. Functional and constructional scheme of the stand

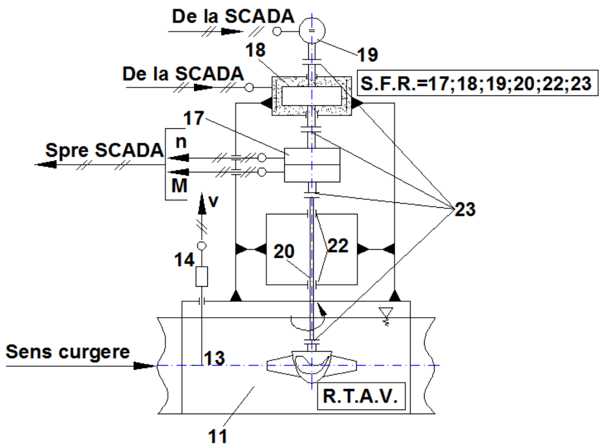

Fig. 2. The detail of the turbine with vertical shaft coupled at adjustable brake system

Fig. 3. The assembly of the main modules of the stand

The stand in figures 1, 2 and 3 forcibly circulates a volume of clean water in a closed circuit, made by a pumping group with adjustable flow **G.P.D.R**., which sucks from a suction tank of pumps **R.A.P.** and discharges into a modular water tunnel, **T.A.M**., consisting of five horizontal sections, removable and watertight, provided with covers, of which the first three rest on a metal support with adjustable height **S.M.I.R**., and the last one on the suction tank of the pumps **R.A.P.**, with which it communicates. The closed water circuit is made on the route **R.A.P.- G.P.D.R.- T.A.M.- R.A.P.**
The first three sections of the modular water tunnel **T.A.M**., from which two have a variable section, contribute to the stabilization and uniformity of the flow in the fourth section, made of a transparent and resistant material, in which the fixed rotor blades are mounted, to determine of the speed

distribution, respectively the axial turbine rotor with horizontal axis **R.T.A.O**., figure 1 or with vertical shaft **R.T.A.V**., figure 2, which is to be tried.
These models of hydraulic turbine rotors couple, through a vertical or horizontal shaft, to an adjustable braking system **S.F.R.,** which simulates the load of the rotor immersed in the modular water tunnel, when it is driven by the kinetic energy of the water.
Through a SCADA monitoring, control and data acquisition system, three transducers and a **PC** computer, the following is achieved: *the control* of the adjustable braking system and the flow regulation of the pumping group; *the monitoring and acquisition* of the adjustable parameters of the stand, namely the flow rate **Q** and the speed **v** of the water in the fourth section of the tunnel and the mechanical parameters of the adjustable braking system, namely the moment **M** and the rotational speed **n**.
The stand allows the experimental determination of three functional characteristics for the tested hydraulic turbine rotor models, respectively: moment at the rotor axis as a function of flow at constant load, i.e. $M=f(Q)$ ***at*** M_r ***=const***., rotor speed as a function of load at constant flow, i.e. $n=f(M_r)$ at ***Q=const.*** and rotor speed as a function of flow at constant load, i.e. ***n=f(Q)*** at ***Mr =const.***
The pumping group with adjustable flow **G.P.D.R.**, located under the modular water tunnel **T.A.M.**, consists of three centrifugal pumps **3**, identical and mounted in parallel to sum up the flows, which have a common suction collector and a discharge collector **1**, each of the three pumps can be separated from the collection pipes of the group by means of two isolation valves **2**, one on the suction and the other on the discharge, with a directional valve **7** installed before the valve on the discharge, and each pump being driven by a motor electric of 380 V ac. **4**, coupled to the pump shaft by means of an elastic mechanical coupling **6** and powered by means of an adjustable frequency converter **5**, with the help of which the drive rotational speed of the pump is regulated and, through it, the flow rate of the pump. The adjustable flow pump group sucks through a suction line **AC** from a suction tank of the pumps **R.A.P.** and discharges through a discharge pipe **C.R.** in a. modular water tunnel **T.A.M**; to prevent the propagation of vibrations generated by the pumping group towards the tunnel and tank, four elastic sleeves **24** are to be installed.
The modular water tunnel **T.A.M**. is composed of five sections provided with covers, removable and watertight, which form a continuous assembly, without thresholds near the joints. In the first section **8**, acting as a diffuser in the flow, the pumped water enters the tunnel through a cylinder made of PVC pipe, with a glued plastic cover, provided with large perforations on its side surface, then meets on its way a plate made of perforated sheet metal, mounted transversely to the flow direction. The second section **9**, of constant section and equal to the exit section of the first section, contains sieve packs, perforated sheet screens and honeycomb structures, all with the role of stilling the flow and equalizing the current lines. The third section **10**, is contraction because its output section is reduced to 1/6 of the input section. The first three sections of the modular water tunnel rest on a metal support with adjustable height **S.M.I.R**. Next comes the test/visualization section **11**, where the water flow is uniform and stable due to the shapes, sizes, quality of the inner surface and the quality of the joints of the first three sections of the tunnel, and the output section **12**, through which the water tunnel communicates and supports with/ on the suction tank of the pumps **R.A.P**.
The suction tank of the pumps, **R.A.P**., contains inside: a deflector, which directs the flow of water from the tunnel to the outlet of the tank; a fine screen, mounted transversely to the direction of water flow in the tank, to break air bubbles and a PVC elbow, at 90^o, mounted at the bottom of the tank, to reduce bottom vortexes in the suction area of the pumps.
The axial turbine rotor model with horizontal shaft **R.T.A.O.**, or with vertical shaft **R.T.A.V**., to be tried on the stand, is coupled by means of a horizontal or vertical shaft **20**, to an adjustable braking system **S.F.R.**
Adjustable braking system **S.F.R.** contains: two bearings, one radial **21** and another radial-axial **22**, in the case of coupling to **R.T.A.O**., two bearings radial-axial **22**, in the case of coupling to **R.T.A.V**; a torque and speed transducer **17**; a brake with magnetic powders **18**, with the possibility of horizontal or vertical mounting, with adjustable resistance moment depending on the supply current; a 24 V d.c. electric motor **19**, necessary for driving the brake before carrying out the tests on the stand, for the homogenization of the magnetic powder and the determination of the friction

in the bearings, and three mechanical couplings **23**, from the kinematic chain model shaft rotor-torque transducer and speed-brake-24 V d.c electric motor.
The monitoring, control and data acquisition system **SCADA** contains: an electric box, equipped with programmable controller, two electrical sources of supply, for brake and for electric motor of 24 V d.c., four numerical displays, for flow, for differential pressure, for torque and rotational speed; an electromagnetic flowmeter **15** and a flow transducer **16**, mounted on the discharge pipe **C.R**.; a Pitot-Prandtl tube **13**, movable in three orthogonal directions and a differential pressure transducer **14**, mounted on the frame of visualization test section; a **PC** calculator. The **SCADA** system ensures: monitoring and acquisition of four parameters, respectively water flow **Q** and speed **v** (indirect by converting the differential pressure in speed) in the test/visualization section, torque **M** and rotational speed **n** at the shaft of the test rotor model; three controls, one for adjusting the flow of the pumping group, one for adjusting the resisting torque of the magnetic powder brake and one for driving the 24 V d.c. electric motor.
Three frequency converters **5** and three electric fans for cooling the motors are mounted in the electric power cabinet **DE**, which supplies the three electric motors driving the pumps. The electric cabinet ensures: power supply for electric motors of 380 V a.c. starting and stopping the pumping group; monitoring and regulation of the pumping group flow, carried out locally, from the cap of the electric cabinet, by means of three rotatable potentiometers provided with numerical displays.

Table 1: The function of the stand and the tests carried out procedure

<table>
<tr><th>Name of the activity</th><th>Name of the stage</th><th>Description of the stages</th></tr>
<tr><td rowspan="4">Preparing stand for testing</td><td>Water tunnel rightness</td><td>checking and restore , if it is the case, of the water modular tunnel rightness;</td></tr>
<tr><td rowspan="3">Filling the stand with water and pumps aeration</td><td>filling the stand with clean and filtered water until a preset level;</td></tr>
<tr><td>adjustment water level in tunnel, from discharge pipe or filling pipe from the network;</td></tr>
<tr><td>pump aeration by unscrewing / tightening vent caps of each pump.</td></tr>
<tr><td rowspan="4">Starting and preliminary checks of stand</td><td rowspan="2">Starting up pumping group and stand aeration</td><td>- it starts successively each pump, from minimum flow to maximum flow;</td></tr>
<tr><td>- with the maximum flow, resulted by summation of maximum flows of the three pumps, water is recirculated through modular tunnel for 15 minutes, for aeration, elimination of air bubbles being made at the transparent section level, the only one in which the flow is on the surface.</td></tr>
<tr><td rowspan="2">Preliminary checks of the stand</td><td>Checking the water flow uniformity in transparent section:
- is done at maximum flow of the pumping group, in three parts of the section (two at the ends and one in the middle), with Pitot-Prandtl tube;
- in each section is measured the water speed, in five equidistant points of the section width; in each point of the width are measured five equidistant point on the depth section. The total number of measure points of water speed, in order to certificate placement of deviation of the speed fluctuation in an accepted interval, is of 75;
- reduction of speed fluctuation, is done by mounting of an additional sieves in the second section of the modular water tunnel.</td></tr>
<tr><td>Optimization of hydrodynamic form of rotor blade.
- is injected in the transparent tunnel, from exterior, a colored liquid heavy miscible in water;
- are successively introduced in the transparent tunnel more blades with diverse hydrodynamic profiles, fixed and without possibilities of movement in the tunnel;
- for each introduced blade the current spectrum lines for different speed rates of water are shot with a laser camera;
- spectral comparative analysis of speed distribution around the blades profile establishes which is the blade with the best hydrodynamic profile.</td></tr>
</table>

Determination of functional characteristics of tested turbine model	Characteristic M=f(Q) at Mr=const.	*Stage 1*- brake with magnetic powder unfed with current: - *it starts up* the first electropump at a minimum flow corresponding to the adjusted frequency of the convertor at the value of *20Hz*; - *it increases progressively* the frequency of the first converter until at *50Hz*, respectively the flow of the first pump until a maximum flow, following the value of the flow at which the turbine starts to rotate; - *if it is the case,* the obtained flow rate by adjustment of the other two electropumps *is overlapped* over the maximum flow rate of the first pump, by slowly actuating the converters potentiometers of corresponding frequency; - *if the turbine does not rotate* neither at the maximum flow rate of the stand, nor at the maximum speed achieved in the transparent tunnel, it means that the turbine does not generate a couple greater than the minimum resistant torque of the **S.F.R** ; - *the value of the flow rate at which the turbine rotates with a minimum imposed speed* , for instance *50 rpm*, represents the flow rate at which the turbine generates a couple equal to the minimum resistant torque, (the minimum resistant torque of the unpowered brake and the low-friction bearings of the **S.F.R.)** denoted $Q_{0,1}$.
		Stage 2 – the test will continue with the flow adjustment from $Q_{0,1}$ to the maximum value, followed by the adjustment of the supply current of the brake with magnetic powders, respectively: - *the torque* at the turbine shaft will be determined for the maximum stand flow and the rotational speed of *50 rpm.* For this purpose, the three pumps will be connected at the maximum flow, the brake supply current will be progressively increased until the rotational speed drops to 50 rpm; after determining the torque value at maximum flow, M_{QMAX}, the test will continue as follows: - the resistant torque of the adjustable brake system will be progressively adjusted, in an increasing direction, with equal steps, for 10 values from the interval *Mmin...* M_{QMAX}; - *for each of ten current values* of the adjusted load, the flow will be progressively increased, from the value corresponding to the previous load up to the value corresponding to the rotational speed of *50 rpm* of the tested model; - *the 10 values of the flow* corresponding to the load increase and the rotational speed obtaining of *50 rpm* for the tested model will be acquired; - *the test will be repeated identically* also for the descending direction of the load, from M_{QMAX} to *Mmin*; - another *10 values of the flow* corresponding to the decrease of load and rotational speed obtaining of *50 rpm* for the tested *model will be acquired*, With the 20 pairs of values (flow, torque) can be drawn the characteristic *M=f(Q) / Mr=const*.
	Characteristic n=f(Q) at Mr=const.	- *the minimum flow rate* $Q_{0,1}$, at which the turbine generates a torque equal to the minimum resistant torque Mmin, as in the previous case, stage 1, and the torque of turbine rotor at the maximum flow rate M_{QMAX}, as in the previous case, stage 2 are found; - *the adjustable brake will be fixed* at a value of the resistant torque included in the range *Mmin...* M_{QMAX}, which will remain constant; - *for that load value* the flow that crosses the test /visualization section is varied in an increasing direction, from Q_{MAX} to $Q_{0.1}$; - *for each value of the flow*, the rotational speed value of the tested turbine model is acquired. A family of stationary characteristics can be build, rotational speed as a function of flow at constant load, where each characteristic of the family belongs to a constant value of the load in the interval *Mmin...* M_{QMAX}.
	Characteristic n=f(Mr) at	- *The minimum flow rate* $Q_{0,1}$, at which the turbine generates a torque equal with the minimum resistant torque *Mmin*, as in the first case,

	Q=const.	stage1 and the torque of the turbine rotor at the maximum flow rate M_{QMAX}, as in the first case, stage 2 are found; - *a water circulation flow value* will be set in the range $Q_{0,1}...Q_{MAX}$; - *for that value of the flow,* the resistant moment of the adjustable braking system is varied, in an increasing and decreasing direction, with a constant step, included in the interval *Mmin... M_{QMAX}*; - *for each value of the resistant moment,* the rotational speed value of the tested turbine model is acquired. A family of stationary characteristics can be build, rotational speed as a function of load at constant flow, where each characteristic of the family belongs to a constant value of the flow in the interval $Q_{0,1}...Q_{MAX}$.

2.2. Stand with tilted water ford for testing some hydraulic turbines

The **constructive solution** for this stand is shown in figures 4...8.

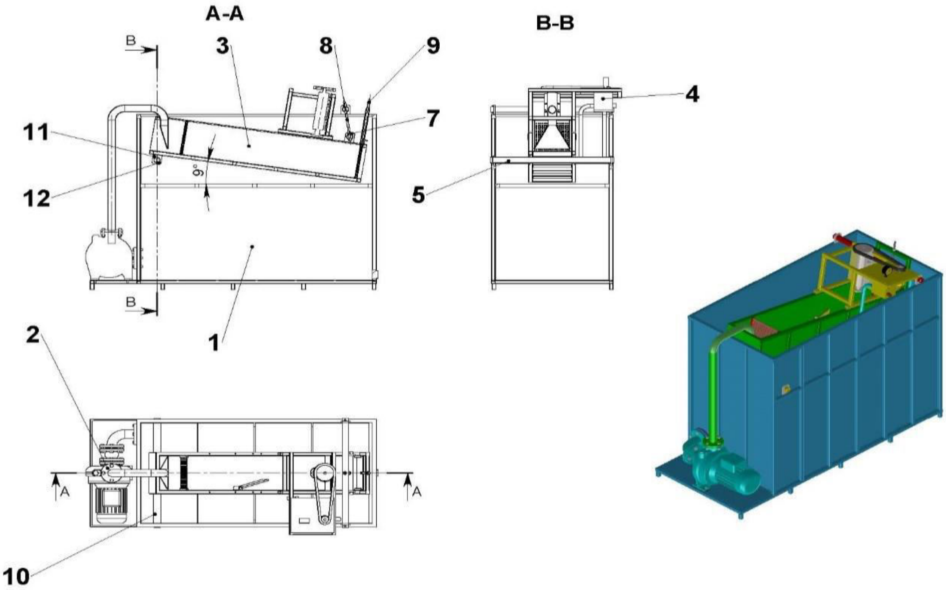

Fig. 4. Assembly-mounting drawing and isometric view of the stand

The hydraulic microturbines test stand with tilted water ford, figure 4, consists of a water tank **1**,an adjustable flow pumping module **2**, which sucks from the bottom of the tank and discharges at the left end of a water ford with constant section **3,** in the form or trough, mounted on the upper side of the tank, the water ford being equipped, at the opposite end of the water supply ,with a load simulation device **4**, and having the possibility of adjustable tilting, with maxim 9^o, to the right of the horizontal position, around a shaft **5**, equipped with two bearings and two spacers **10**, when a screw-nut mechanism **8** is manually actuated**,** which moves the lifting cross-bar **7,** mounted on the upper part of the right end of the ford , in front of the lifting cross-bar **6**, mounted at the superior side of the right end of the water tank , each of two cross-bars being equipped with two bearings.
The tilting shaft of the ford **5** and the two lifting cross-bars **6** and **7** are secured at the ends, against the detachment from the bearings, by two screws **11** and two nuts **12** each, and the stand also contains another mechanism screw-nut **9,** which actuates a flat weir, that regulates the water level upstream of it, in the ford **3**.

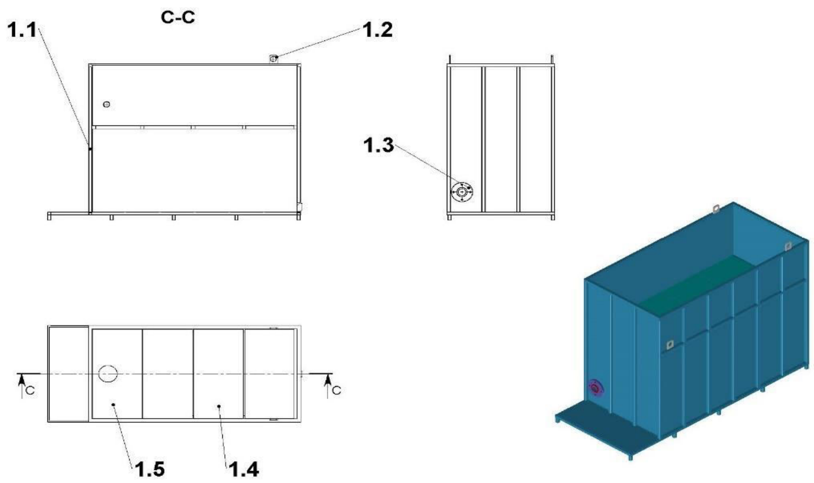

Fig. 5. Assembly-mounting drawing and isometric view of the water tank

The **water tank 1**, figure 5, built of pieces of stainless-steel sheet, welded on a resistance structure of metal profiles **1.1**, is provided at the top, at about half of its height, with a cover made of four tin plates, of which three whole, **1.4** and one perforated, **1.5**. The tank is provided with four bearing supports, **1.2**, of which two, for the ford tilting shaft, are positioned on the left side above the cover, and the other two, for the ford lifting cross-bar, are positioned on the right side. On the left side, close to the bottom of the tank, is positioned the suction flange of the pumping module.

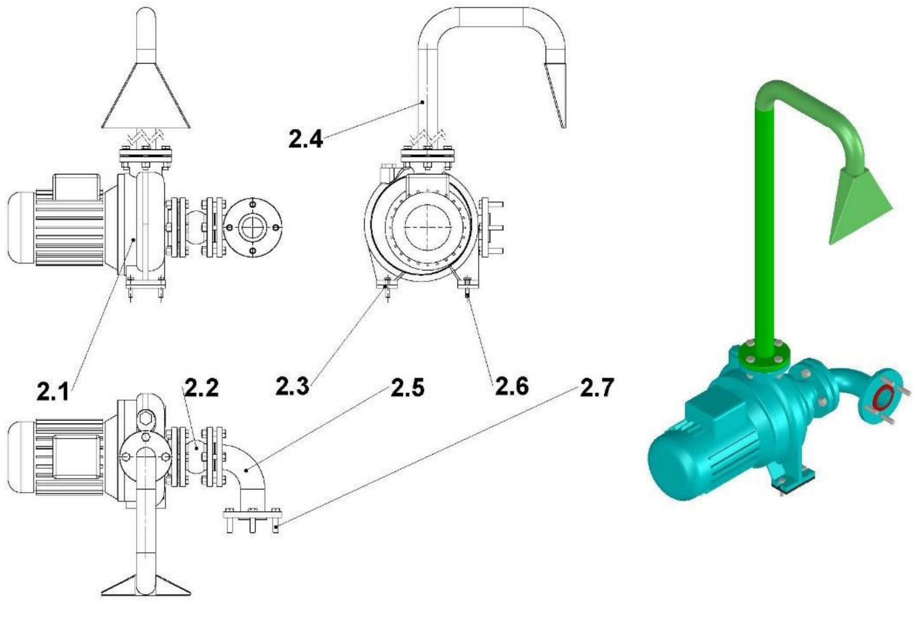

Fig. 6. Assembly-mounting drawing and isometric view of the pumping module

The pumping module **2**, figure 6, consists of an electric pump **2.1**, with adjustable flow rate by varying the frequency of the electric drive motor supply current, provided on the suction pipe with an anti-vibration connection **2.2**, a flange connection **2.5**, screws **2.6** and nuts **2.7**, and the discharge pipe **2.4** contains two welded elbows and a water flow diffuser (not figured) in the ford. The pump base is fixed on a pedestal, by means of two vibration dampers **2.3** and four screws **2.6**.

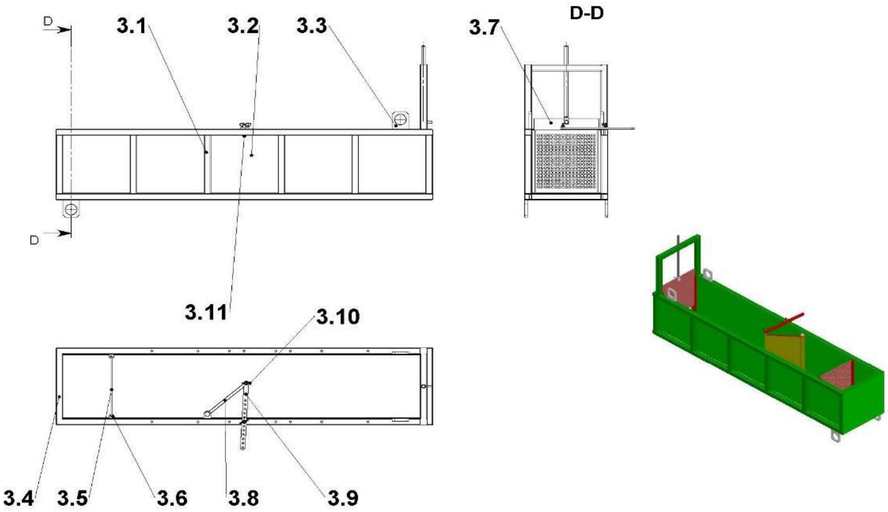

Fig. 7. Assembly-mounting drawing and isometric view of water ford

The water ford 3, figure 7, contains a tilting frame **3.1**, on which a water through **3.2** is welded, parallelepipedal in shape and made of pieces of stainless-steel sheet, which is closed at the front, on the left side, with a plate **3.4**, and at the opposite end with a **3.7** flat sluice, for regulating the water level in the trough. The ford is also equipped with four bearings **3.3**, two mounted on the lower-left side and two mounted on the upper-right side, a stainless steel sheet perforated screen for stilling the flow **3.5**, transversely mounted, with two skids **3.6**, inside the trough and a flap **3.8** for deflection the flow to the tested turbine, equipped with an angle adjustment lever **3.9**, with penetrated transverse holes, which can be locked in the desired position with the help of a screw **3.10** and a wing nut **3.11**.

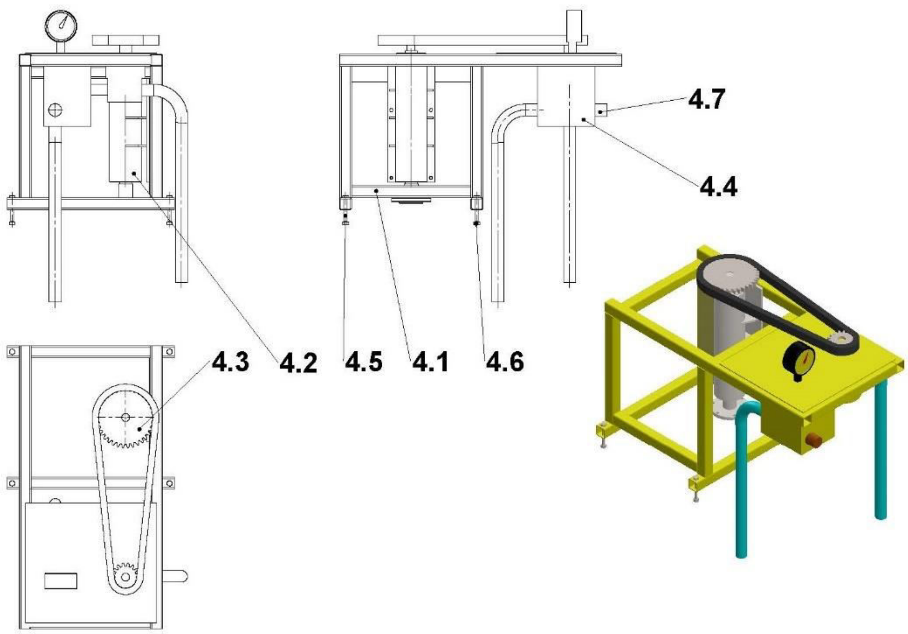

Fig. 8. Assembly-mounting drawing and isometric view of load simulation device

The load simulation device 4, figure 8, consists of a support **4.1**, on which the turbine to be tested is mounted, the turbine shaft being inserted into the bearing **4.2**, equipped at the bottom with a flange for holding the turbine rotor, and at the top with a large diameter gear for a transmission with toothed belt **4.3**, with a 10:1 ratio between the turbine shaft and the gear pump shaft (not figured) that sucks and discharges from/into the water tank , when is driven by the tested turbine, by means of the transmission with the toothed belt, the pump load being carried out by tightening an adjustable needle throttle (hydraulic resistance) **4.7**, mounted on the discharge

pipe of the gear pump, and the pressure created by the load being read on a pressure gauge (not positioned). The load simulating device is fixed with four screws **4.5** and four nuts **4.6** to the upper edge of the water ford **3**, on which a bracket with performed holes for screws is welded. To carry out the tests, the stand is equipped with three transducers (not positioned): one for rotational speed, which measures the rotational speed in the shaft of the tested turbine, one for speed and one for level, which measures the speed / water level in the ford.
The **test flow** is measured indirectly by means of velocity and level transducers. It is expressed with the relation: $Qp=v\cdot S=v\cdot l\cdot h$, where Qp is the test flow rate $[m^3/s]$; v is the water velocity in the ford $[m/s]$; S is the water flow section in the ford $[m^2]$;
The **load** with which the tested turbine is loaded is measured indirectly with the help of the manometer (not figured) on the load simulation device **4**. It is expressed by the relation: $Mr = p\cdot c$ where Mr is the resisting torque (couple) [Nm] with which device loads the tested turbine; p is the pressure on the discharge pipe of the gear pump of the device $[10^5\cdot N/m^2]$, read on the manometer and adjusted from the needle throttle **4.7**; c is the gear pump capacity $[10^{-6}\cdot cm^3/rot]$ of the device.

Table 2: Stand functionality and the ways of carrying out the tests

Name of the activity	Name of the stage	Description of the stages
Preparing stand for testing	Water ford rightness and turbine rotor mounting on stand	*The water ford is horizontally positioned **3**,* by means of the screw-nut mechanism **8-9** and is totally opened the flat sluice **3.7**;
		The hydraulic turbine rotor for tested is mounted in the bearing and the flange of the load simulation device **4**;
		*The device of load simulation **4*** is fixed on the frame of water ford **3**, with the four screws **4.5** and the four nuts **4.6**;
		*The water ford **3** is deflected,* by adequate positioning of the flap **3.8**, followed by its fixation on position with screw **3.10** and butterfly nut **3.11**;
	Filling the water tank, pump aeration, checking flow adjustment	*The tank is filled with clean and filtered water from the network,* with a volume equal with ¾ from the maximum volume, bounded by the side walls, bottom and the cover.
		The pump is started and aerates by unscrewing / tightening of the vent cap. After starting, the centrifugal pump of the electric pump **2.1** will work in a closed circuit (sucks from the tank **1**, through the flange connection **2.5**, discharges into the free surface water ford **3**, through the flow diffuser, then the volume of water "flows" through the ford, passes under the sluice, drains on the tank cover and ends up in the tank);
		It is being checked the flow adjustment of the centrifugal pump with the help of the frequency converter, in the range of 20 Hz, corresponding to the minimum flow and 50 Hz, corresponding to the maximum flow*;*
		*It is being checked the easy adjustment, without stiffening, of the angle of inclination of the water ford **3**, by operating the screw-nut mechanism **8-9**.*
Determination of functional characteristics of tested turbine model	Characteristics n=f(Q) at Mr=const.	*The load is kept constant, the flow rate* in the water tank is varied and the speed at the turbine shaft is measured.
	Characteristics n=f(Mr) at Q=const.	*The flow is kept constant in the ford, the load* in the turbine shaft is varied and the speed at the turbine shaft is measured.

The variation of the flow rate, regarding the determination of the first characteristic, is carried out in two steps, respectively:
- *establishing a water level upstream of sluice* **3.7** at the minimum flow rate of pumping group **2** and for the horizontal position of ford **3**;
- *maintaining the predetermined level*, when the ford is positioned horizontally, for its inclined positioning. In this sense, the tilting of the ford with an angle in the range of 1...9° will be followed

by the increase of the flow rate of the pumping group in the range of $Q_{min}...Q_{max}$, by the variation of the electric motor supply frequency in the range of 20...50 Hz.
By adjusting the angle of inclination of the ford, with a step of 1^o, in the ranges $0^o...9^o$ and $9^o...0^o$, followed by the adjustment of the centrifugal pump flow, so that the water level in the ford to remain constant (with a tolerance of ±5%),18 distinct turbine test flow values can be obtained.
The load variation, regarding the second characteristic, is achieved by actuating the needle throttle **4.7** of the load simulation device **4**. The needle throttle has a fine adjustment characteristic (pressure on the gear pump discharge depending on the throttle opening) which allows that the load simulator device to make a fine-tune of the load of the tested turbine.

3. Constructive stands solutions for testing small head hydraulic turbines

A constructive solution for a stand fed with a constant level reservoir, intended for testing low head hydraulic turbines, is presented in figure 9.

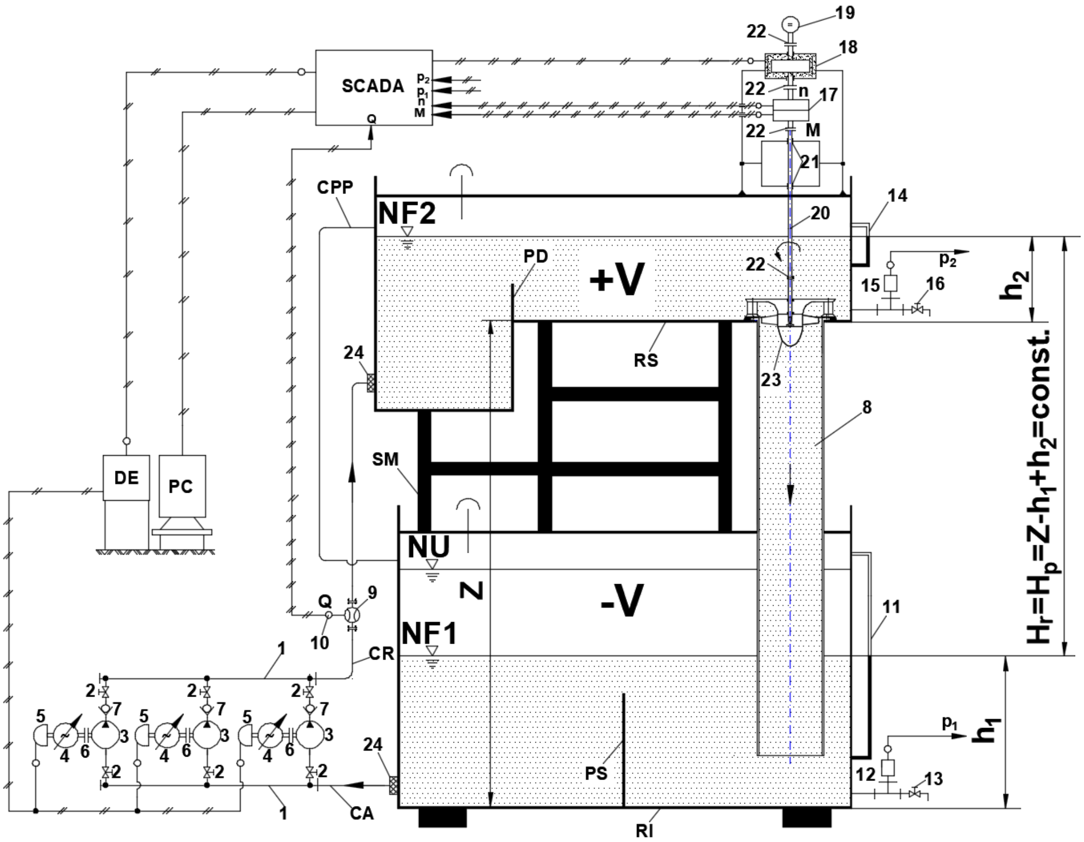

Fig. 9. Constructive-functional diagram for a hydraulic turbine test stand fed with constant level tank

The stand from figure 9 circulates a flow of clean water in a closed circuit, with the help of a pumping group with adjustable flow, consisting of three centrifugal pumps **3**, identical and connected in parallel to sum up the flows, each of them having a common suction manifold and a common discharge manifold **1**, each of the three pumps being able to be separated from the collection pipes of the group by means of two isolation valves each **2**, one on the suction and the other on the discharge, a one-way valve **7** being mounted before the valve on the discharge, and the drive of each pump being made by an electric motor of 380 V AC, **4**, coupled to the pump shaft by an elastic mechanical coupling **6** and powered by means of an adjustable frequency converter **5**, with the help of which the drive rotational speed of the pump is adjusted and, by through it, the flow of the pump is adjusted.
The adjustable flow pumping group sucks through a suction pipe CA from a first suction tank **RI**, mounted on the ground, inside which a wall **PS** is provided to separate the discharge / suction compartments, and discharges through a pipe discharge **CR** into a second upper tank **RS**,

mounted at a height and overlapped on the first one, which has a spillway **PD** separating two compartments, one connected to the discharge pipe and another connected to a transparent vertical pipe connected to the lower tank RI, both tanks having caps that communicate with the atmosphere and being fixed on the same metal support **SM**, equipped with screws for adjusting the verticality of the subassembly tanks-covers-support (not shown in the diagram).
The tributary flow, with which the pumping group feeds the upper tank, drains by gravity into the lower tank through a transparent vertical pipe **8**, provided with a flange glued at one end, which is mounted between the tanks, the flanged end of the pipe being fixed to the bottom of the upper tank, inside, and the other end, which penetrates the cap of the lower tank, remaining permanently completely immersed in water. To prevent the propagation of vibrations, generated by the pumping group, to the two overlapping tanks are equipped with two elastic sleeves **24**.
Each of the two tanks also contains: an emptying valve, **13** and **16**, mounted in a T-shape connection, in which the hydrostatic pressure transducers **12** and **15** are also mounted; one level indicator each, **11** and **14**. In case of accidental damage to the automatic flow regulation system, an overflow pipe **CPP** is considered, through which any excess flow will be discharged from the upper tank to the lower tank**.**
The model 23 low-head hydraulic turbine to be tested on the stand is mounted inside the upper tank, with the turbine stator fixed to the flange of the transparent tube and the rotor coupled to the shaft **20** of an adjustable braking system resting on the upper tank cap.
The adjustable braking system contains: two radial-axial bearings **21**; a torque and rotational speed transducer **17**; a brake 18 with magnetic powders, with adjustable resistance moment depending on the supply current; an electric motor 19 of 24 V d.c., necessary to drive the brake before the start of tests on the stand, to homogenize the magnetic powder and determine the value of the friction moment in the bearings, and four mechanical couplings 22 on the kinematic chain of the components of the braking system.
The SCADA system for monitoring, control and data acquisition contains: an electrical box, equipped with a programmable controller and power source; two transducers, **12** and **15**, mounted at the base of the tanks, which measure the hydrostatic pressures, $\mathbf{p_1}$ and $\mathbf{p_2}$, in each tank, and are used to measure the water levels $\mathbf{h_1}$ and $\mathbf{h_2}$ in each tank; an electromagnetic flow meter **9** associated with a flow transducer **10**, mounted on the discharge pipe of the pumping group; a brake **18** with magnetic powders; a torque and a rotational speed transducer **17** in connection with a **PC** computer, by means of which the adjustable braking system is controlled, i.e. the regulation of the flow to the pumping group, so that the drop **H** achieved by the transfer of a volume **V** of water from the lower tank to the upper tank and defined so that the distance between the free surfaces of the water in the two tanks remains constant, at a prescribed value, during the tests. Through the **SCADA**, the test flow rate **Q**, the levels $\mathbf{h_1}$ and $\mathbf{h_2}$ of the water in the two tanks and the mechanical parameters of the tested turbine (rotational speed **n** and moment **M**) are monitored.
By changing the prescribed H_p drop, respectively the stabilized **NF1**, **NF2** levels of tank operation, measured with transducers **12** and **15**, the **SCADA** system of the stand can adjust the achieved drop **Hr**, in an interval of length proportional to the volume of the tanks and the **Z** elevation of the front positioning of soil of the **RS** tank. Each adjusted value of the drop H will correspond to a value of the influent flow rate to the upper tank, equal to the effluent flow rate of the tank that flows through the transparent tube, respectively the flow rate required to test the model 23 of the tested low-head hydraulic turbine.
The determination of the functional characteristics of the low-head hydraulic turbine models tested on the stand is done after the homogenization of the magnetic powder from the brake, by operating it in empty position, for 10-15 min., with the help of the electric motor of 24 V d.c.**19,** followed by its dismantling.

Table 3: Stand functionality and the ways of carrying out the tests

Name of the activity	Name of the stage	Description of the stages
	Verticality tanks	*Checking and restoring,* if it is necessary of the verticality of the overlapping tanks assembly;
		Fill the lower tank, with clean and filtered water from the mains, until

Preparing stand for testing	Filling the stand with water, adjusting the water level, pumps aeration, mounting the turbine and braking system	the water reaches the **NO** filling level, visualized on the level indicator **11**. This level is calculated so that the volume of water in the tank ensures the filling of the pumping circuit consisting of: suction pipe + pumping group + discharge pipe + upper tank maximum level + transparent vertical pipe;
		Water level adjustment. If it is necessary, discharge valve **13** is also used to adjust the filling level;
		Pump aeration by unscrewing / tightening of the vent caps of each pump;
		The turbine model **23** *is mounted,* on the flange of the stand transparent tube.
		The adjustment braking system is mounted on the superior tank cover, then this is coupled at the shaft of the turbine model which will be tested;
		The value of the fall $\mathbf{H_p}$ is prescribed from the programmable automaton, defined as the distance between the free surfaces of the water in the two tanks, respectively: $\mathbf{H_p=Z-h1+h2}$, in which: **Z** represents the positioning elevation of the bottom of the upper tank **RS** in the compartment to the right of the spillway threshold, against the bottom of the lower tank **RI**; $\mathbf{h_1}$ represents the water level in the lower tank **RI**, measured indirectly with the hydrostatic pressure transducer **12** ($\mathbf{h_1=p_1/\rho g}$); $\mathbf{h_2}$ represents the water level in the upper tank **RS**, measured indirectly with the hydrostatic pressure transducer **15** ($\mathbf{h_2=p_2 / \rho g}$).
	Start group of pumping and flow control program initiation	**step 1:** the pumps of the group are started, at ½ of the nominal rotational speed, to fill the hydraulic circuit and the upper tank up to the level of the overflow threshold **PD**, which separates the tank into two compartments;
		step 2: water reaches the level of the spillway in the tank **RS** and drains by gravity through the transparent tube into the lower tank **RI**. The discharge flow **Qs** through the transparent vertical tube (effluent flow of the upper tank **RS**), which depends on the shape of the tested turbine and the vortex formed at the exit of the turbine is compared with the flow **Qp** of the pumping group (tributary flow of upper tank **RS**) by analyzing the water levels in the tanks.
		for **Qs>Qp**, because in the upper tank the water stagnates at the level of the spillway threshold for a calculated time interval, in which the hydrostatic pressure transducer **15** does not transmit information of the level increase in the upper tank **RS,** the **SCADA** system commands the automatic increase of the flow of the pumping group, by increasing the drive rotational speed of the pumps, until the achieved drop $\mathbf{H_r}$ equals the prescribed drop $\mathbf{H_p}$. From that moment, when the operating levels **NF1** and **NF2** are stabilized in the two tanks, and a volume V of water is transferred by pumping from the lower tank **-V** to the upper tank **+V,** the **SCADA** system will provide a closed-loop adjustment of the rotational speed of the pumps, implicitly of the influent flow to the upper reservoir, for the constant maintenance of the drop $\mathbf{H_r=H_p=Z\text{-}h_1+h_2}$, implicitly of the effluent flow to the upper reservoir;
		if **Qs<Qp**, the **SCADA** system commands the automatic reduction of the pump rotational speed, and upon receiving the prescribed value of the fall $\mathbf{H_p}$, the system acts to keep it constant, implicitly the effluent flow to the upper tank;
Determination of functional characteristics of tested turbine model	Characteristic M=f(Q) at Mr=const.	*the moment at the turbine axis as a function of flow at constant load* is determined experimentally for several constant drops **H**;
	Characteristic n=f(Q) at Mr=const.	*the rotational speed at the turbine shaft as a function of flow at constant load*, is determined experimentally for several constant drops **H**;
	Characteristic	*the rotational speed as a function of load at constant flow rate*, is

	n=f(Mr) at Q=const.	determined experimentally for several constant flow rates **Q**.

4. Conclusions

The summary of the main conclusions is presented in table 4.

Table 4: Synthesis of the main conclusions

Stand / Particularity	Subchapter 2.1	Subchapter 2.2	Chapter 3
Stand destination.	Determining speed distributions on rotor blades and testing small flow axial hydraulic turbines, with vertical or horizontal axis.	Testing small flow axial hydraulic turbines, with vertical or horizontal axis.	Low-head, vertical axis axial hydraulic turbine testing.
The technical problem that the stand solves	It accumulates two functions in a single means of testing, respectively: *optimization* of the hydrodynamic shape of the rotor blades*; rotor experimenta*l *test*.	Simple solutions for: *fine adjustment of the flow rate* in three successive steps flat weir + adjustable centrifugal pump + water ford tilting angle adjustment; *load simulation* with a gear pump with adjustable needle throttle mounted on the discharge, which is driven by the tested turbine.	The stand is fed by a *constant-level height tank*, *for which the influent flow*, respectively the supply flow of the stand, *is equal to the effluent flow*, respectively the useful flow of the stand for low-head hydraulic turbine tests.
The main functional characteristic of the stand	Regulates *the speed / flow* of water in the horizontal test section of the turbine; keeps the adjusted value constant.	Regulates *the speed / flow* of water in the horizontal test section of the turbine; keeps the adjusted value constant.	Regulates the fall of water in the vertical test section of the turbine; keeps the adjusted value constant.
Stand simulated natural conditions, for in-situ assembly of small hydraulic turbines	Flow from permanent watercourses is simulated in a transparent horizontal plexiglass section.	The flow from permanent watercourses is simulated in a tilting water ford, with a maximum inclination of 9° from the horizontal, made of stainless steel.	The fall of water from permanent streams is simulated in a transparent stainless steel vertical pipe fed by a constant level reservoir.
Functional characteristics determined on the stand	M=f(Q) at Mr=const.; n=f(Q) at Mr=const.; n=f(Mr) at Q=const.	M=f(Q) at Mr=const.; n=f(Q) at Mr=const.; n=f(Mr) at Q=const.	M=f(Q)at Mr=const.; n=f(Q) at Mr=const.; n=f(Mr) at Q=const.
How to adjust the flow	Pumping group consisting of 3 centrifugal pumps, connected in parallel, driven by electric motors with adjustable speed.	Flat sluice, plus an adjustable centrifugal pump, plus adjustment of the inclination of the tilting water ford.	Pump group consisting of 3 centrifugal pumps, connected in parallel, driven by electric motors with adjustable rotational speed.
Load simulation mode	Magnetic powder brake.	Gear pump and needle adjustable throttle.	Magnetic powder brake.

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Pulsation Characteristics on Volumetric Gear Pump Operation within Hydraulic Circuit

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Abstract: *Hydraulic pumps are essential components in hydraulic systems requiring precise and powerful motion control. The choice of pump depends on factors like the required flow rate, pressure, fluid type, and application environment. Pulsation in the context of hydraulic actuation systems refers to the periodic fluctuation of pressure and fluid flow rate within the hydraulic circuit, often caused by the operation of the pump or other components. Pulsation can have several effects on the performance and reliability of a hydraulic system, and understanding its causes and mitigation strategies is essential.*

Keywords: *Hydraulic actuation, volumetric pump, gear pump, pulsation*

1. Introduction

Within a hydraulic circuit the hydraulic pump is a mechanical device used in hydraulic systems to convert mechanical energy into hydraulic energy. It generates fluid flow, which in turn creates pressure that can be used to power hydraulic machinery and systems.

The common types of hydraulic pumps includegear pumps, with external gear, which is the most common type, using two gears to create flow, it represents simple, durable, and cost-effective solution and internal gear variants, featuring a gear within an internal gear design, often used for high-viscosity fluids.

Other constructive variants of volumetric pumps are represented by vane pumps, namely sliding vane pumps, which use a rotor with extendable vanes able to move within a casing. These variants are efficient and quiet during operation, ideal for moderate pressure applications.

The force units are represented by axial piston pumps, having a certain number of pistons placed in a circular array within a cylinder block. These constructive variants are well known for high efficiency and high-pressure capabilities.

Other piston pumps are the radial piston units, where the pistons are arranged radial around the pump's center, being suitable for very high pressures in operation.

The pump receives mechanical energy from an engine or motor, being able to circulate the hydraulic fluid from a reservoir into the hydraulic system (circuit), which in time provide a continuous circulation with pressure generation. As fluid is moved into the system, pressure is created and together with the volumetric flow rate can be harnessed to do work, such as moving pistons, lifting loads, or powering linear or rotating motors.

The applications that require hydraulic actuation are represented by construction equipment namely in equipment's for excavators, bulldozers, and cranes, industrial machinery used in presses, lifts, and conveyor systems, automotive systems found in power steering, brake systems, and automatic transmissions, aviation industry where is essential for operating aircraft control systems and landing gear.

The key considerations for the volumetric pumps units are represented by volumetric flow rate, which is the fluid volume that pump can move, usually measured in litres per minute (L/min), pressure rate which is the maximum pressure the pump can operate, often given in bar, efficiency value as a parameter that provide the effectiveness of how the pump converts mechanical energy into hydraulic energy and maintenance of the unit, because regular maintenance is required to prevent leaks and ensure longevity in operation.

Positive displacement pumps inherently produce pulsations due to their cyclic nature of fluid displacement. Each cycle of the pump can cause a surge in pressure and flow.

As an undesirable phenomenon in pump operation is registered when a pump's suction side doesn't have enough fluid and can cause the cavitation, leading to irregular flow and pressure spikes.
Although, the cyclic operation related to fluid aspiration and discharge rapid opening or closing valves can create pressure surges and pulsations within the hydraulic system.
Once created and further the lack of proper damping components, such as accumulators or pulsation dampeners, can allow pulsations to propagate through the hydraulic system circuit being possible to reach resonance. Certain system designs can create resonant conditions, amplifying pulsations at specific frequencies.

2. Effects of Pulsation

The continuous operation of the hydraulic circuit with high values of the pulsations provided by the pump leads to the fatigue of the components and the rapid wear of their materials precisely due to the stresses inevitably induced in this way.
Repeated pressure fluctuations can lead to accelerated wear and fatigue of hydraulic components like seals, hoses and fittings [1-7].
Regarding the noise and vibration, pulsations often cause noise and vibration, which can be problematic in environments where quiet operation is necessary.
The hydraulic system pulsations can reduce the efficiency of the working equipment, leading to less precise control and energy losses.
Over time, pulsations can contribute to the breakdown of hydraulic fluid, reducing its effectiveness and leading to imminent contamination.
In this sense, the produced pulsations are stated as total disadvantage and must be reduced at maximum.
In this purpose installing a pulsation dampener can represent a solution to absorb the pressure fluctuations, reducing the severity of pulsations.
Hydraulic accumulators can provide pulsation mitigation solution while these devices are able to store hydraulic energy and release it smoothly, helping to minimize pressure spikes and dips [8-9].
Regarding proper system design, the contribution of the hydraulic circuit design engineer must also be emphasized because a correct dimensioning and adoption of the circuit components so that the disadvantages produced by pressure pulsations are minimized and even avoided.
Regular maintenance of pumps, valves, and other components can prevent issues like cavitation and ensure the system operates smoothly.
Pulsation is a common issue in hydraulic systems, but with proper design, component selection, and maintenance, its effects can be minimized.
Addressing pulsation not only improves system performance but also extends the life of the hydraulic components, ensuring reliable and efficient operation [10-13].

3. Pulsation values for external gear pumps

Pressure pulsations cause vibrations that are transmitted throughout the hydraulic system and affect the components of the drive system in the long term by degrading their material qualities
Reducing pulsation at system pump level is critical for improving the performance, efficiency, and longevity of hydraulic systems.
The external gear volumetric units are particularly used within hydraulic transmission systems for the good mechanical characteristics, high efficiency and low price.
There are also disadvantages which are related to the high noise in operation, the generation of vibrations and pressure pulsations.
The constructive principle of the gear pump is based on a pair of gear wheels that are in gear performing a rotational movement so that the fluid is taken from the low-pressure inlet area through the gaps between the teeth, being circulated in the radial area along pump casing then discharged into the high-pressure discharge area.
The pressure pulsation pattern is thus established between the two low- and high-pressure zones in which the respective volume unit operates [14-17].

An external gear pump is a positive displacement pump commonly used for fluid transfer, wherethe two meshing gears rotate in opposite directions, creating a vacuum that draws fluid into the pump chamber and forces it out under pressure.
The performance of an external gear pump can be described using several equations related to flow rate, torque, and efficiency [18-20].

$$Q = 2 \cdot V \cdot \omega$$

$$V = n_d \cdot V_d \cdot l_l \cdot d_r$$

$$Q_r = Q - Q_l$$

$$N_h = \Delta P \cdot Q_r$$

$$T = \frac{\Delta P \cdot V}{2 \cdot \pi \cdot \eta_m}$$

$$\eta_m = \frac{N_i}{N_h}$$

where:

V-displaced volume per revolution (m³/rev);

ω - rotational velocity (rev/s or rev/min);

Q -theoretical flow rate (m³/s or L/min);

Q_r - realflow rate (m³/s or L/min);

Q_l - flow rate lost due to internal leakage (m³/s);

N_h -hydraulic power (W);

ΔP- pressure rise across the pump unit(Pa);

T - torque (Nm);

η_m - mechanical efficiency of the pump unit;

N_i - input power (W).

The volumetric pumps inherently produce pulsation due to their cyclic nature, but there are several strategies that can be employed in order to minimize the pulsation values during operation.
Pulsation reduction in an external gear pump is crucial for improving the performance, reducing vibration, noise, and enhancing the reliability of the system.
Gear pumps produce pulsating flow due to the nature of their operation, where fluid is moved in discrete volumes between the gear teeth.
A dual or multi-chamber pump design can smooth out the flow by offsetting the timing of fluid delivery between the gears. This design distributes the pulsation peaks more evenly, reducing the overall magnitude of the pressure spikes.
Instead of using standard spur gears, gear pumps with helical or herringbone gear teeth can reduce pulsations. These gears ensure that the meshing occurs more gradually, leading to smoother fluid displacement. The benefits of using helical gears include smoother engagement between the gear teeth, which reduces the suddenness of flow changes and further less abrupt pressure changes, reducing the pulsations intensity.

Fig. 1. External helical gear volumetric unit

Increasing the pump rotational speed while decreasing the displacement per revolution can smooth out flow and this technique reduces the size of the pulses per cycle, leading to a higher frequency but smaller magnitude pulsation, while the smaller individual displacement volumes can create a more continuous flow.
Design improvements in the flow paths of the pump housing, such as optimized intake and discharge ports, can reduce turbulence and pulsations. For example, the tuned port shapes which act for gradually open and close the flow channels minimize sudden changes in fluid velocity.
Incorporating internal baffle help smooth the transitions of fluid flow as the gears engage and disengage continuously.
Implementing torsion dampers in the drive shaft reduces the mechanical vibrations that contribute to pulsation generation. By damping torsion vibrations, the pump operates more smoothly, reducing pressure surges.
Operating two or more gear pumps in parallel, with slightly different timing or phase angles, reduce pulsations and this setup effectively staggers the flow delivery from each pump, ensuring that pulsation peaks do not occur at the same time, leading to a more uniform flow.
Since pulsations often result in noise, focusing on noise reduction techniques like adding noise suppressors or sound-damping materials help reduce the impact of pulsations and these include acoustic enclosures around the pump, or vibration isolation with mounts or pads.
In advanced systems, electronic feedback control systems are used in order to regulate the motor speed or valve positioning dynamically. By adjusting the motor speed, pulsations are mitigated by smoothing the torque applied to the pump unit.
Using flexible hoses or tubing in the discharge line is absorbed some of the energy from pressure surges, helping to smooth out pulsation effects. Soft lines allow for some expansion and contraction, which naturally dampens pulsations [18-19].

4. Numerical analysis on external gear pump pulsation

A numerical approach analysis on pulsation values generated by an external gear volumetric unit involves the simulation and calculation of characteristics related to pressure and flow rate variations in time. This can be achieved by an analytical method based on volumetric unit geometry and operating conditions.
In order to model the pulsation within an external gear unit the following variables are considered:

- Flow rate *(Q)* representing the circulated fluid volume in time unit;
- Pressure *(p)*registered at pump outlet or within the main chambers;
- Rotational velocity (ω) – wheels velocity;
- Fluid volume displaced *(V)*- volume of fluid displaced by the gear teeth per revolution, for which are used the number of teeth, area swept by a single gear tooth, and width of the gear:

$$V = 2 \cdot z \cdot A_d \cdot l$$

Pulsation in the flow can be analyzed by examining the difference between theoretical flow and the actual instantaneous flow due to the discrete nature of gear displacement.
The instantaneous flow rate at any given moment can be modeled as [20-21]:

$$Q(t) = Q \cdot \left[1 + A \cdot \sin(2 \cdot \pi \cdot f \cdot t)\right]$$

Where:

A - amplitude of pulsation, representing the extent of flow variation;

f - frequency of pulsation, determined by the gear rotation speed;

t - time.

The number of teeth can be considered as 10, 12 and 14, the rotational velocity of 1500 the frequency values are 250, 300 and 350 Hz.

The pressure pulsation at the outlet can be obtained using a sinusoidal model:

$$p(t) = p + \Delta p \cdot \sin(2 \cdot \pi \cdot f \cdot t)$$

where:

p -mean outlet pressure (Pa);

Δp - amplitude of pressure pulsation (Pa).

f - pulsation frequency (Hz).

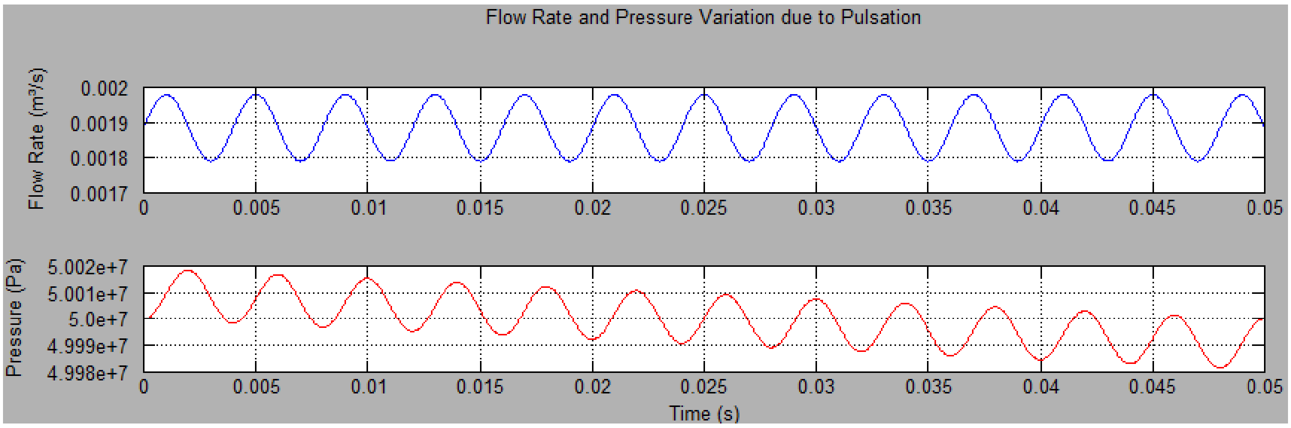
t - time (s).

The amplitude of the pressure pulsation can be determined from the compressibility of the fluid and the flow pulsations, or from empirical data based on the specific pump design.
To numerically analyze the flow and pressure pulsation over time, the time domain must be discretized into small intervals *(Δt)* and compute the flow and pressure for each step.
In table 1 are presented the numerical values used for analysis.

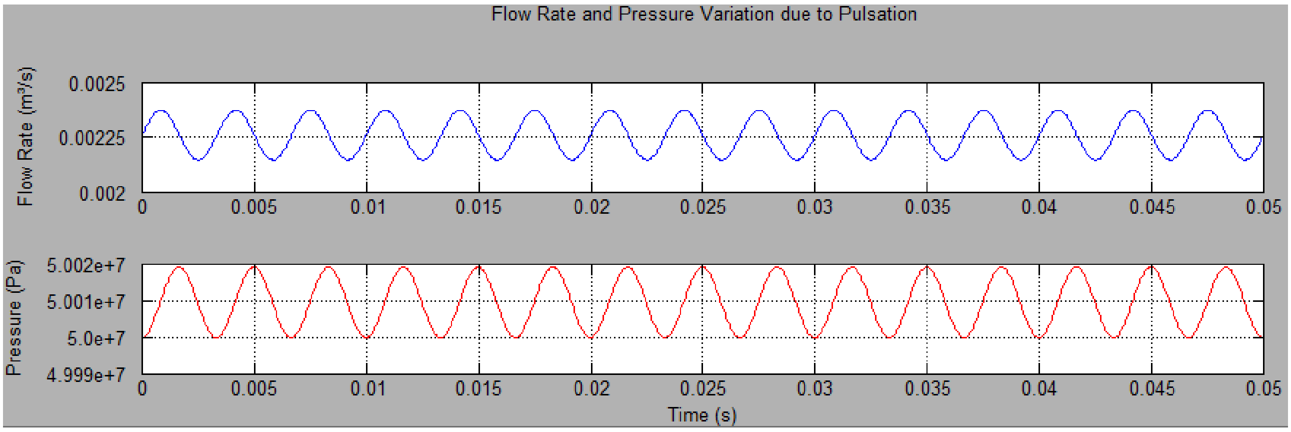
Table 1: Numerical initial values

Crt. No.	Parameter	Value		
1.	Gear diameter	0.05 (m)		
2.	Gear width	0.02 (m)		
3.	Number of teeth	10	12	14
4.	Rotational velocity	1500 (rpm)		
5.	Mean outlet pressure	5 (MPa)		
6.	Pressure pulsation amplitude	0.2 (MPa)		
7.	Pulsation frequency	250 (Hz)		

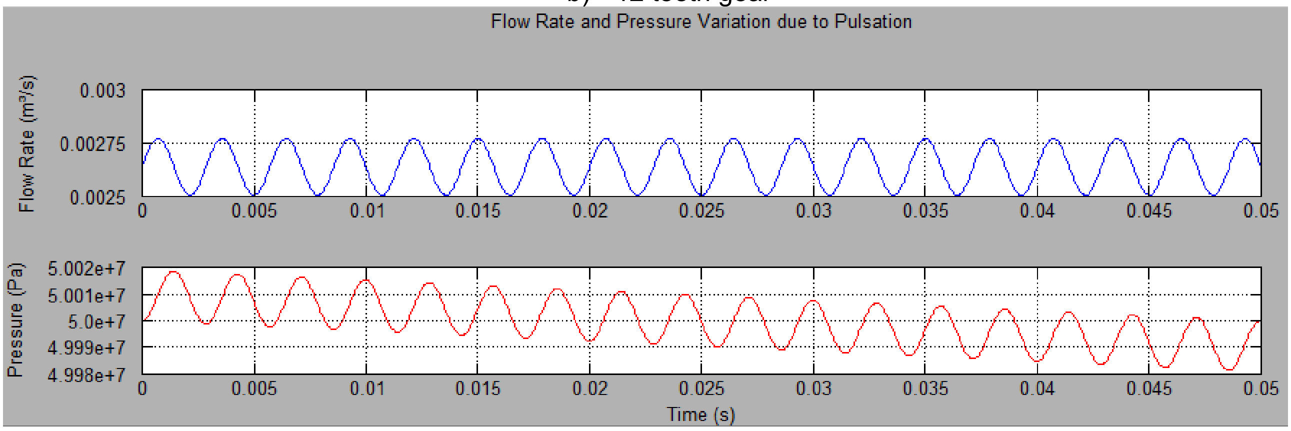
The results obtained are presented in figure 2, being emphasized the fluid flow rate and pressure variations due to generated pulsation in operation of volumetric unit.



a) 10 teeth gear



b) 12 teeth gear



c) 14 teeth gear

Fig. 2. The results for flow rate and pressure due to pulsation according with the number of teeth

The fluid flow rate oscillates around the theoretical value with a 5% amplitude variation due to pulsation, while the pressure fluctuates between 4.9 MPa and 5.0 MPa, corresponding to the mean pressure and pulsation amplitude.
The frequency of the pulsations depends on the rotational speed (RPM) and the number of teeth on the gears and for this case, it will be around 250 Hz.
The obtained results are obtained on a pulsation analysis for the external gear pump, showing how both the flow rate and pressure vary due to pulsations.

5. Conclusions

External gear volumetric units operate by trapping fluid between the rotating gears' teeth and the casing, moving it from the inlet to the outlet. They are positive displacement pumps, meaning that each revolution of the gears displaces a fixed fluid amount and this feature provides a constant theoretical flow rate.
However, due to the discrete nature of the fluid being displaced by individual teeth, pulsations are inevitable. Pulsations are periodic fluctuations in flow rate and pressure, which are linked to the rotational velocity and number of teeth on the gears.
The pulsation frequency in an external gear pump is primarily dictated by the rotational velocity (RPM) and the number of teeth on the gears. In this case, with 10, 12 and 14 teeth and a rotational speed of 1500 RPM, the pulsation frequency is calculated to be in range of 250-350 Hz.
The pulsation frequency corresponds to the frequency at which the pressure and flow rate variations occur as the teeth pass through the pump's high and low-pressure zones and this can be observed as a periodic oscillation in both the flow rate and pressure data.
The flow rate is not perfectly steady and fluctuates around the theoretical value due to pulsation, while the sinusoidal variation in flow rate represents how each tooth displaces fluid intermittently, causing small ripples in the flow.

Although the flow pulsations amplitude is relatively low (5% variation in this case), the pulsations can become significant in high-precision applications or systems sensitive to flow stability.
Similarly, the pressure at the outlet of the pump experiences fluctuations, with a mean pressure of 5 MPa and an oscillation amplitude of 0.2 MPa (±0.2 MPa from the mean). The pressure pulsations follow the same frequency as the flow rate, since they are caused by the same gear tooth interaction.
Pressure pulsations can lead to noise, vibration, wear in hydraulic systems and further if the pulsation frequency resonates with the natural frequency of other components in the system (pipes, valves), it could amplify the effects, causing mechanical stress or failures.
The frequency analysis (FFT) confirms that the dominant pulsation occurs at the calculated frequency, with additional harmonics possibly present depending on the gear geometry and system configuration.
The harmonics represent higher-order pulsations and are typical of mechanical systems where repetitive interactions occur (such as the engagement and disengagement of teeth in gears), contributing to vibration and noise within the system.
While external gear pumps are generally reliable, pulsations can affect the efficiency of fluid delivery, especially in high-precision applications and pulsation dampeners or flow smoothing mechanisms might be necessary in such cases.
Repeated pressure pulsations can lead to fatigue and wear on pump components and connected hydraulic systems. Long-term exposure to pulsation-induced vibrations can reduce the lifespan of the pump and its components.
The gear pump's pulsations, especially at higher frequencies, contribute to acoustic noise and mechanical vibrations, which can be disruptive in sensitive environments or high-performance applications.
While external gear pumps are widely used due to their simplicity and durability, pulsations are an inherent feature that must be managed, especially in applications that require steady flow and low noise. Understanding the pulsation frequency and amplitude allows engineers to design systems with appropriate dampeners or vibration isolation in order to mitigate these effects, ensuring smoother operation and improved pump and system longevity.

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Research on the Involvement of Intelligent Robots in the Assembly of Modern High-Performance Computers

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Abstract: *This research examines the use of programmed intelligent robots for the assembly process of supercomputers (high-performance computers - HPCs), drawing on multiple and credible/reputable scientific sources, highlighting the impact on the efficiency and quality of this industrial production, flawlessly achieved by handling and assembling the complex components of supercomputers (HPCs), once with reducing errors and improving the accuracy of this complex manufacturing process. The clear advantages of using programmed robots for supercomputer assembly are highlighted in this paper, such as: optimizing production time and reducing labor costs, significant potential to improve production efficiency and quality.*

Keywords: *High-performance computers, intelligent robots, assembly of HPC, artificial intelligence*

1. Introduction

A supercomputer – or a high-performance computer HPC – as it is known in the specialized literature – is an extremely powerful and complex type of computer designed to perform extremely intensive and complex calculations at an incredibly high speed.
These computers are used to solve highly complex scientific and technical problems that require enormous processing power, such as molecular modeling, genome data analysis, climate simulations, and starburst simulations, among others.
A supercomputer/ HPC is composed of a network or cluster of interconnected powerful processors, fast memory and advanced technologies for storing processed data. HPCs can be used in various fields such as: scientific research, design and engineering, financial analysis and even military analysis.
The main characteristics of HPC include massive computing power, a scalable architecture, and the ability to run diverse and complex applications in parallel.
Due to the increased importance of supercomputers/ HPCs in the contemporary world, the need has been created to assemble them as quickly, accurately and reliably as possible, thus giving rise to the idea of using intelligent robots with AI in the industrial environment for the high-quality manufacturing of those.

2. Robots intelligently programmed to assemble high-performance computers

In the last decades, a very large number of robots have been integrated on the production lines of factories, for the purposes of increasing the pace of manufacturing or data with the substantial increase in the quality of the products made. Currently, technological developments allow robots [2-14,17,18] to work interactively with humans in the same environment and within the same process, even without resorting to increased security measures. Communication and easy cooperation between humans and robots (cobots) is the most important requirement in modern working relationships, which has already been successfully achieved in many automated workplaces and even on many technological lines of automated manufacturing, in many countries with highly automated industries.
Moreover, with the development of complex and massive data processing methods, as well as the explosive growth of artificial intelligence in recent years, it has become natural and efficient to

achieve continuous and progressive improvement of intelligent robots by implementing their AI facilities, which thus transformed into extremely capable super-robots for more and more complex, more efficient and more and more autonomous work tasks (see figure 1).

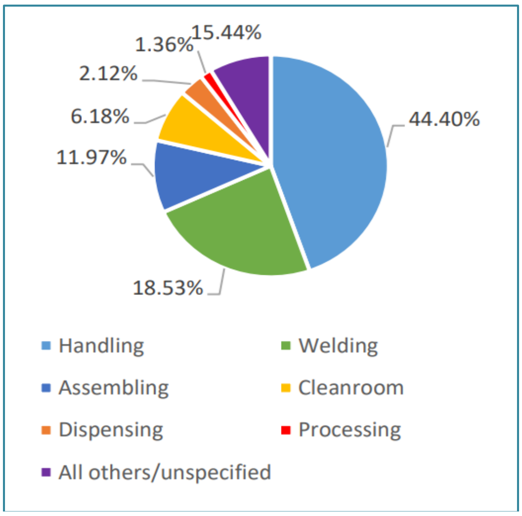

Fig. 1. Share of international distribution of industrial robots by specialized industrial tasks/ operations, in 2022

Artificial intelligence (AI) has successfully entered the field of science and engineering, where a particularly significant development has taken place for the coordination and control of robotic systems and/or intelligent robots [1 -5, 15-18], which have thus acquired superior characteristics, associated with human-level intelligence superior. Artificial intelligence uses several technologies that currently allow robots to understand, feel, plan, act and learn with a level of intelligence equivalent to and often superior to that of humans, so the time perspective creates the premises for highly sophisticated AI robots and with an intelligence far beyond that of the smartest human genius - it is even expected that the future model of AI will surpass all the top human intelligences put together at a given time or that would work closely together like a superman.

Fundamentally, AI systems perceive their surroundings, recognize objects, contribute to complex decision-making, solve, learn from past experiences and imitate patterns, which immediately recommended them as suitable and necessary for intelligent robots (figure 2), with several operational specializations.

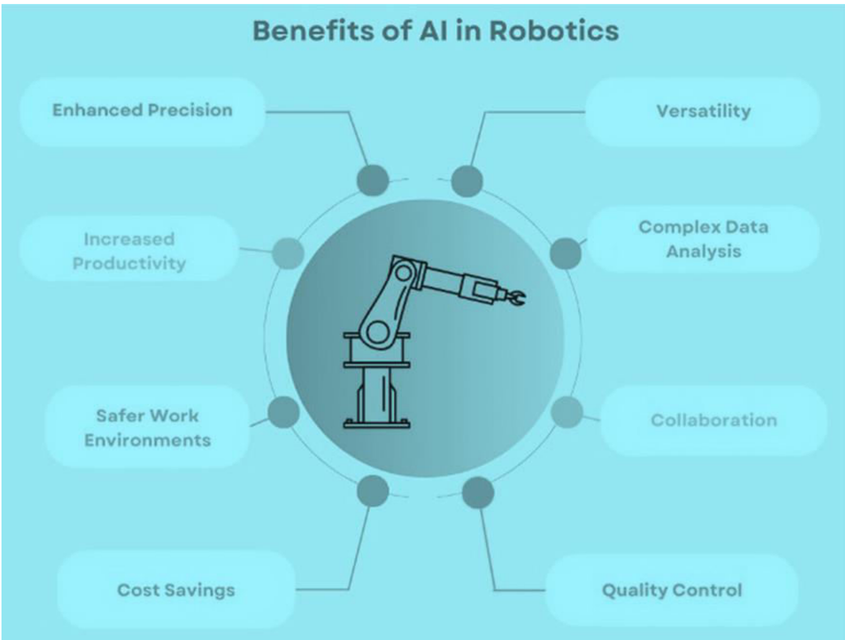

Fig. 2. Benefits of AI implemented on industrial robots in present

On a global level, recent years have highlighted the major role of AI-enabled industrial robots in performing various complex operations and specific tasks across different competitive industries that have significant social impact, such as electronics, manufacturing, automotive, pharmaceuticals, and others.
The main features of modern industrial robots equipped with AI include:
◘ **Programmability**: Industrial robots can be programmed to execute certain operations and very complex movements. Their programming can be tailored to accomplish specific tasks, such as lifting, handling, assembling, welding, painting, inspecting, etc., as well as composite or multiple tasks.
◘ **Repeatability and precision**: They are capable of executing the same operations repeatedly and with high accuracy, which ensures uniformity and maximum quality in production processes.
◘ **Flexibility**: Many models of industrial robots are flexible and can be reprogrammed to perform various tasks or adapt to production changes.
◘ **Robust structure and safety**: Industrial robots are built to withstand harsh working environments and to perform tasks that may be dangerous or difficult for humans. They are also equipped with safety features to prevent accidents around them.
◘ **Use of processing equipment**: They are often outfitted with specialized tools or processing devices, such as welding arms, cutting tools, painting systems, etc., to carry out advanced technological processes on production lines.
◘ **Integration in production lines alongside ai facilities**: These robots are designed to operate efficiently within an industrial production line, collaborating with other autonomous machines and specialized equipment.
The demand for supercomputers, which, in addition to telecommunications and advanced automotive applications, also support autonomous driving, is exponentially increasing in modern society. Consequently, there is a growing need for automation solutions to assemble their component parts.
A compelling example is the automation process at Schnaithmann Maschinenbau GmbH, which has programmed seven KUKA robots to be involved in the production of supercomputers for the German automotive industry.
High-performance supercomputers represent significant brainpower for highly digitized vehicles and, as a result, must process vast amounts of data while being lightweight and compact enough to fit into relatively smaller vehicles. To produce these high-performance supercomputers cost-effectively, efficient and flexible automation solutions were necessary.
In this context, the German automotive industry has turned to KR AGILUS robotic arms, which handle specific urgent components needed for the creation of High-Performance Computers (HPC). Thus, a KR AGILUS robotic arm places the necessary component into the correct compartment of the sequential storage buffers, where another KR AGILUS robot picks up the deposited parts. The process continues with subsequent robotic arms, each programmed individually for another specific operation with each part/component obtained from its predecessor.

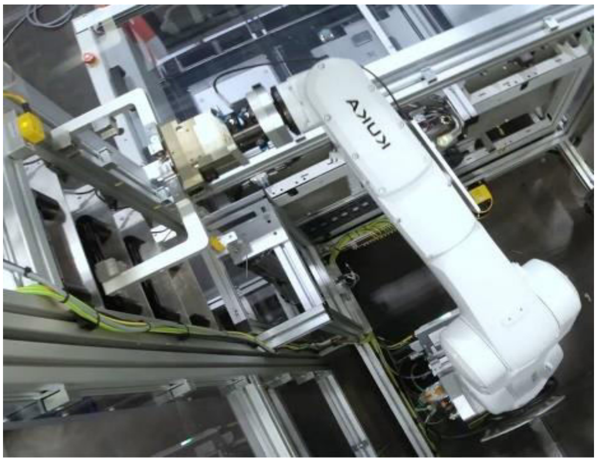

Fig. 3. KR AGILUS robotic arm in automated workflow – View

A successful assembly application involving seven KR AGILUS robots has been developed, which work rapidly and precisely "hand in hand" according to an intelligently programmed technological process in the assembly of modern supercomputers. These KR AGILUS robots (figure 3) never stagnate, do not let anything fall, and assemble and monitor HPC supercomputers with the utmost care; they also contribute to the assembly of vehicles' supercomputers only with the highest quality components by utilizing quality detection facilities for mini-micro-components.
Currently, numerous significant mega-projects have already been completed for international clients using KUKA robots, as these KUKA robots are globally present in many highly technological countries and in various high-tech applications related to Industry 4.0.
The optimized and slender construction of the KR AGILUS arm, along with its versatile real-world utilization capabilities combined with the compact control module of the KR C5 robot, were among the main reasons that propelled this type of KUKA industrial robots into the launch of a massive innovative automation initiative for supercomputer manufacturing, which began globally with the end of 2021, led by the global leader in industrial automation, KUKA.

2.1 KUKA Robots in Chaku-Chaku Workflow

Industrial robotic automation at an international level often employs assembly lines with conveyor belts; however, this approach imposes strict limitations on manufacturing enterprises, as products are initially designed within a specific range of dimensions. If there are dimensional changes to the product, even partially, at the end of the production line, costly structural modifications will be necessary due to the existing intrinsic limitations of the conveyor systems.
As a countermeasure, a technical solution featuring multiple autonomous robots working in tandem, without conveyor belts, has been proposed—this is known as the Chaku-Chaku principle.
The Chaku-Chaku principle eliminates the need for additional transport means, such as traditional conveyor belts, between various workstations. In this setup, robots transfer parts directly from one station to another, sequentially performing specific processing actions at each workstation. This approach provides greater flexibility for future adjustments to the workstations, as robots can be easily relocated and reprogrammed to different manufacturing areas.
However, the Chaku-Chaku principle requires that the robots communicate intelligently with one another and effectively manage their working spaces. The classic Chaku-Chaku handling application allows robots in an open space to execute their operational steps in a predefined order.
Furthermore, for Chaku-Chaku applications, the six-axis robot is ideally suited to be paired with the KR C5 micro control module, which is notably compact and energy-efficient.
The compact design of the KR AGILUS, combined with one of the most compact robot control modules available on the international market, ensures maximum flexibility and cost-effectiveness for the assembly of HPC supercomputers.
Moreover, KUKA has recently demonstrated through an ambitious research project that the mobile robot KMR iiwa is highly suitable for rapidly equipping printed circuit boards (PCBs) with components. This is made possible thanks to its unique features that combine the advantages of the lightweight sensitive robot LBR iiwa with a mobile and autonomous platform, rendering it location-independent and highly flexible. As part of the splicing process, the KMR iiwa reliably, quickly, and accurately places sensitive component parts into designated positions on the PCB.

2.2. Use of KUKA Robots for Supercomputer Assembly Processes through Voice Control

The software developed by KUKA for the assembly processes of supercomputers using voice control includes several subprograms for sequential processing. The subprograms, flowchart, and data types are illustrated in figure 4.
The logical flow of using human vocal language to coordinate the KUKA industrial robot is depicted as a logical diagram and can be understood through the explanations provided below:

- At the beginning of the recording, a single sound "Beep!" is heard, followed by a double sound "Beep! Beep!" through the headset when the recording has concluded.
- The recording starts as automated and continues in an infinite loop.
- The operator records voice data by speaking naturally into the microphone.

If the spoken data or commands do not conform to the "typical KUKA voice data format," the recording resumes between the “Beep!” sounds.

If the voice data are "typical KUKA voice data," the duration between a single "Beep!" and a double "Beep! Beep!" is adjusted to allow for the recording of additional voice data.

• The recorded voice data are converted into text through Automatic Speech Recognition (ASR) and subsequently transmitted to the Improvement Module of Mispronounced Words (IMMW) to obtain enhanced data for the intelligent robot.

• At this stage, the operator must confirm the task assigned to the robot by pronouncing commands such as "Evet" (yes) or "Hayır" (no).

If the recorded voice data do not match the operator's speech, the operation returns to the initial step of issuing voice commands.

If the assigned task corresponds to the task requested by the operator, the Text Understanding (TU) unit is activated. The robot then transitions to the object detection module within its workspace, activating the robot's position control. This immediately leads to the activation of the specific movements required for the operations requested by the human operator, who continually analyzes, through visual sensors and a nearby display, how the robot's movements align with the verbally assigned tasks from a distance relative to the operational area of the intelligent robot.

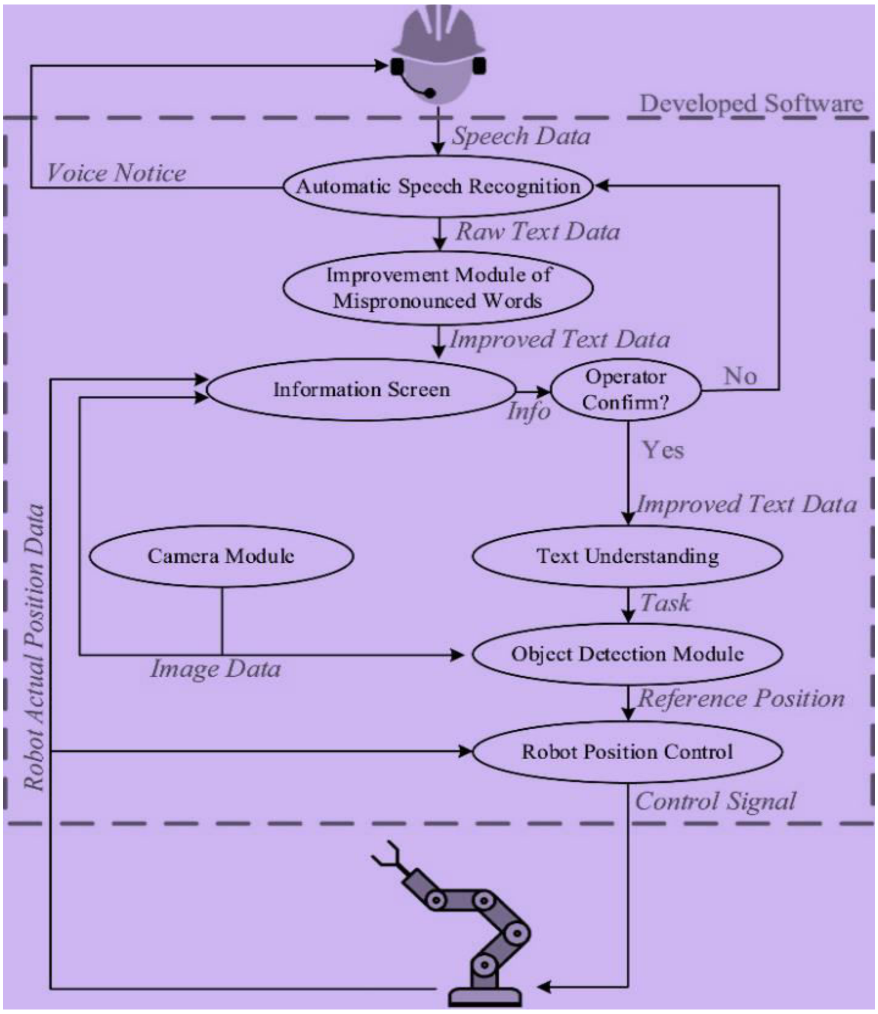

Fig. 4. Software developed by KUKA for voice-controlled supercomputer assembly processes. Logical scheme

2.3. Software developed for understanding surroundings by intelligent robots and mapping a specific sequential trajectory

This dedicated software consists of convolutional neural network (CNN) modules designed for the following roles: process selection, trajectory generation, and regulation of the sequential trajectory to be executed. The KUKA software developed and the data traffic between the CNN modules are presented in figure 5.

A video camera was used to make the robot aware of its environment and to perceive the desired process. The camera's task was to record the movement of the operator's hand within the robot's workspace. The operator starts the video recording before the operation, and the recording is stopped by the operator when the demonstration of the defined process is completed.
Once the video recording is separated into images, these images are sent to the CNN structure. The CNN classifies the images based on hand gestures. In the selection process and trajectory generation module, the type of operation and the start and end timings are selected, such as welding or sealing, which are determined by the hand movements.
The trajectory of the process is then calculated, and the obtained trajectory is subject to the operator's approval. If the operator does not confirm the process or the obtained trajectory, the system returns to the video recording stage. If the operator confirms the action and the trajectory, the trajectory regulation phase follows, which is again confirmed by the operator. Subsequently, the determined process is executed by the KUKA KR AGILUS robot. After the process of a specific trajectory is completed, the program returns to the initial stage.

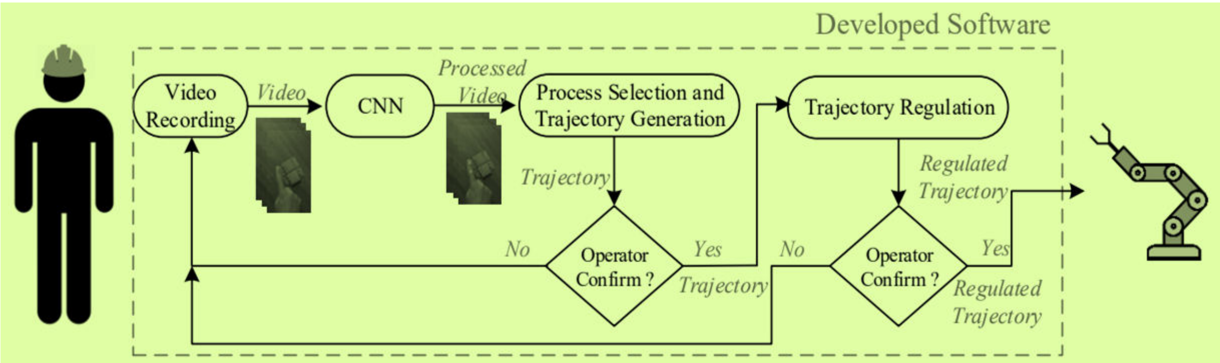

Fig. 5. Developed KUKA software and data traffic between CNN modules

3. Conclusions

It can be concluded that the success of high-performance computers (HPC) constructions [5-9, 17,18] with the help of intelligently programmed robots is fundamentally based on the direct and consistent contribution of AI. As mentioned earlier, artificial intelligence is continuously experiencing qualitative growth and expansion into various fields of science and diverse human activities, which astonishes us every day, but also generates concerns due to the unclear regulations currently governing the functioning of AI in public spaces, which often have an overly broad and uncontrolled access for a diverse public that can sometimes be unethical in behavior.
Even large global companies have turned their attention to the development of artificial intelligence, striving to create the most powerful AIs possible. A recent example from the media is Mark Zuckerberg's promise to develop this type of artificial intelligence at an ultra-advanced level, practically the most powerful AI that could match human intelligence, and be open to the public. "This technology is so important and the opportunities are so great that we should open it up and make it available at the largest possible scale in a responsible manner, so everyone can benefit", stated entrepreneur Mark Zuckerberg.
On the other hand, experts estimate that the need for supercomputers HPC for innovative electric vehicles will continue to grow, and automation solutions such as those offered by KUKA contribute to meeting the high demand for high-performance computing (HPC) and the cost-effective and reliable long-term production of these HPCs.
Currently, several automotive suppliers are known to be working with KUKA and their integrators on other innovative solutions for the future of mobility through the implementation of high-performance computers (HPC).

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Hydrostatic Transmission for Small-Power Wind Turbines

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Abstract: *This research explores the use of a dual open-circuit hydrostatic transmission system for small-power wind turbines, replacing the traditional closed-circuit design. Through AMESim simulations, the system's performance was evaluated, focusing on power transmission, electric generator frequency regulation by a PID controller, and system stability. The results show that the proposed system reduces the nacelle's mass, simplifies maintenance, and ensures steady generator output frequency at 50 Hz. Bode plot and Root Locus analyses confirmed the system's robustness under varying wind conditions, demonstrating its potential as an efficient and cost-effective solution for small-scale wind energy generation.*

Keywords: *Dual open-circuit hydrostatic transmission, wind turbines, PID controller, system stability, reduction of nacelle mass*

1. Introduction

Wind energy is a rapidly growing sector in the renewable energy landscape, driven by the need to reduce greenhouse gas emissions and transition to sustainable energy sources. Small-power wind turbines, typically used for localized energy production in rural or off-grid areas, represent an important segment of this sector. However, achieving both efficiency and cost-effectiveness in small-scale wind energy systems presents several challenges, particularly with respect to the mechanical-to-electrical energy conversion process. One critical component in this process is the transmission system that converts the rotational energy from the wind turbine into a form suitable for driving an electric generator. Initially, this transmission was a mechanical one, but after 1980, hydrostatic transmission variants also appeared, due to specific advantages [1,2].

Traditionally, closed-circuit hydrostatic transmissions (HSTs) have been employed in wind turbines to transmit mechanical power from the turbine's rotor to an electric generator. This type of transmission is highly efficient at converting rotational energy into hydraulic energy and then back into mechanical energy to drive a generator. However, closed-circuit HSTs are often bulky, heavy, and expensive, and their placement in the nacelle of a wind turbine complicates maintenance and increases the overall cost of the system.

In the light of these challenges, this study explores an alternative approach: the use of dual open-circuit hydrostatic transmissions in small-power wind turbines. This novel design separates the transmission system into two distinct units—one placed in the turbine's nacelle with a fixed transmission ratio, and the other on the ground, near the electric generator, with a variable transmission ratio. The main objective is to reduce the mass of the nacelle by relocating the electric generator and part of the transmission system to the ground, thereby simplifying maintenance and reducing costs.

Problem Statement - One of the key limitations in small-power wind turbines is the weight and complexity of the transmission system. The conventional closed-circuit hydrostatic transmissions used in many wind turbines require heavy components to be placed in the nacelle, which adds to the structural demands of the turbine tower. Additionally, these systems require regular maintenance, and accessing them in the nacelle at elevated heights can be difficult and costly. Moreover, the high cost of closed-circuit components makes them less viable for small-scale wind turbine applications, where cost efficiency is critical.

Another challenge lies in regulating the speed of the electric generator to ensure a steady frequency output. For grid-connected wind turbines, maintaining a consistent generator output frequency—typically 50 Hz or 60 Hz depending on the region—is essential. Variations in wind speed lead to fluctuations in the rotational speed of the turbine, which in turn affect the generator's speed and output frequency. A control system is therefore required to adjust the transmission ratio and regulate the generator's speed in response to wind speed changes.

The dual open-circuit hydrostatic transmission system proposed in this study addresses both of these challenges by reducing the nacelle's weight and placing the electric generator on the ground for easier access. Additionally, the open-circuit design simplifies the transmission system, using less expensive and more readily available components. A key feature of this system is the use of a fixed transmission ratio in the nacelle, with a variable transmission on the ground that adjusts flowrate to regulate the generator's speed and frequency.

Objectives - The primary objective of this research is to evaluate the performance of a dual open-circuit hydrostatic transmission system in small-power wind turbines. Specifically, the study aims to:

- *Reduce the nacelle's weight* by relocating part of the transmission system and the electric generator to the ground.
- *Simplify maintenance* by reducing the complexity of the transmission system and providing easier access to the generator.
- *Ensure steady generator output* by integrating a control system that regulates the speed of the generator to maintain a consistent frequency output, despite variations in wind speed.
- *Analyze system stability and performance* using numerical simulations to assess the response of the transmission and control system to different operating conditions.

To achieve these objectives, the study uses a numerical simulation approach, employing the AMESim software to model the performance of the hydrostatic transmission system. The simulation network allows for the analysis of various parameters, including wind turbine power, shaft speed, hydraulic pressures, and flowrates in the two hydrostatic transmissions. Control system stability is assessed through Bode plots and Root Locus analyses, while the dynamic response of the system is evaluated by examining the frequency of the electric generator and control error.

Literature Review - Hydrostatic transmission systems have been widely used in various industrial applications, including wind turbines, because of their high efficiency and the ability to transmit power over relative long distances with minimal losses. In wind turbines, HSTs convert the mechanical energy of the rotating blades into hydraulic energy, which is then used to drive a hydraulic motor connected to an electric generator. While closed-circuit hydrostatic transmissions offer high efficiency, their complexity, cost, and maintenance challenges have limited their use in small-scale applications.

Several studies [3,4,5] have explored alternative transmission methods for wind turbines to improve efficiency and reduce costs. For instance, research on open-circuit hydrostatic transmissions has shown that they offer a simpler and more cost-effective solution compared to closed-circuit systems. However, most of these studies have focused on large-scale wind turbines, where the design and operational requirements differ significantly from small-power turbines. Few studies [6,7] have specifically addressed the unique challenges of small-power wind turbines, such as the need for lightweight and low-cost components that are easy to maintain.

In terms of control systems, PID (Proportional-Integral-Derivative) controllers have been widely used in wind turbines to regulate generator speed and ensure steady power output [8,9]. The effectiveness of PID controllers in maintaining system stability, particularly in the face of fluctuating wind speeds, has been well-documented. Bode plot and Root Locus analyses are commonly used to assess the stability of control systems in wind turbines, providing valuable insights into the dynamic performance of the transmission system and the overall wind turbine.

Contributions of This Research - This study builds on the existing research by investigating the potential of dual open-circuit hydrostatic transmissions for small-power wind turbines. The key contributions of this research include:

- A novel dual transmission design that relocates the electric generator to the ground, reducing nacelle weight and simplifying maintenance.
- A detailed analysis of the dynamic performance of the system, including the behavior of pressures and flowrates in both transmissions and the response of the PID-controlled generator.

- Stability analysis using Bode plots and Root Locus techniques to assess the effectiveness of the control system in maintaining a consistent generator frequency.
- Evaluation of the system's overall feasibility as a low-cost, efficient solution for small-power wind turbines.

The results of this study provide valuable insights into the design and operation of hydrostatic transmission systems for small-scale wind turbines, offering a potential pathway for improving the cost-effectiveness and reliability of wind energy in distributed applications.
In the following sections, we present the methodology used for system design and simulation, the results of the simulation analysis, and a discussion of the findings in the context of existing research. Finally, the conclusions highlight the potential of the proposed system and future areas of exploration.

2. Material and Methods

Hydrostatic Transmission Design - The hydrostatic transmission (HST) system investigated in this study was modeled for a small-power wind turbine using the AMESim simulation platform. The proposed system consists of two open-circuit hydrostatic transmissions. One transmission is placed in the nacelle of the wind turbine and is designed with a fixed transmission ratio, while the second transmission is located on the ground near the electric generator and has a variable flow, allowing for secondary adjustment to regulate the speed of the synchronous generator by changing the displacement of the hydraulic servomotor.
The purpose of using two separate transmissions is to reduce the nacelle's weight by removing the heavy electric generator, which is conventionally housed in the nacelle. This design also makes maintenance more accessible and lowers the cost of components.
Simulation Setup - The entire hydrostatic transmission system was modeled in the AMESim environment, which provides a network-based approach to simulate mechanical, hydraulic, and control system behaviors. The AMESim simulation model depicted in **Figure 1** consists of various components that model the hydraulic transmission, including pumps, motors, pressure lines, pressure control valves, and the PID controller used to regulate the electric generator frequency.

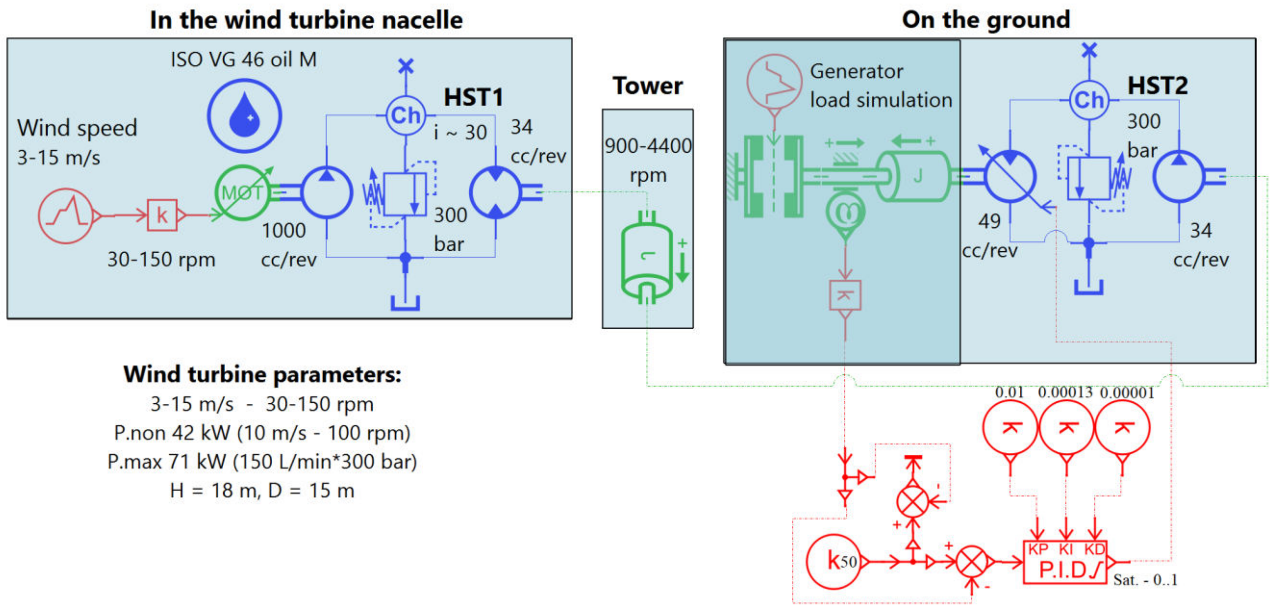

Fig. 1. AMESim simulation network of hydrostatic transmission for small-power wind turbines

The fixed-ratio transmission in the nacelle transfers mechanical energy from the wind turbine to the hydraulic transmission on the ground. The flowrate of the hydraulic pump located on the ground is sent to the servomotor, which is responsible for adjusting the shaft speed to match the required generator speed and maintain a steady output frequency of 50 Hz.

Control and Stability Analysis - A PID controller was integrated into the model to regulate the electric generator's output frequency. Bode plot was generated to analyze the system's frequency response and phase shift between the control signal and the system's response. The stability of the system was assessed through Root Locus analysis.

Data Collection and Processing - Simulation was performed with variable wind speeds, and the output data included the wind turbine power, shafts speed, pressures, and flowrates of the two hydrostatic transmissions. These values were then analyzed to assess the system's performance across various wind speeds and the response of the PID-controlled electric generator frequency.

Figure 1 shows the AMESim simulation network for the hydrostatic transmission system under study. The layout includes the fixed-ratio transmission in the nacelle and the variable-ratio transmission on the ground. Key components such as hydraulic pumps, motors, and pressure control valves are interconnected to represent the entire transmission system. The control loop incorporating a PID controller is managing the speed of the electric generator that operates at the required 50 Hz frequency. The simulation network effectively demonstrates how the energy generated by the wind turbine is transmitted hydraulically to the generator located on the ground.

3. Results and Discussion

The performance of the hydrostatic transmission system for small-power wind turbines was assessed through a simulation conducted in the AMESim environment. The results presented here focus on the operational characteristics of the wind turbine, the behavior of the two hydrostatic transmissions (HST1 and HST2), and the effectiveness of the PID controller in maintaining a steady output frequency. Key performance indicators such as power output, shaft speed, pressure, and flow rates were analyzed across varying wind speeds, highlighting the system's response and stability under different operating conditions.

Figure 2 illustrates the relationship between wind speed, shaft speed, and the power output of the wind turbine. As expected, the power generated by the turbine increases with wind speed, which is characteristic of wind turbines. Additionally, the shaft speed of the turbine rises proportionally with wind speed. The graph shows that at lower wind speeds, the turbine operates at suboptimal efficiency, but as wind speed increases, both shaft speed and power output approach the turbine's rated values. This characterization is essential for understanding how the hydrostatic transmission adapts to varying wind conditions to maintain efficient energy transfer and regulate the electric generator's speed.

Figure 3 depicts the pressure and flow rate behavior in the two open-circuit hydrostatic transmissions (HST1 in the nacelle and HST2 on the ground) under varying wind conditions. The graph shows that the pressure in HST1 and HST2 is proportional to the wind turbine power. The flow rate in HST1 & HST2 shows a direct correlation with wind speed, increasing as the wind turbine generates more mechanical power.

Figure 4 presents the Bode plot, showing the magnitude and phase response of the system under the control of the PID regulator. The plot illustrates how the system reacts to changes in the control signal, with particular focus on the frequency of the electrical generator. The magnitude plot indicates a reduction in system response at higher frequencies, with a notable roll-off starting around 0.3 Hz, reflecting the system's decreasing sensitivity to rapid fluctuations in wind speed or load.

The phase plot shows a progressive phase lag as frequency increases, with a significant phase shift occurring between 0.3 Hz and 0.76 Hz. This indicates that at higher frequencies, the system response lags behind the control command, which is typical in systems with inertia, such as hydrostatic transmissions. The PID controller successfully maintains stability within the operating frequency range, with the phase remaining within acceptable limits to ensure that the system response is both steady and efficient. These results confirm that the PID controller is effective in regulating the electric generator's frequency, ensuring that the hydrostatic transmission system can adapt to changing wind conditions while maintaining a steady 50 Hz output for the electrical grid.

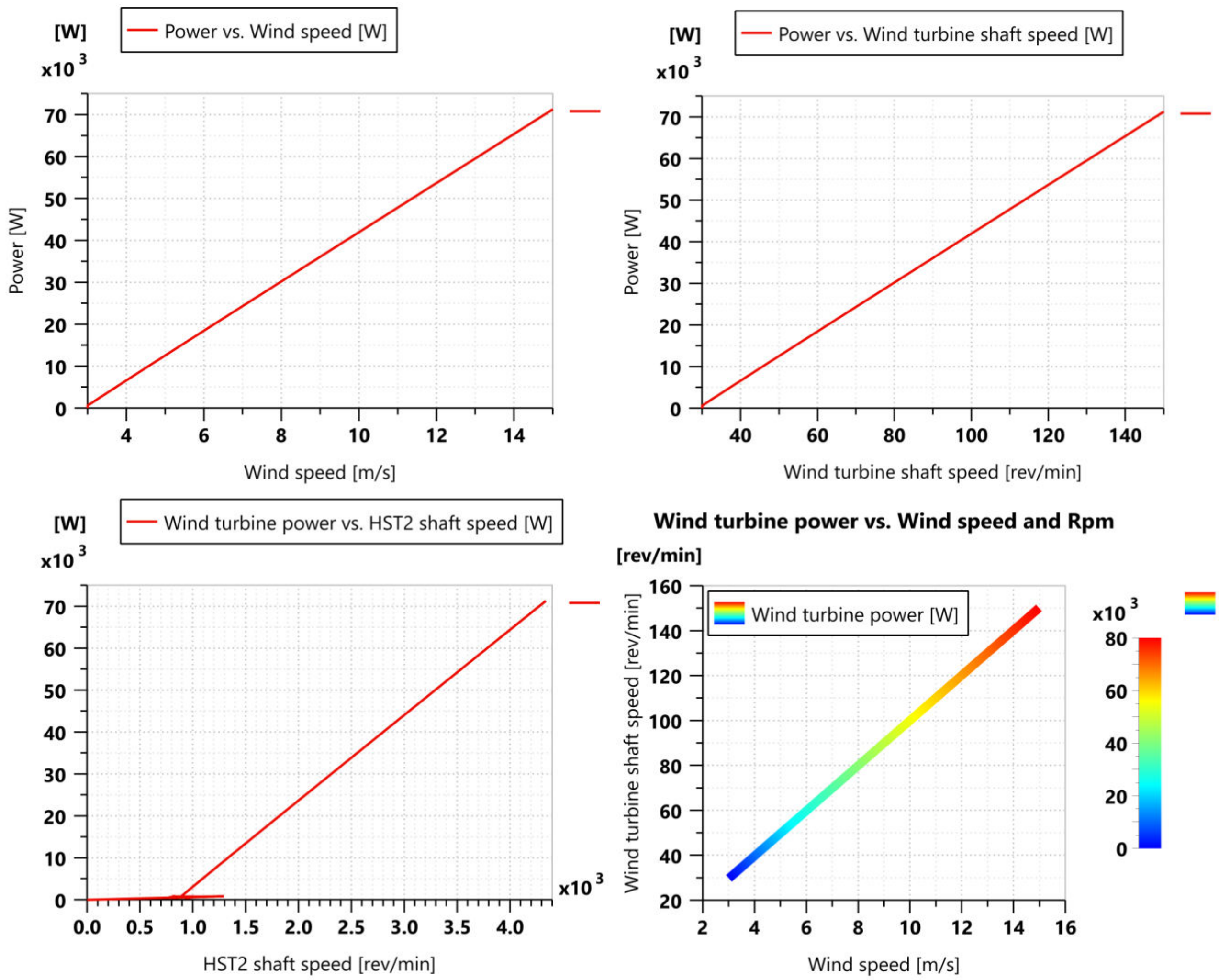

Fig. 2. Wind turbine characterization – power vs. wind speed, shaft speed

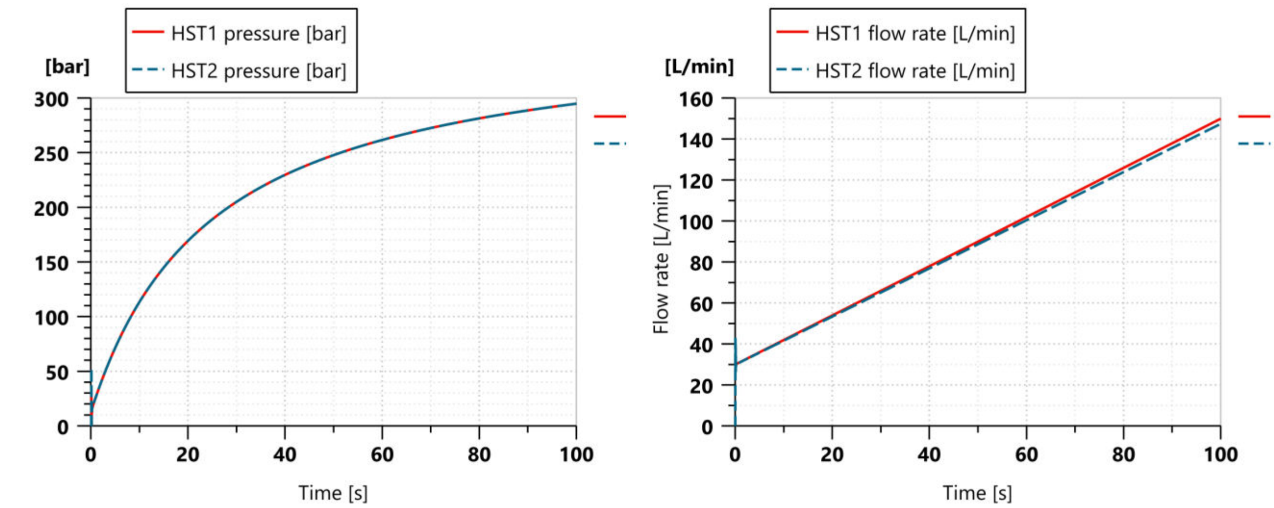

Fig. 3. Pressure and flowrate of the two hydrostatic transmissions (HST1 and HST2)

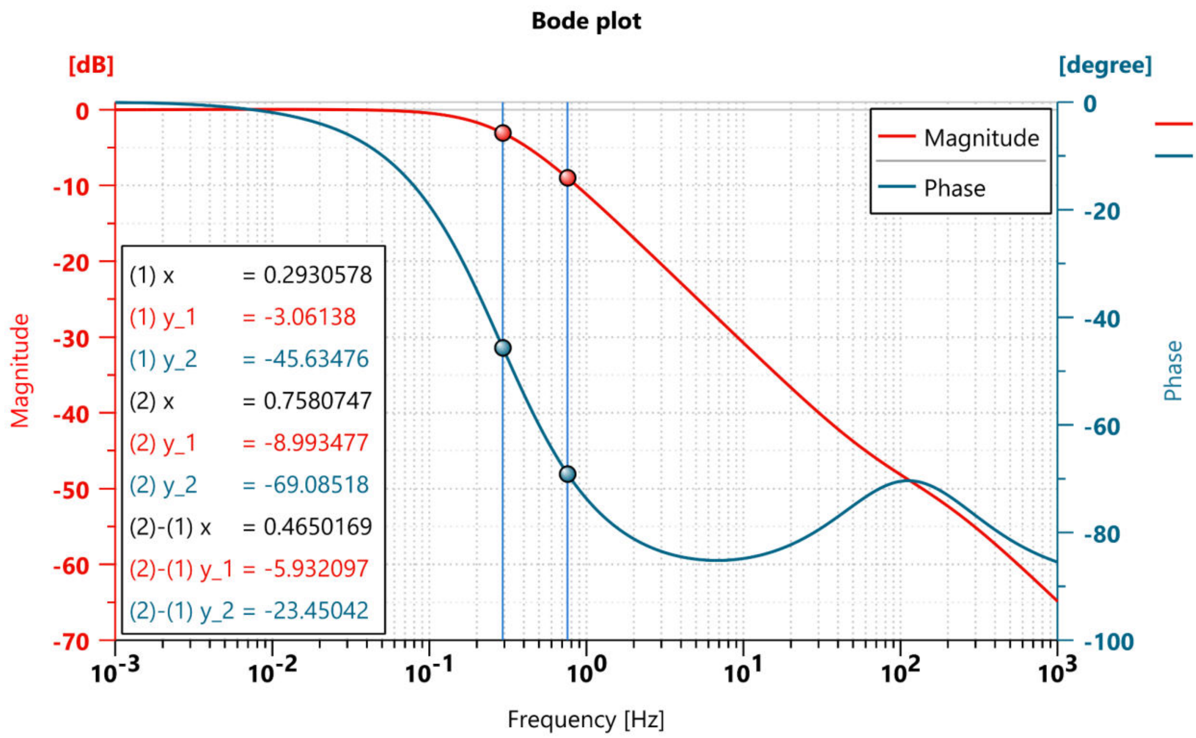

Fig. 4. Bode plot – magnitude and phase of the PID output (system command) and system response (electrical generator frequency)

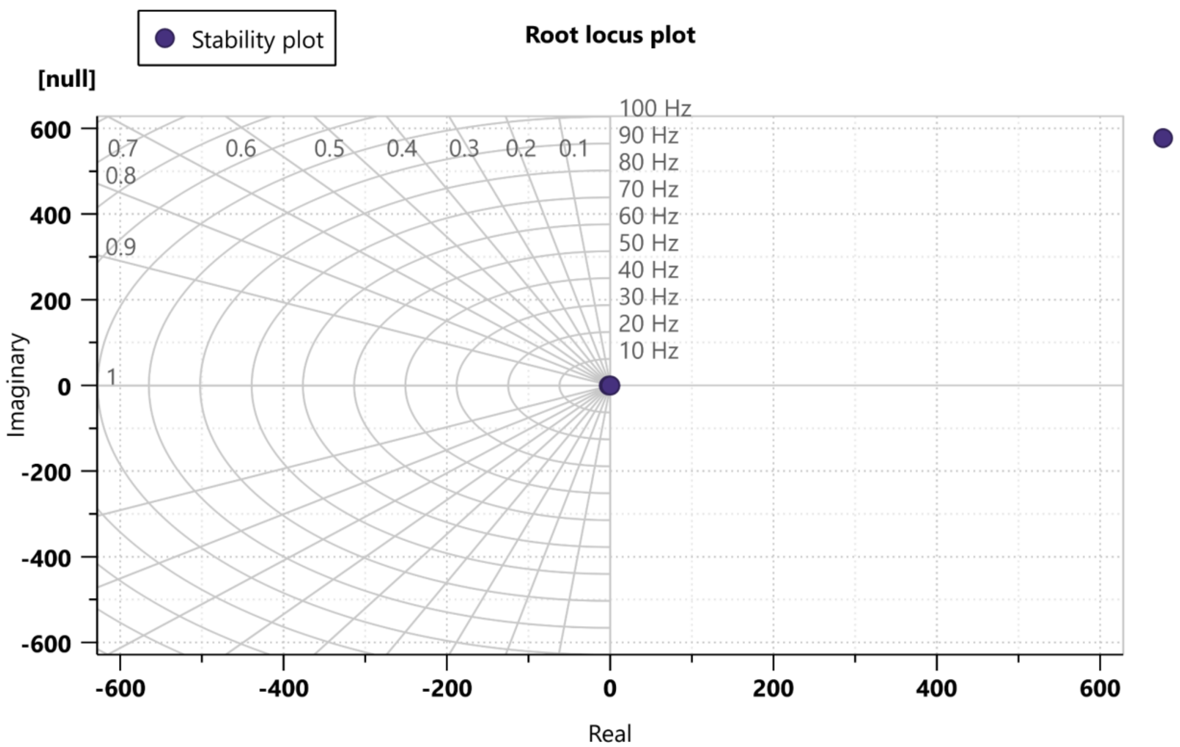

Fig. 5. Stability of the system – Root Locus plot

Figure 5 displays the Root Locus plot used to assess the stability of the PID-controlled hydrostatic transmission system. The plot shows the movement of the system poles as the gain of the PID controller varies. The Root Locus analysis is crucial for evaluating whether the system can maintain stability across a range of operating conditions. In this figure, one can see that the system poles remain in the left half of the complex plane for a wide range of gains, indicating that the

system remains steady under these conditions. The poles are sufficiently far from the imaginary axis, ensuring that the system is both steady and responsive, with minimal risk of oscillatory or unsteady behavior.
Figure 6 provides a detailed view of the Root Locus plot, zooming in on the region where the poles are closest to the imaginary axis. This close-up highlights how small changes in the controller gain affect the system's stability margins. The detailed plot shows that, even in this sensitive region, the poles do not cross into the right half of the plane, confirming that the system remains steady throughout the range of gains tested. The proximity of the poles to the imaginary axis suggests that, while the system is steady, it may exhibit slower dynamic response at certain gain values, necessitating careful tuning of the PID controller to balance stability with performance. Together, **Figures 5 and 6** demonstrate that the hydrostatic transmission system is inherently steady under PID control, with sufficient margins to handle varying operating conditions while avoiding instability.

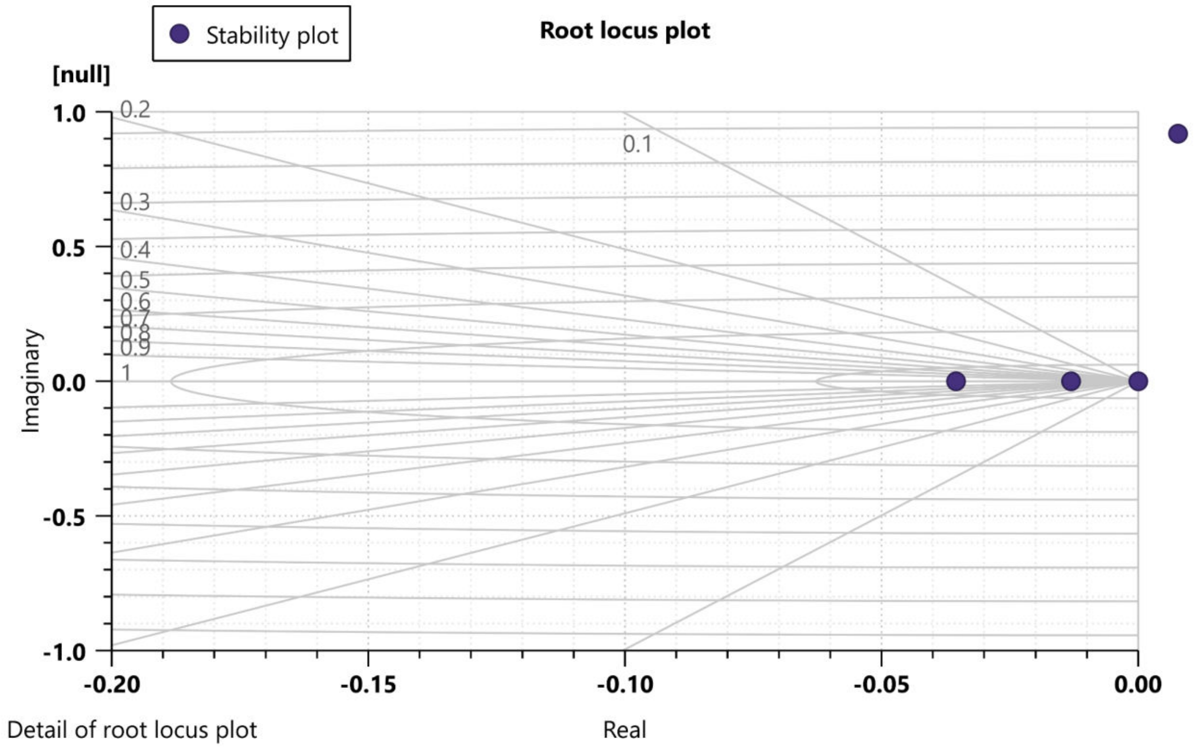

Fig. 6. Stability of the system – Root Locus plot (detail)

Figure 7 illustrates the dynamic behavior of the electric generator's output frequency and the associated control error over time. The graph compares the actual frequency of the generator with the desired setpoint of 50 Hz and tracks the error signal produced by the PID controller.
The frequency plot shows that the generator initially experiences deviations from the target frequency, particularly during transient periods when inertia of the system acts. However, the PID controller effectively adjusts the system to minimize these deviations, bringing the generator frequency back to the 50 Hz setpoint. Over time, the fluctuations become smaller, indicating that the control system successfully stabilizes the output.
The control error plot reveals the magnitude of frequency deviations and the controller's response. Initially, the error is higher due to the system's response to wind speed variations and inertia, but it decreases steadily as the PID controller compensates for these changes. The diminishing error confirms the system's ability to maintain a steady and accurate frequency output, which is critical for ensuring the reliability of the electrical grid connected to the wind turbine.

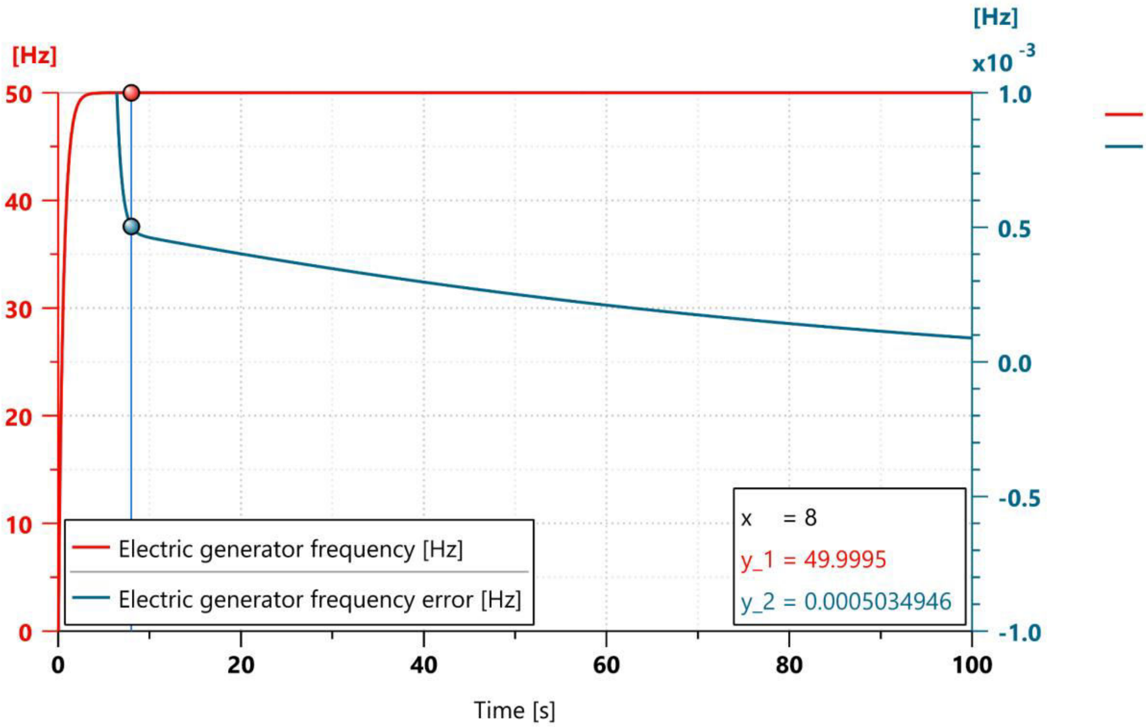

Fig. 7. Electric generator frequency and its control error

This figure highlights the efficiency of the PID-controlled hydrostatic transmission system in dynamically adjusting to varying wind conditions while keeping the generator frequency steady, with minimal error over time.

4. Conclusions

This study demonstrates the feasibility and advantages of employing a dual open-circuit hydrostatic transmission system for small-power wind turbines. By replacing the conventional closed-circuit transmission in the nacelle with two open-circuit systems—one in the nacelle with a fixed ratio and another on the ground with a variable ratio—several key benefits are achieved. These include a significant reduction in the mass of the nacelle, easier access to components for maintenance, and overall cost reduction.

The AMESim simulations confirmed the effectiveness of this setup in ensuring steady power transmission and efficient regulation of the electric generator frequency. The use of a PID controller successfully maintained the generator output frequency at 50 Hz, even under severely varying wind conditions. The system's dynamic response was validated through Bode plot analysis, and the stability was confirmed through Root Locus plots, showing robust performance across a wide range of operating conditions.

The results highlight the system's ability to handle pressure and flow variations effectively between the two hydrostatic transmissions, ensuring reliable performance. The control error analysis showed that the PID controller efficiently minimized frequency deviations, ensuring consistent output for grid integration.

In conclusion, this dual open-circuit hydrostatic transmission system provides a promising alternative for small-power wind turbines, offering advantages in terms of weight, cost, maintenance, and operational stability. Future work could explore further optimization of the controller and the performance of the system under fluctuant wind conditions.

Acknowledgments

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Simulation and Analysis of Fire Sprinkler Systems Using EPANET for Enhanced Hydraulic Performance

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Abstract: *EPANET is a simulation software program developed by the United States Environmental Protection Agency (EPA) used to model water distribution systems. It is used by engineers and hydraulics specialists to design and analysis networks of pipes, tanks, pumps, valves and other components of water distribution systems. EPANET can simulate the distribution of water flow and pressures in each network component.*
The program performs a detailed hydraulic analysis, calculating water flows, pressures and storage levels in the network, and can simulate the dynamic behaviour of the network over time, allowing users to see how conditions vary based on changes in water demand or other factors.

Keywords: *EPANET, hydraulics, water flow, water distribution*

1. Introduction

Conventional strategies for analysis of looped water distribution systems accept that accessible nodal streams are equal to the nodal requests and get available pressure heads at distinctive hubs. Available pressure heads less than the minimum required heads at one or a few hubs appear as network's failure to supply the craved requests. Beneath such pressure deficient conditions, the amount of water can supply at diverse hubs is requires in arrange to estimate short-fall in supply.
Such an analysis has been used in different networks issues like multi objective network design [1], calibration [2] and reliability based on design [3-7].
In this paper, we want to improve the hydraulic efficiency of a sprinkler system to achieve the maximum efficiency and required flow at the farthest sprinkler head and obtain an isometric diagram that facilitates the understanding and design of such a system.
The computer simulation is carried out using the EPANET program, which helps us to carry out detailed hydraulic analysis, calculate water flows, pressures and storage levels in the network.

2. Choice of input data for the EPANET software

The equivalence coefficient ("emitter coefficient") is a parameter in EPANET that can be assigned to a connection point (node or hole). The special device called a sprinkler cannot be recognized by the program, so it is equated with a simple hole through which water flows and which is characterized by the equivalence coefficient, just as the nominal value K characterizes the sprinkler head.
To determine the equivalence coefficient, an elementary network consisting of a tank, a connecting pipe and a node is created. The linear hydraulic pressure losses through the pipeline are completely reduced by assigning a very small length (1 m), a very large diameter (10000 mm) and a low roughness value (0.000001). The reservoir was also assigned an estimated value of 10 mH2O.
These steps are entered in the software according to Fig. 1.

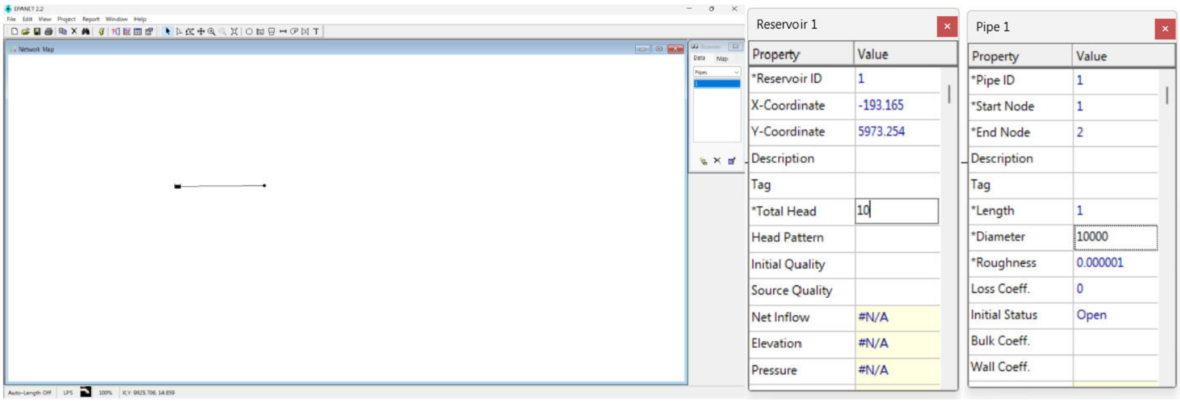

Fig. 1. Assigning properties for the elementary lattice

The equivalent coefficient is determined by tests and is correctly chosen when, after running the test, the node flow is equal to the water flow discharged through the hole of the last sprinkler head: qis= 1.91 l/s.

After the tests, the value of 0.605 was obtained for the equivalent coefficient (Fig. 2).

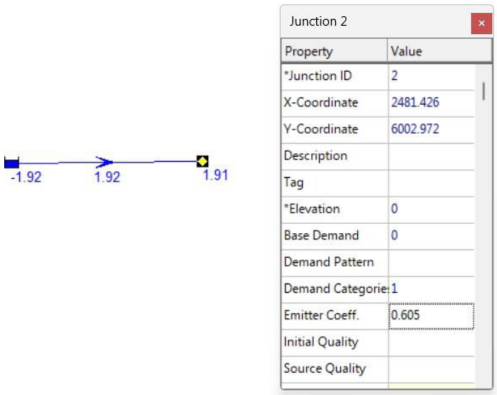

Fig. 2. Equivalent coefficient

3. Drafting of the isometric scheme of the simultaneous triggering area

The isometric diagram of the simultaneous release area is created in the AutoCAD program and uses simple lines whose intersection is read by the EPANET program as a node point. Basically, the sprinklers are marked by discontinuity points that are not visible in the AutoCAD program. The diagram in Fig. 3 shows the isometric diagram of the simultaneous release area, which is saved using a file with the extension "dxf".

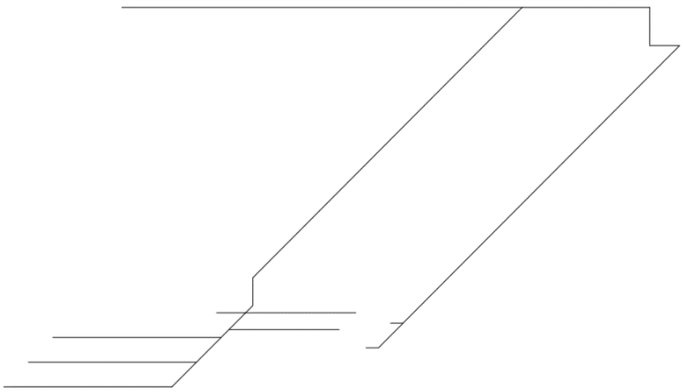

Fig. 3. Isometric diagram

The file with the extension "dxf" is imported into another program called EPACAD, which uses the extension "inp" to import the isometric scheme into the EPANET program, as can be seen in Fig. 4.

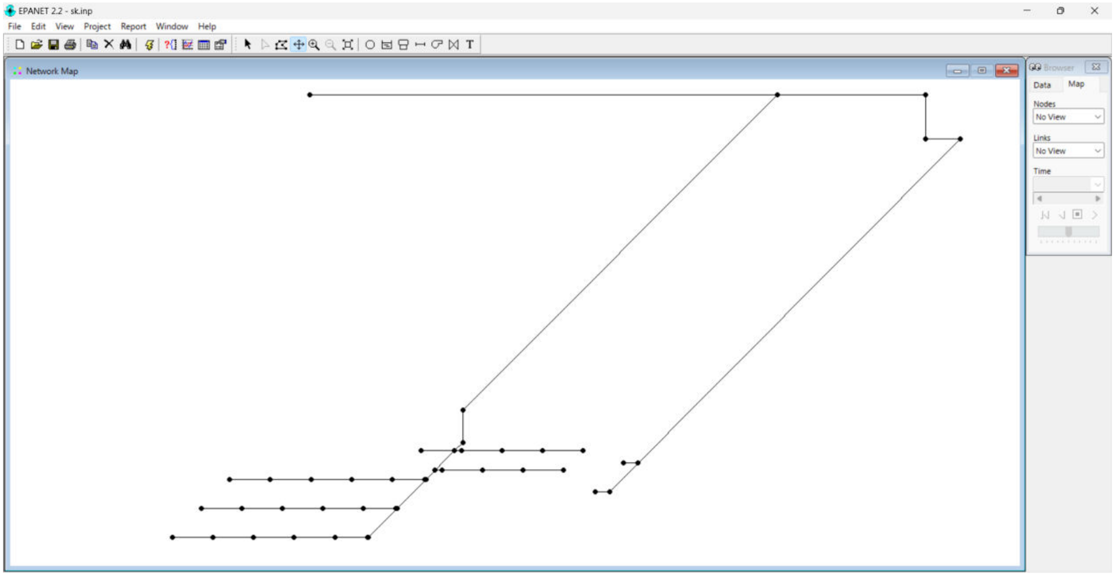

Fig. 4. Isometric diagram in the EPANET program

4. Assigning properties in the EPANET program

First, the water tank and the connecting pipe to the network of nodes are placed. The program automatically adopts the length units used in the AutoCAD program. All pipes are also assigned a roughness value of 0.01 (Fig. 5).

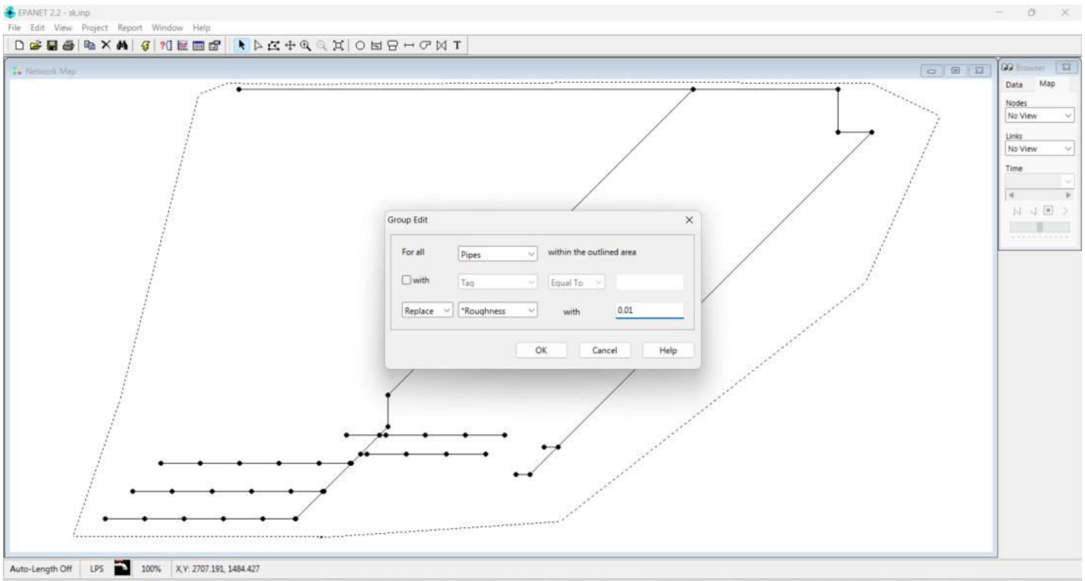

Fig. 5. Roughness assignment

The next step is to assign diameters to the pipes in the network. They will be assigned initial values, which will be returned to later in order to achieve the appropriate dimensioning. Branches containing sprinklers will be assigned DN50 diameter, secondary pipes DN80 and main pipes DN100. This is done by selecting the region on which the changes are made and assigning the desired value. In Fig. 6 shows the assignment of the diameters for the branches, and in Fig. 7 shows the same action for the secondary and main pipes.

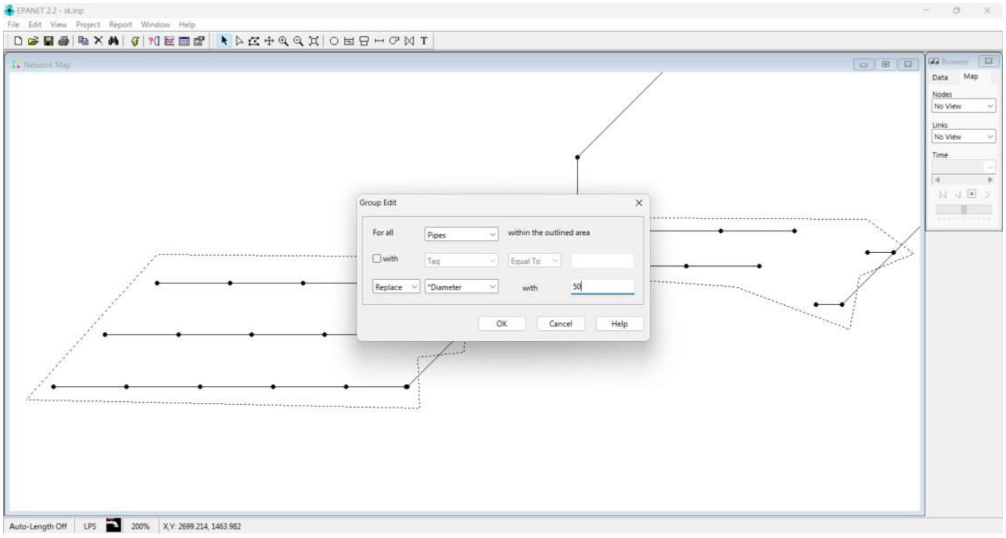

Fig. 6. Selecting the region containing the branches and assigning diameter values

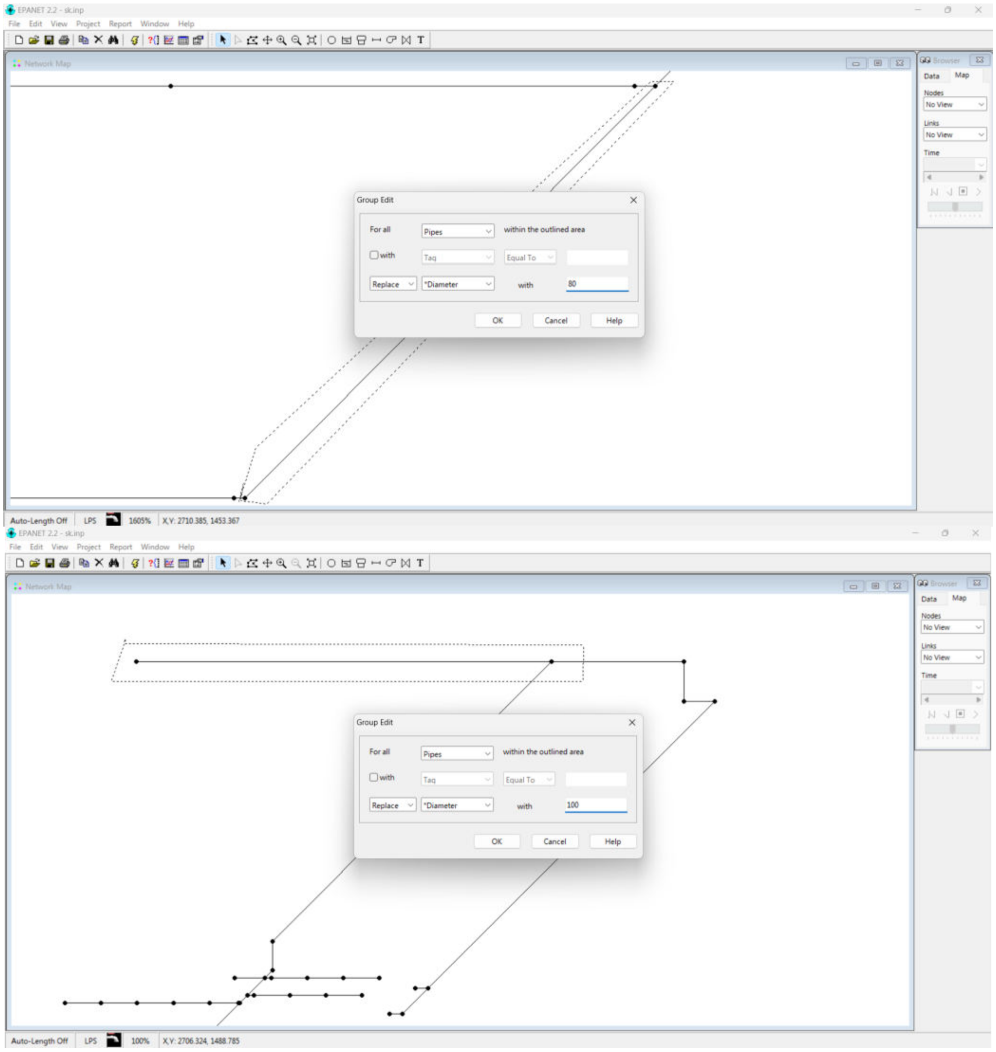

Fig. 7. Selection of the region containing the secondary and main pipes respectively and the diameter assignment

The next step is to assign values for the position height of the nodes (elevation) as shown in Fig. 8, taking into account the distance from the sprinkler head deflector to the elevation ±0.00 m: 6.55 m.

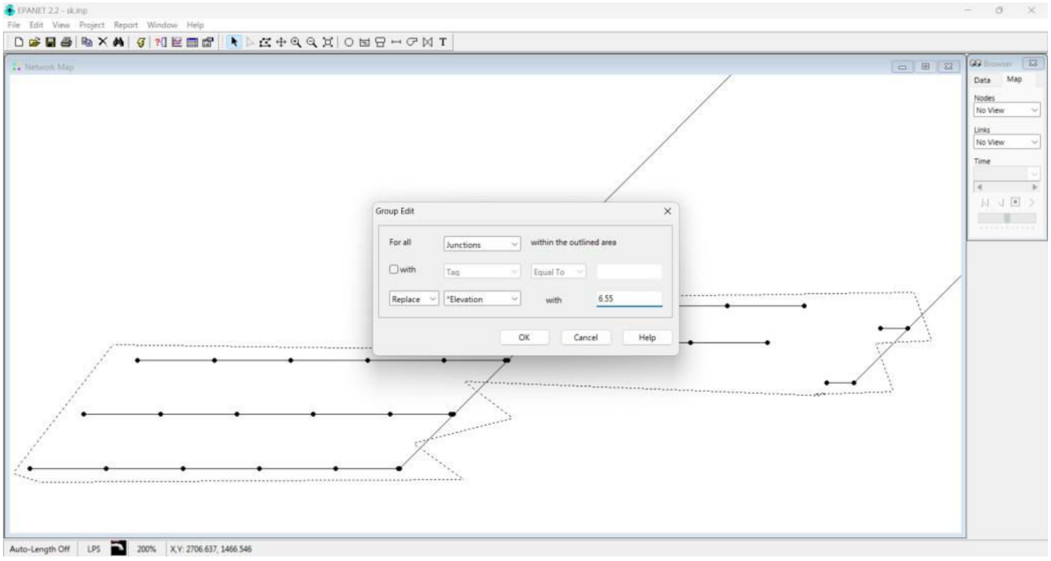

Fig. 8. Assigning values for node placement height

At the same time, for these nodes representing the sprinklers in the area of simultaneous release, the value of the equivalence coefficient determined in the initial design phase was assigned, as can be seen in Fig. 9. Later, we went back to the nodes representing directional changes and deleted this value, as they should not be read as holes by the program.

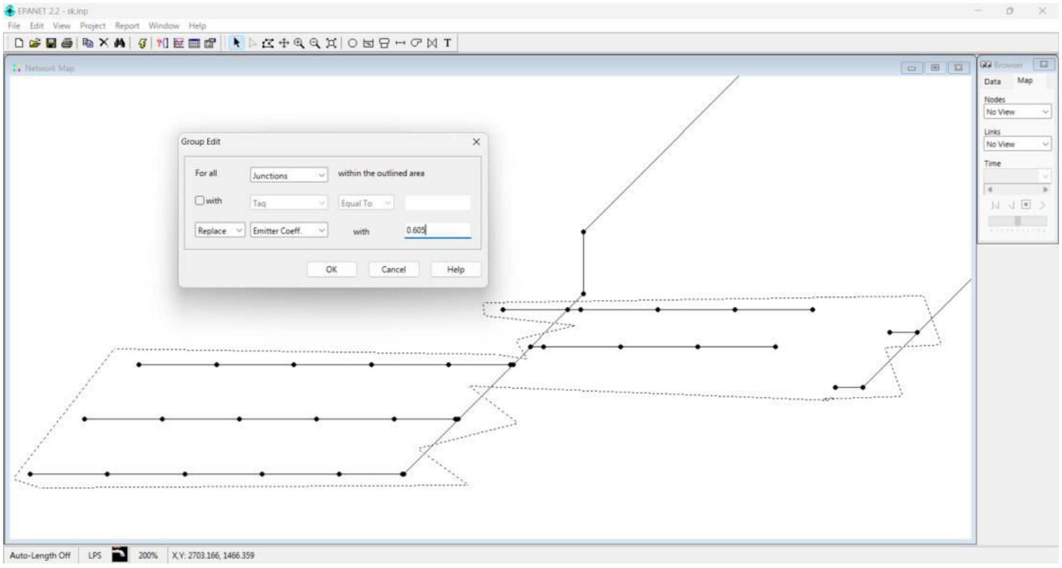

Fig. 9. Assigning the value of the equivalent coefficient

Finally, before performing the test, the water tank is assigned a value of 20 mH2O, which is estimated by summing the pressure of 1 bar determined for the last sprinkler head with a pressure loss of also 1 bar in the distribution network (Fig. 10).

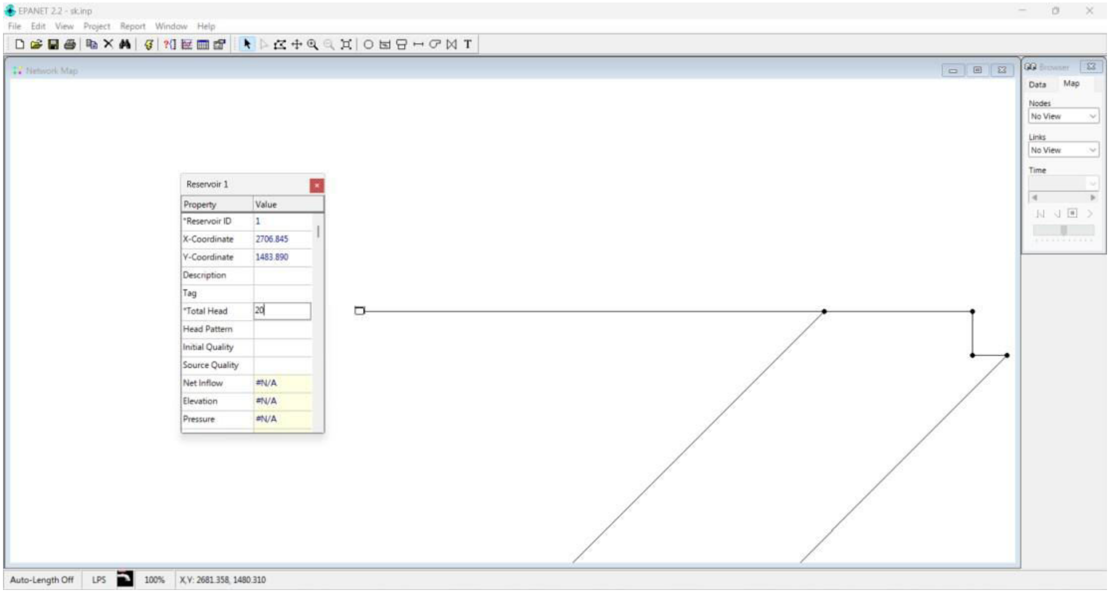

Fig. 10. Assigning the value of 20 mH2O for the water tank

5. Running the test to obtain the required flow at the farthest sprinkler head

Carry out the test and obtain the values shown in Fig. 11. To obtain the flow rate value of 1.91 l/s resulting from the calculation instead of 2.17 l/s displayed after the first run, the pipe diameters are reduced, as shown in Fig. 11 and Fig. 12.

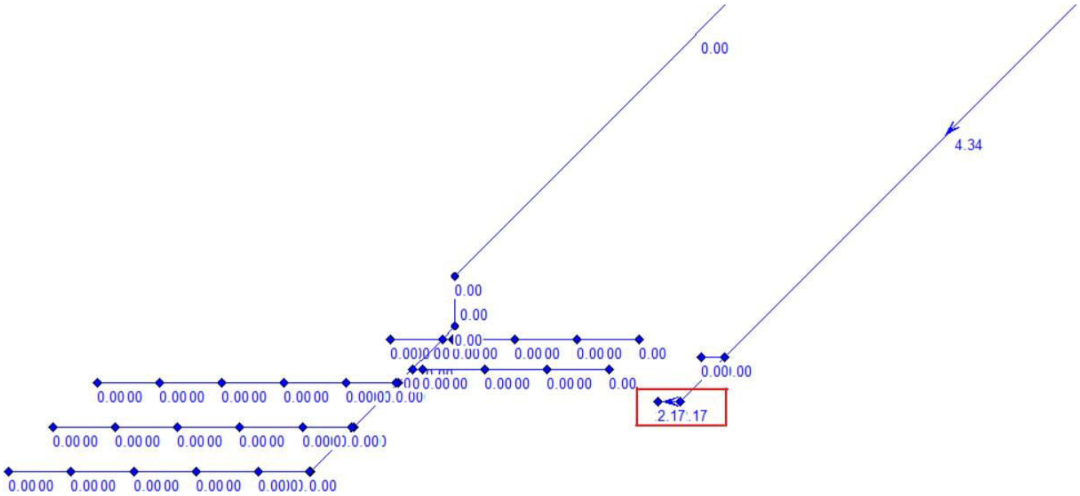

Fig. 11. Obtaining a flow rate of 2.17 l/s after the first test run

Following changes in the diameter of the secondary pipe from the value DN80 to the value DN50, a flow value for the farthest sprinkler of 1.95 l/s is obtained (Fig. 11), so that the diameter of the last branching portion from the DN50 value to the DN25 value (Fig. 12).

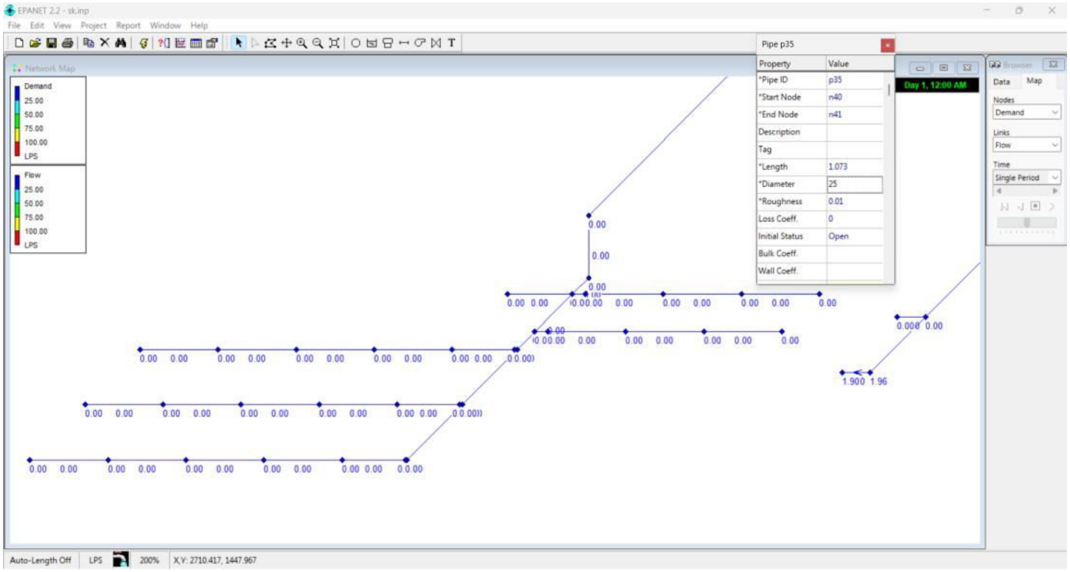

Fig. 12. Reducing the diameter of the last branch portion from DN50 to DN25

Thus, a value very close to the desired one of 1.90 l/s was obtained, being very close to the desired value of 1.91 l/s. In this way, the dimensioning of the supply network of the simultaneous triggering area was achieved by adapting the diameters in accordance with the STAS in force, so that the flow of water discharged through the office of the last sprinkler head corresponds to the calculated specific flow: qis = 1.91 l/s.

6. Conclusions

EPANET proves to be an effective tool for modeling and analyzing the hydraulic performance of sprinkler systems. Its ability to simulate complex pipe networks with different flow rates, pressures and pump dynamics enables accurate assessment of sprinkler system performance in different fire scenarios. Through hydraulic simulations, EPANET helps identify critical areas of pressure loss, inadequate water supply or inefficient systems, enabling engineers to optimize their fire protection designs.

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Challenges and New Approaches regarding Devices, Mechanisms, Robotic Systems, and Sensors Used in Modern Military Technique

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Abstract: *This article presents a comprehensive overview of the integration of robotic systems and artificial intelligence (AI) in military applications, focusing on land-based robotic platforms. It highlights the mobility mechanisms of military robots, including wheeled, tracked, and biomechanical (legged) systems, as well as the power sources and control technologies that enable their operation. The analysis extends to the leading nations in military robotics development, such as the United States, Japan, South Korea, and key European nations, and emphasizes the importance of emerging players like Singapore, India, and the UAE. The challenges related to AI integration, cybersecurity, and sustainability are discussed, along with the ethical considerations surrounding the future deployment of autonomous robotic systems in military contexts. Finally, the article points to the need for international collaboration and the establishment of regulatory frameworks to ensure the responsible and effective use of military robotics in a rapidly evolving technological landscape.*

Keywords: *Military robotics, artificial intelligence, autonomous systems, biomechanics, tracked mobility, wheeled mobility, military devices and mechanisms, cybersecurity, military innovation, ethical robotics development*

1. Introduction

In the context of continuous advancements in cutting-edge technologies, military robotic systems represent one of the most revolutionary and challenging innovations of the 21st century. The evolution of these systems is closely tied to rapid technological progress, and with the implementation of new innovations, we are opening new pathways to better understanding and utilizing them in the military field. A crucial aspect of the development of these technologies is the integration of artificial intelligence (AI), which promises to transform military operations by enabling autonomous or assisted decision-making processes.

Artificial intelligence (AI) is based on the hypothesis that certain aspects of human thought can be implemented within mechanized systems. Though it has long been a subject of philosophical debates, mathematical models, and computer science research, it has only recently moved to the forefront of public, governmental, and military interest, primarily due to substantial increases in computing power, access to large data sets, and advancements in algorithmic techniques. However, complex issues related to safety, ethics, and sustainability also arise and must be addressed to ensure the responsible and efficient use of these AI-controlled and optimized military technologies.

The evolution of military robotic systems [1-7,10-15] is closely linked to the rapid advancement of technologies and AI [13,14,18]. The introduction of new innovations and AI offers the promise of significant progress in understanding the phenomena associated with science.

2. Main components of devices, mechanisms and sensors in terrestrial robotic systems used in modern military technology

Throughout history, nations have sought to employ various devices and systems to reduce the risk of damage and gain a tactical advantage over their adversaries. As technology advanced, countries began to rely on sophisticated robotic systems, both for military and civilian purposes.

Today, military robotic systems [1-7,10-15,17,21,22,24] are used for various applications, ranging from neutralizing/destroying explosive devices, surveillance, and logistics, to rescue operations. Over time, these systems will be increasingly deployed for reconnaissance, surveillance, and other specialized applications.

Initially, robotic systems were designed to perform repetitive, difficult, or dangerous operations across several industries. In military operations, robotic systems are used for the following purposes:

- To reduce personnel exposure to various dangers (rescue, decontamination, evacuation, biological attacks, intelligence gathering, etc.);
- To enhance decision-making under stressful conditions by integrating artificial intelligence assistance, enabling data collection, analysis, fusion, and providing suggestions for decision-making and execution;
- To reduce labor and operational costs associated with personnel in various missions.

In addition to these roles, robotic systems demonstrate specific capabilities, including:

- Robotic systems can perform tasks consistently due to their immunity to fatigue;
- Robots are immune to stress or emotions, enabling them to operate under extreme conditions without prior training;
- Robotic systems allow personnel to focus on other tasks;
- These systems are durable, capable of operating in extreme environments;
- Robotic systems are significantly faster than humans in terms of mobility, data analysis, and decision-making suggestion development.

The main disadvantage in developing these sophisticated systems lies in the complexity of the mechanical and electronic components required to create highly efficient and intelligent robots, capable of executing both simple and complex tasks.

The primary components that form the foundation of designing and developing a complex military robotic system include sensors, mobility mechanisms, power sources, electronic components, body elements, utility systems, attack and/or reconnaissance devices, and localization mechanisms.

2.1. Sensors used in robotic systems for military applications

Robotic systems can be equipped with a wide range of sensors [20,23], each serving specific functions that enhance surveillance, recognition, navigation, detection, and other operations. These sensors are generally used to enable the robot to analyze its surroundings, navigate, and execute both simple and complex missions. Below, we provide a detailed description of the main types of sensors used in military robotic systems:

a) Optical Sensors:

Optoelectronic devices record images of the surrounding environment. This category includes devices with visible spectrum vision and infrared (IR) vision for nighttime observation. IR devices use both image intensifier technology and thermal imaging. Optical sensors are typically employed for surveillance, reconnaissance, target identification, etc.

Image intensifier technology allows IR devices to detect radiation reflected by a body by amplifying the illumination level in the visualized field to a point where the object can be observed (see **Figure 1**).

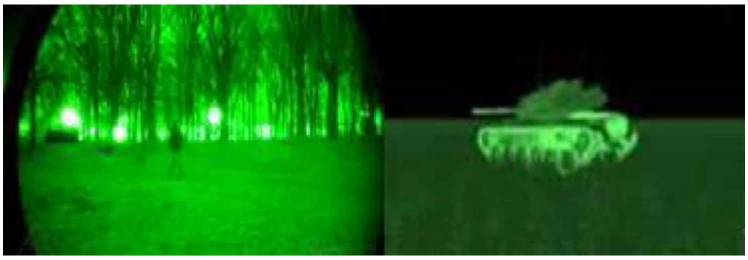

Fig. 1. Photos captured using IR cameras with image intensifiers

Thermal imaging technology enables IR devices to detect thermal energy emitted by objects within the field of view by creating an image based on the thermal contrast between the target and its background (see **Figure 2**).

Each of these two types of devices operates in distinct portions of the electromagnetic spectrum, specifically within different infrared domains, due to operational differences.

Fig. 2. Image obtained through thermal imaging

b) Proximity Sensors:
Proximity sensors are vital in the field of robotics, including military applications, as they detect the physical presence of nearby objects without making physical contact. These sensors are particularly useful in the development of autonomous navigation and obstacle avoidance systems.
• **Ultrasonic Sensors** [25]**:** These sensors operate on the principle of echolocation, similar to that used by bats. They emit sound waves at ultrasonic frequencies (typically between 25 kHz and 40 kHz, which are inaudible to humans) and measure the time it takes for the waves to return to the sensor after reflecting off an object.
• **LIDAR Sensors (Light Detection and Ranging)** (**Figure 3**) [27]**:** use laser light technology to measure various distances. These sensors scan the surrounding environment by emitting multiple light pulses and measuring the time it takes for each pulse to return to the sensor after reflecting off an object. Robotic systems commonly employ these sensors for precise 3D navigation and mapping.

Fig. 3. Example of a LIDAR sensor mounted on a terrestrial robotic system [28]

c) Acoustic Sensors:
Acoustic sensors, also known as microphones, are used in military robotic systems to detect and analyze sounds from the surrounding environment. These sensors are critical in reconnaissance, surveillance, rescue missions, and other operations, as they can capture sounds produced by vehicles, people, explosions, and other significant acoustic sources.
Functionality – Acoustic sensors convert sound waves from different environments into electrical signals. The physical properties of sound waves and their interaction with various materials determine how these sensors function. This process, known as acoustic transduction, involves several steps as outlined below:
1. **Sound Capture** – Sound waves are captured using a diaphragm, which is a thin membrane that vibrates in response to sound wave pressure. The diaphragm is the primary component of an acoustic sensor.

2. **Mechanical to Electrical Conversion** – The mechanical movement of the diaphragm is transformed into electrical signals through a transducer.
3. **Signal Processing** – The electrical signal generated by the microphone is typically weak and requires amplification and filtering. Additionally, acoustic analysis techniques, such as digital signal processing (DSP), are used to analyze the sound's characteristics, including the direction, type of sound (voice, vehicle, etc.), and the distance to the sound source.

d) RADAR Sensors (Radio Detection And Ranging):

In military operations, RADAR sensors are critical devices for navigation, detection, and tracking of distant objects, regardless of weather or lighting conditions. They work by emitting high-frequency radio waves and detecting their reflection from various encountered objects.

The essential components of a RADAR sensor include:

- **Transmitter:** Generates the high-frequency radio waves needed for target detection.
- **Receiver:** Captures the reflected waves and converts them into electrical signals. The sensitivity of the receiver is crucial for detecting distant targets.
- **Processing Unit and Display System:** This unit analyzes the signals from the receiver to extract data about targets, such as distance, angle, altitude, and speed. Advanced mathematical calculations, including Fourier transforms, are employed to interpret the frequency of signals, helping to determine whether a target is approaching or moving away from the radar.

e) Navigation Sensors:

Navigation sensors are vital components that enable military robotic systems to navigate through various environments while accurately determining their position and orientation. These sensors combine different technologies to ensure precise data collection needed for location determination.

- **GPS (Global Positioning System) Sensor** – This sensor uses a network of satellites that emit radio signals. A GPS receiver, such as the one installed on a military robot, captures these signals to pinpoint its exact position on Earth. By calculating the time difference between when the signals are transmitted by the satellites and when they are received by the robot’s system, the GPS sensor can determine longitude, latitude, and altitude.
- **INS (Inertial Navigation System) Sensor** – Robotic systems that operate across three axes, such as aerial and underwater robots, need to be aware of their position, altitude, and speed. Inertial sensors, which include accelerometers and gyroscopes, are used to collect data around the X, Y, and Z axes of the robot. These sensors form an **Inertial Measurement Unit (IMU)** that provides crucial information for navigation and positioning.

Both **INS** and **GPS** sensors are essential for navigation and localization, each offering unique advantages and disadvantages. INS can outperform GPS in certain military applications, particularly in the following areas:

- **GPS Dependence –** While GPS is widely used for location determination, it relies on satellite signals, which may be blocked or jammed in hostile environments, such as urban warfare or under heavy foliage.
- **Autonomous Operation –** INS is independent of external signals, allowing it to continue providing location data even when GPS signals are unavailable, making it especially useful in GPS-denied environments.
- **Precision Over Time –** Although INS accuracy degrades over time due to drift (a gradual loss of precision), it can be highly effective for short-term precision in high-speed operations, where quick data feedback is necessary for stability and control.
- **Complementary Use –** In many military applications, both systems are used together, with GPS providing absolute position data and INS offering relative movement data to fill in the gaps during GPS signal outages.

By using a combination of GPS and INS, military robotic systems achieve enhanced reliability and accuracy in navigation, even in challenging and dynamic environments.

2.2. Mobility and propulsion platform of terrestrial robotic systems for military applications

Mobility and propulsion are key factors for achieving efficient movement and adapting robotic systems to the different environments in which they operate. The mobility platform varies from one robot to another, depending on mission requirements and terrain difficulty. Below, we will review the main types of mobility and propulsion platforms used in military robotic systems:

a) Wheel-Based Mobility:
Due to their efficiency, simplicity, and reliability, wheel-based propulsion is a preferred choice for many military robotic systems. These systems [11] are designed to offer mobility over various types of terrain but perform best on relatively smooth surfaces, making them ideal for logistics missions.
The most common types of wheels used in robotic systems are:

- **Standard Wheels** – These are used primarily on stable terrain and are the most common and easiest to manufacture.
- **Wheels with Independent Suspension** – These wheels enhance the stability and traction of the robotic system by absorbing shocks from uneven surfaces. Each wheel has its own suspension system, allowing for additional terrain adaptability.
- **Mecanum Wheels** – These wheels can rotate like ordinary (standard) wheels, moving simultaneously, but they can also rotate independently. This feature allows robots to move in any direction without turning their entire body. Thanks to the arrangement of rollers along the circumference of the wheels, they provide increased maneuverability in confined spaces.

Certain materials allow wheels to operate successfully on a variety of surfaces.
Rubber is one of the most commonly used and manufactured materials because it provides grip, reliability, and excellent shock absorption. In addition to rubber, **polymers** and **composites** are also used in special applications, offering enhanced properties such as abrasion resistance, chemical resistance, or reduced weight.
The selection of wheels depends on the intended use of the robotic system. Furthermore, the type of wheel chosen is determined by the steering mechanism available on the robot.
The steering mechanism can take several forms, including:

- **Fixed Steering** – In this configuration, the wheels do not turn laterally to change direction, and directional changes are achieved solely by varying the wheel speeds.
- **Articulated Steering** – The robot's direction can be changed by articulating or bending its body, which offers improved maneuverability over rough terrain.
- **Common (Standard) Steering** – This is the type of steering found in most vehicles, where only the front wheels steer.
- **Omnidirectional Steering** – This setup uses specialized wheels, such as the Mecanum wheels mentioned earlier or Omni wheels, which allow the robot to move in any direction by independently controlling the movement of each wheel.

Each steering mechanism is chosen based on the specific requirements of the mission and the environment in which the robotic system will operate, ensuring the optimal balance between mobility and control.
Each of the directional assemblies or wheels selected has advantages and disadvantages depending on the specific application, and choosing the right construction variant depends on the operational needs of the military robot, the terrain it must operate on, and other tactical mission requirements.
For the movement of robotic systems on the ground to be as efficient and smooth as possible, the type of suspension used must also be considered. Suspensions are essential components in the construction of military robots that use wheels for movement, as they absorb shocks from different types of terrain and improve traction during movement.
Suspensions are the elements that ensure the wheels remain in contact with the ground, even on rough terrain. These can be of several types, including:

- **Spring and shock suspension**, the most common type of suspension.
- **Independent suspension**, which allows control of each wheel independently from the others.

b) Mobility using tracks:
Ground robotic systems designed to perform missions over rough terrain must be equipped with appropriate mobility elements, such as **tracks**, as stability and traction are crucial for strict movement requirements. Tracks are used instead of wheels or other mobility elements because they provide better weight distribution and superior traction on challenging surfaces such as sand, mud, or rocky terrain.
The essential components of the crawler propulsion system include:

- **Tracks** – usually made from articulated steel plates, rubber reinforced with steel cables, or hard rubber. The material can be chosen depending on specific needs, such as durability, flexibility, or grip.
- **Drive wheels and tensioner wheels** – The drive wheels are usually located at the rear of the chassis and provide the power needed to move the tracks. These wheels engage with their own teeth in the gaps of the track to move the robotic system. The tensioner wheels are placed at the ends and help maintain tension on the track while also guiding it.
- **Support wheels** – These wheels help distribute the weight of the robotic system over a larger area and absorb shocks from rough terrain. They are placed along the chassis between the drive wheels and the tensioner wheels.
- **Suspension** – Ground robotic systems that use tracks as mobility means can be configured with multiple types of suspensions. Suspensions can range from simple systems using springs to hydraulic or pneumatic suspensions. They serve the same purpose as the suspensions used in wheels, helping to maintain stability and contact between the tracks and the surface.

The maneuverability of ground robotic systems using tracks is achieved through differential speed control between the two tracks. By reducing the speed of one track and accelerating the other, the robot can turn in the desired direction.

Ground robotic systems equipped with tracks as mobility elements have several advantages, including: uniform weight distribution due to the large contact surface area of the tracks, the ability to traverse obstacles such as bumps and craters, and overall stability.

The only "major" disadvantage is the need for regular maintenance of these track-type mobility elements; however, due to their benefits regarding flexibility across various terrains in military applications, they are unmatched.

c) Mobility using biomechanical elements:

Robotic systems with biomechanical mechanisms, meaning legs—either bipedal (two legs) or quadrupedal (four legs)—as mobility elements, represent proof of the continuous technological advancement in the field of robotics. These mechanisms are designed to mimic the biomechanics and dynamics of movement in animals or humans, providing the capability to navigate challenging environments where robotic systems with wheels or tracks are not as effective.

The primary characteristics of robotic systems that utilize biomechanical elements for movement on the ground include:

- **Imitation of natural movement** – Robotic systems [12] with biomechanical elements use joints or segments similar to bones and muscles to replicate the function of human or animal legs (see **Figure 4**).
- **The main components of these subassemblies** are actuators, which are responsible for generating the force necessary for movement. Actuators convert input signals into mechanical energy, which is developed by the joints, similar to how the muscles of humans or animals receive signals from the brain, thus enabling the required movement for the robots to traverse various surfaces.

Fig. 4. Atlas and Spot robots belonging to Boston Dynamics

The control of movement using legs is a complex phenomenon that requires extensive algorithms to coordinate their movements. The dynamics of walking, including adaptation to terrain changes or encountered obstacles, must be managed by well-optimized control systems.

Several advantages regarding mobility using biomechanical elements are presented below:

- **Traversal of rough terrain** – This refers to the capability of overcoming large obstacles, such as rocks, tree trunks, or stairs, which may be inaccessible to robotic systems utilizing wheels or tracks for movement.
- **Adaptability and flexibility** – This characteristic represents the ability to modify the direction of movement and adjust the steps of robotic systems based on the immediately encountered environmental conditions.
- **Silent movement** – In this case, we will discuss only the systems that utilize electric power sources for operation and thus can move relatively quietly on legs.

The disadvantages and challenges of these robotic systems with legs can be highlighted by the following aspects:

- **Control complexity** – Maintaining balance and coordinating movements present plausible technical challenges, requiring rapid processing of input data and the use of well-adapted algorithms.
- **Energy consumption** – Repetitive movements and maintaining balance can consume a lot of energy, potentially reducing the operational autonomy of robots when using electric power sources. Therefore, combustion engines can be used for long-duration applications where autonomy can be a strong point.
- **Durability and maintenance** – Due to performing missions on harsh/unfriendly terrains and mechanical complexity, the lifespan of the robotic system components may be shortened, leading to increased repair times and costs resulting from more frequent replacements of defective elements.

Propulsion of ground robotic systems that utilize wheels, tracks, or biomechanical elements (legs) for mobility can generally be powered by the following energy sources:

- **Rechargeable batteries based on electrical energy** – These are the most commonly used due to their ease of recharging.
- **Fuel-based energy sources** – These are typically used for long-duration operations in extreme environments or in larger robots.

The aspects mentioned above, encompassing the mobility and propulsion of robotic systems, pertain only to ground robotic systems. The chapter will continue with a discussion on aerial and maritime mobility and propulsion platforms.

2.3. Structure and classification of ground military robotic systems:

The **main components of ground military robotic systems are:**

- **Sensors:** These are used for navigation, surveillance, reconnaissance, and environmental detection. Examples include optical sensors, proximity sensors, acoustic sensors, RADAR, and GPS. Sensors are critical to ensure the efficiency of operations without human crews.
- **Mobility and Propulsion Platforms:** The variety of platforms includes systems with wheels, tracks, and biomechanical elements (legs), adapted for different terrains and missions. For example, tracks are used for rough terrain, while biomechanical legs are used for navigating complex environments.
- **Electronic Components and Control Programs:** This includes processing units (microprocessors, microcontrollers), memory, and other elements that enable control of robotic systems. They must be robust and able to withstand extreme conditions.

Classification of Robotic Systems:

- **Ground Systems (UGVs):** Ground robots are used in logistics missions, reconnaissance, and explosive ordnance disposal. Examples include robots with wheels, tracks, and biomechanical legs.
- **Maritime Systems (UMSs):** These are used for underwater operations and maritime surveillance. Propulsion with propellers and navigation systems are key elements in their operation.
- **Aerial Systems (UAVs):** These include drones used for reconnaissance and surveillance, as well as for attacks. Modern UAVs are equipped with advanced sensors and efficient propulsion systems.

Military Applications:
Military robotic systems are used for a wide range of applications, including explosive device neutralization, hostile territory surveillance, rescue and evacuation operations, and logistics. Technological advancements have enabled the creation of faster, more precise, and more efficient systems, reducing risks for human personnel.

3. Challenges and new approaches in ground robotic military technology

- **Control and Automation Technology:** The integration of artificial intelligence (AI) into robotic systems is a crucial step, facilitating autonomous and semi-autonomous capabilities.
- **Resilience and Durability:** The development of materials and mechanisms capable of withstanding extreme conditions is a constant challenge.
- **Security and Protection:** In addition to reliability and efficiency, cybersecurity becomes a critical aspect to protect robotic systems from attacks.

Global and regional insights from leaders in robotic and AI technologies for military applications:

- **North America (USA and Canada):** The United States has been a leader in developing military drones (UAS - Unmanned Aerial Systems) used for surveillance and targeted strikes. Canada focuses on AI technologies for logistics purposes and humanitarian missions.
- **Asia (Japan and South Korea):** Japan emphasizes the use of robotics for defense and dual applications, while South Korea has developed autonomous guard robots in the demilitarized zone with advanced detection and rapid response technologies.
- **Europe (Germany and France):** Germany focuses on international collaboration for developing interoperable technologies, emphasizing cybersecurity and ethics. France explores advanced technologies in autonomous ground and aerial vehicles, aiming to enhance logistics and reduce risk for human personnel.
- **Singapore** has made significant investments in military robotics and autonomous systems, focusing on urban warfare and defense against asymmetric threats. The country emphasizes the development of advanced drones and robotic platforms that enhance situational awareness and operational effectiveness in densely populated environments.
- **India** is rapidly advancing its capabilities in military robotics, with a particular focus on indigenous development. The Indian Armed Forces are exploring various unmanned systems, including drones and ground robots, for surveillance, reconnaissance, and logistics. India also aims to integrate AI into these systems to improve decision-making processes and operational efficiency.
- **The UAE (United Arab Emirates)** has emerged as a regional leader in military robotics, investing heavily in unmanned aerial vehicles (UAVs) and autonomous ground systems. The country has developed advanced platforms for surveillance, reconnaissance, and combat roles. Additionally, the UAE is exploring partnerships with leading defense firms to enhance its capabilities in robotic and AI technologies.
- **Italy** is actively developing military robotic systems, with a strong emphasis on collaborative efforts between industry and academia. The Italian Armed Forces are incorporating robotic solutions for logistics, reconnaissance, and explosive ordnance disposal. Italy also focuses on enhancing interoperability with NATO allies in the development of autonomous systems.
- **Spain** is investing in robotic technologies for military applications, particularly in the areas of maritime security and land operations. The Spanish military is exploring the use of drones and ground robots to enhance surveillance capabilities and improve operational responses in diverse environments. Spain is also engaged in international collaborations to further advance its military robotics initiatives.

Ethical Considerations: Although AI brings many benefits to the military field, such as surveillance, information gathering, detection, and developing suggestions in critical situations, it is important to consider the ethical implications of this type of technology before its use to mitigate potential problems that may arise during military operations. The prospect of fully autonomous weapons systems raises ethical concerns about accountability and decision-making.

Cost and Sustainability Challenges: Challenges regarding costs are determined by the design, development, production, and successful integration of military robotic systems into military operations. Sustaining these systems requires solutions for easy updates as technologies evolve and ecological considerations in their development process.

4. Conclusion

Advances in the field of military robotic systems are highlighted by the various technological initiatives of high-tech nations such as the United States, Japan, South Korea, Canada, Germany, and France. All these countries, together with EU members that have joined NATO, contribute significantly to the development of innovative solutions that promise to redefine the way military conflicts are managed.
However, as these technologies advance, it becomes essential to also address ethical and security issues by creating an international regulatory framework to ensure their responsible and effective use. The ethical implications [8,9,14,16,19], particularly regarding fully autonomous weapon systems, must be carefully considered to prevent potential misuse and to maintain accountability in decision-making processes.
Countries like the United States, Japan, South Korea, Canada, Germany, and France invest heavily in these advancements, highlighting the critical strategic importance of military robotics. These systems are not new, but progress in artificial intelligence (AI), autonomy, and cyber integration has brought them to the forefront of technological innovation.
Emerging players such as Singapore, India, and the UAE are rapidly catching up, introducing new dynamics in the global competition for military robotic supremacy. This reflects the growing democratization of advanced military technologies, which are no longer the exclusive domain of global superpowers.
As we look to the future, fully autonomous military robotic systems [4,13,17] are the next frontier, with challenges not only in technology development but also in ensuring that these systems are sustainable, cost-efficient, and resilient in diverse operational environments. The intersection of robotics, AI, and cybersecurity presents unprecedented opportunities, but it also demands careful oversight and strategic foresight.
Ultimately, the global military landscape will continue to evolve, shaped by these advancements. Ensuring that military robotic systems are developed, deployed, and regulated in a responsible manner will be critical to balancing the benefits of these technologies with the challenges they present. The continued pursuit of international cooperation and innovation will be essential in navigating the complex future of military robotics.

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ISSN 1453 – 7303 **"HIDRAULICA" (No. 3/2024)**
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Recovery of Potential Energy by Using a Digital Hydraulic Cylinder

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Abstract: *The recovery of energy in hydraulic systems is becoming increasingly essential not only to reduce energy consumption but also to lower carbon emissions into the atmosphere. A significant portion of the articles and studies published address the recovery of potential energy in hydraulic accumulators and its use to compensate for consumption peaks. This article presents a solution for recovering potential energy in a lifting/lowering device equipped with a digital hydraulic cylinder, converting this energy into electrical energy, which is stored in a battery and can later supply power during the operational cycle.*

Keywords: *Digital hydraulic cylinders, energy recovery, potential energy*

1. Introduction

In the current context, marked by a new scientific and technological revolution, we are witnessing a rapid transformation of technologies, the expansion of automation, and the accelerated processing and transmission of information. The development of science and technology is occurring exponentially, significantly impacting daily life, the environment, and space exploration. In this new era, competitiveness no longer depends solely on primary production factors such as cheap labor, access to natural resources, or investments. The modern economy is rooted in innovation, which has become the primary source of competitive advantage, involving the ability to develop innovative products and services by utilizing cutting-edge technologies and the most advanced methods available globally.

Thus, energy losses associated with inefficient hydraulic systems contribute to increased production costs and overheating of hydraulic fluid, which can lead to premature equipment failures. This phenomenon is also accompanied by additional greenhouse gas emissions and increased energy consumption for cooling. Hydraulic actuators, which convert pressure into force, play a crucial role in hydraulic systems, where force variation is typically achieved by varying pressure and speed by adjusting the flow rate. However, a more energy-efficient alternative is to vary the actuator's cross-sectional area, as in the case of the digital cylinder. According to theoretical principles, this method of control reduces energy losses compared to traditional pressure or flow rate control.

Regarding digital hydraulic cylinders, it has been demonstrated that varying the surface area is more efficient than adjusting pressure or speed for active cylinder control. The concept of digital hydraulics is based on the discretization of the nominal opening or working surface in the case of cylinders, with each variable defined by binary on/off states. By combining these sections and states, active control of speed or force at the actuator level is achieved.

Recently, multi-area hydraulic cylinders have garnered increasing interest in research on the application of digital hydraulics. These cylinders are used in systems requiring variable forces and speeds during the work process. An example of the application of multi-area cylinders is found in pressing and stamping machines, where rapid advance is achieved using the smaller piston surface, while high pressing pressure is obtained with the larger surface area.

One approach to varying the piston's active surface involves dividing it into multiple concentric, annular zones with binary-multiplied areas (fig. 1c or 1d). These zones are supplied either separately or cumulatively, with constant flow and pressure, following well-defined rules. This method allows for various combinations of zones to be supplied, facilitating linear motion with variable speeds and loads, thereby providing additional control options. As a result, the hydraulic system's energy requirements are met efficiently.

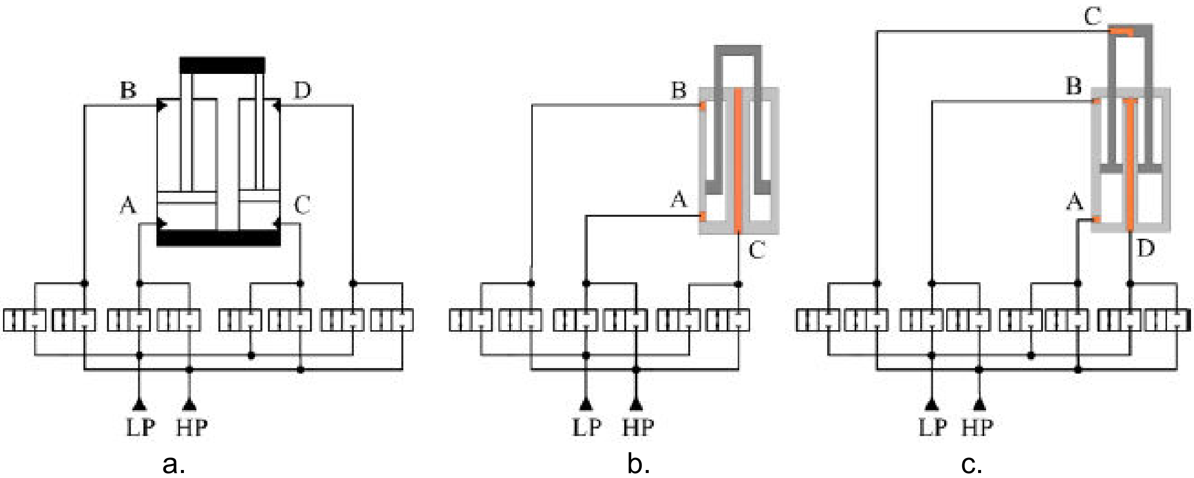

Fig. 1. Digital hydraulic cylinder solutions

The parallel connection of the chambers of multiple hydraulic cylinders (Fig. 1a) has been previously investigated [1,2] and involves the use of several independent cylinders of varying sizes on the same axis, which can be selected based on the system requirements. The literature includes a study on the use of multi-chamber cylinders [3], equipped with discretely controlled start/stop devices that allow for three pressure levels. This study includes relevant examples for improving efficiency in hydraulic installations and describes a highly efficient hydraulic hybrid system for excavators [4] that utilizes multi-chamber cylinders and secondary control. Additionally, a switching control system for hydraulic cylinders with multiple chambers has been investigated [5], enabling the control of force and speed by combining the supplied active areas.

Energy recovery in hydraulic systems is becoming increasingly important for reducing energy consumption and carbon emissions. Recent studies focus on recovering potential energy in lifting and lowering equipment equipped with hydraulic cylinders, using hydraulic accumulators to compensate for consumption peaks. The simplest solution for energy management is the parallel connection of cylinders (Fig. 1a). However, a more compact design can be achieved by integrating multiple chambers into a single cylinder, as shown in Fig. 1(b) and (c). In this case, four integrated chambers are used, generating 16 discrete force values depending on the combination of valve states. An additional increase in the number of force values can be obtained by adding extra supply pressures. The total number of force values is given by the formula \(N_S\), where \(N\) represents the number of supply pressures and \(S\) represents the number of chambers.

Another solution for minimizing or completely eliminating the need for proportional valves is the use of hydraulic transformers, which are supplied from a pressure line that powers both the working mechanisms and the rotational drive of a front loader system [6,7].

A team from the Tampere University of Technology and Aalto University in Espoo, Finland, has developed, simulated, and tested a multi-pressure digital hydraulic actuator that shows a high potential for energy savings [8]. This system includes a hydraulic accumulator and four pressure converters, allowing the connection of six supply pressures to the chambers of the cylinders through on/off valves.

2. The solution for recovering potential energy and converting it into electrical energy

The solution presented in this article for converting potential energy into electrical energy has been evaluated through simulations conducted on a testing stand for digital hydraulic cylinders (Fig. 2). This testing stand is equipped with a force transducer, a displacement transducer, and a cylinder designed to simulate potential energy.

The recovery of potential energy occurs during the return stroke by connecting the exhaust ports of the digital cylinder to a hydraulic motor that drives an electric generator. The produced electrical energy is subsequently stored in a battery via a charger.

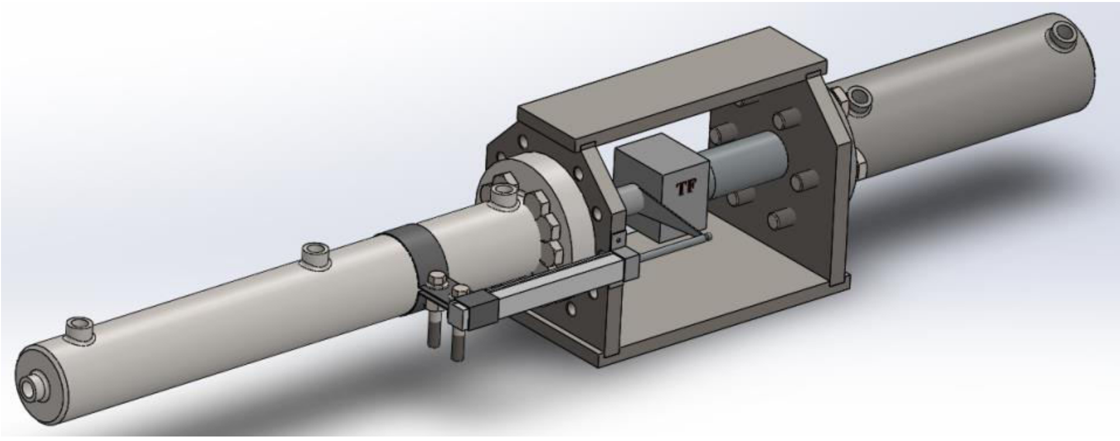

Fig. 2. Testing stand for digital cylinders

For testing, a simplified version of a digital hydraulic cylinder was chosen, featuring two concentric surfaces of 13.5 cm² and 19.6 cm². For the return stroke, the surface area is 20.6 cm² (fig 3)

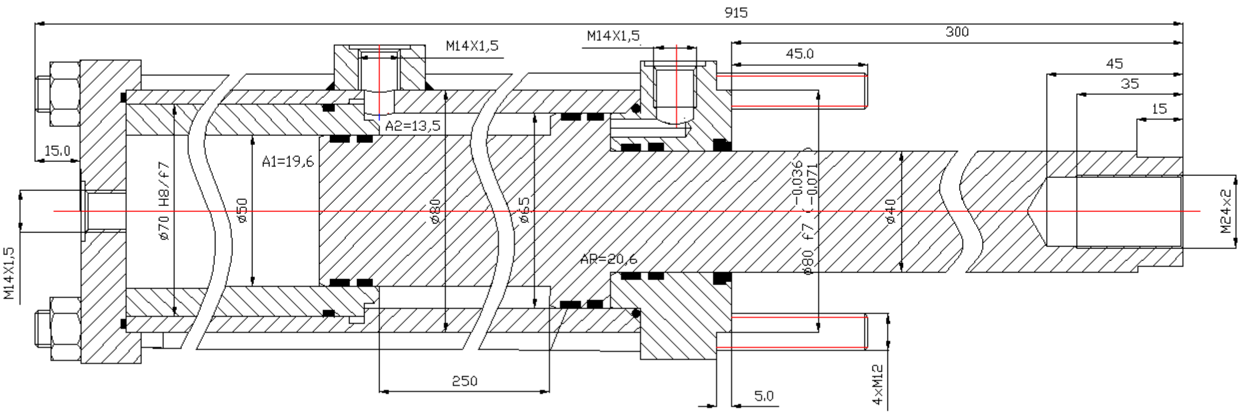

Fig. 3. Digital hydraulic cylinder with two surfaces

Technical characteristics of a digital hydraulic cylinder with two active surfaces S1 = 13.5 cm².

S2 = 19.6 cm²

S1+S2 = 33.1 cm²

S ret = 20.6 cm²

Race = 250 mm

Calculation of the maximum advance speed (constant flow rate supplied by SP1 and minimum area of the digital cylinder), equation (1).

$$V = \frac{Q}{S} \tag{1}$$

Where:
V = speed
Q = flow rate
S = section
Calculation of the maximum feed rate, equation (2).

$$V_{max} = \frac{Q}{S} = \frac{16\ l/min}{13.5\ cm^2} = \frac{16\ dm^3}{0.135\ dm^2 \cdot 60\ sec} = \frac{16\ dm}{8.1\ sec} = \frac{1.6\ m}{8.1\ sec} = 0.197 m/sec \tag{2}$$

The maximum speed of the hydraulic motor MH is 3500 rpm, exceeding the nominal speed of the generator GE, which is 3000 rpm. To rotate MH at 3000 rpm, the speed of the piston rod during the return stroke must be 74.3 dm/min. This speed ensures the necessary flow is discharged from the chambers C1 and C2 of the digital hydraulic cylinder to rotate the hydraulic motor at the optimal speed for the electric generator.
The calculation of the optimal flow rate for SP2 (the retraction speed) during the simulation of potential energy is as follows, equation (3):

$$Q_{nec} = V_g \cdot n \tag{3}$$

V_g= Geometric volume of the hydraulic motor

n = speed of the generator (hydraulic motor)

$$Q_{nec} = 0.0082 \frac{dm^3}{\cancel{rot}} \cdot 3000 \frac{\cancel{rot}}{min} = 24{,}6 \frac{l}{min} \tag{4}$$

Calculation of the rod displacement speed during retraction, equation (5)

$$V = \frac{Q}{S} \tag{5}$$

V = speed of the cylinder rod
Q = required flow rate for discharging chambers C1 and C2
S = moving section (S1 + S2)

$$V = \frac{24.6\ l/min}{0.331 dm^3} = 74.3\ \frac{dm}{min} \tag{6}$$

The flow rate provided by station SP2 to ensure a speed of 74.3 dm/min must be:

$$Q_{SP2} = v \cdot S = 74.3\ \frac{dm}{min} \cdot 1.13\ dm^2 = 83.96\ \frac{l}{min} \tag{7}$$

The pressure supplied by SP2 must be at least equal to the load created by GE plus the pressure losses along the fluid path.

3. Methodology for converting potential energy into electrical energy in a system equipped with a digital cylinder

In Figure 4, the hydraulic schematic of the system for converting potential energy into electrical energy is presented. The digital cylinder is supplied during the advance phase by the pumping station SP1 through the combination of states of the distributors E1 and E2, while retraction is achieved with the help of distributor E3, located on the distribution block BD. The simulation of potential energy is performed using the pumping station SP2. The recovery of simulated potential energy in the EP chamber of the load cylinder occurs during the return stroke of the digital cylinder, with the flow discharged from chambers C1 and C2 directed towards a hydraulic motor (MH). This drives an electric generator (GE), which produces electrical energy, subsequently stored in a battery (BAT). The recovered energy is measured using an electric meter (CE) and transmitted to the BAT battery via a charger (IN). Additionally, the flow and pressure values resulting from the recovery of potential energy are recorded by a hydraulic monitoring system (SHM).

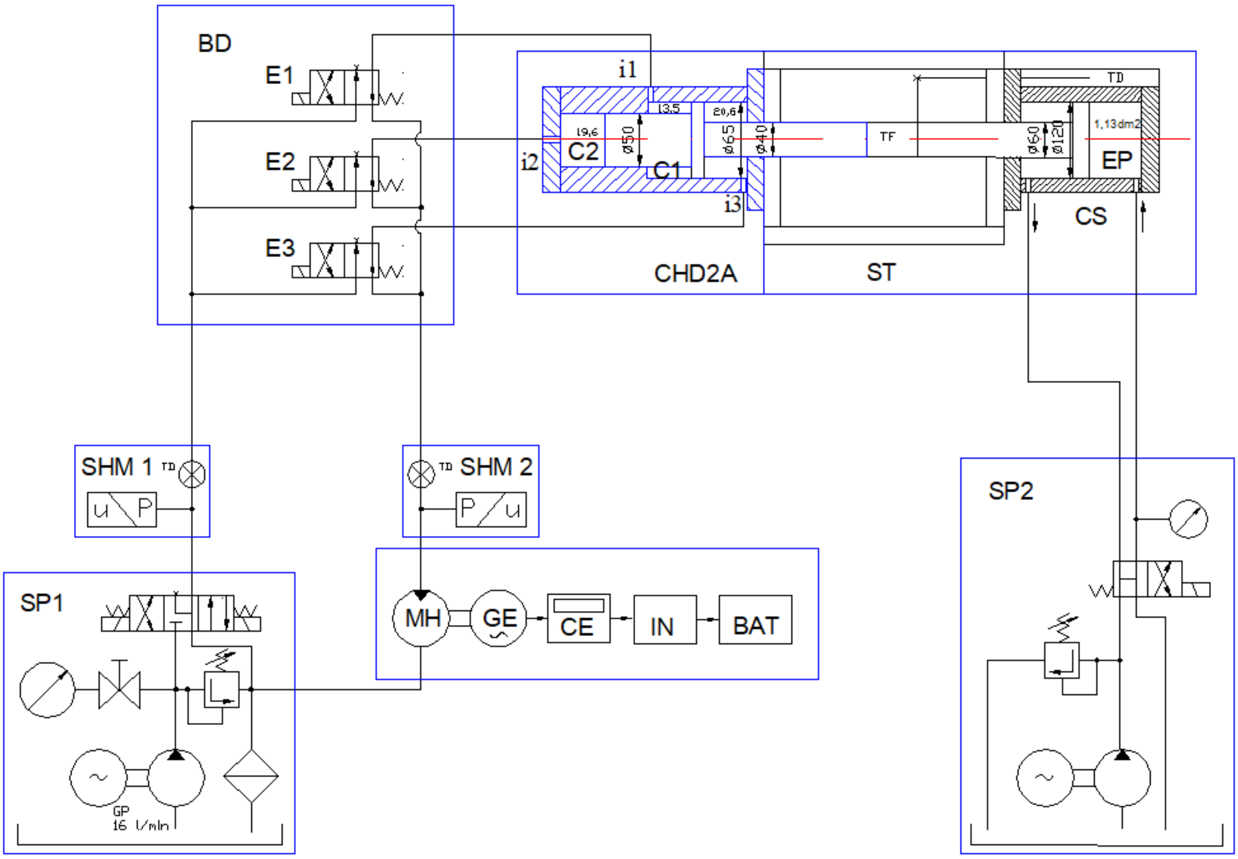

Fig. 4. Hydraulic diagram of potential energy to electricity conversion stand

4. Conclusions

To achieve a speed of 3000 rpm for the hydraulic motor (electric generator), a retraction speed of the cylinder rod of 74.3 dm/min is necessary, thus ensuring a discharged flow from chambers C1 and C2 of 24.6 l/min. To support this retraction speed, the pumping station SP2 must provide a flow rate of 84 l/min.

The need for precise adjustment of force and speed in modern hydraulic systems, in the context of energy efficiency requirements and the simplification of design solutions, highlights the necessity for research and development of cylinders with multiple areas. These cylinders allow for variation in working area, and consequently in operating force and speed, offering innovative solutions for machinery. The hydraulic cylinder, being the most widely used equipment in hydraulic drives, represents an essential starting point in the design of hydraulic installations. The introduction of digital technologies in this field can pave the way for new applications in modernized or newly designed installations.

Digital hydraulics represents an emerging research field that is attracting the attention of numerous prestigious institutes and international companies. This technology offers innovative solutions for implementing more efficient hydraulic systems. Although they may seem more complex, digital systems consist of a reduced number of standardized components capable of replacing a large portion of traditional hydraulic equipment.

The main obstacle to the widespread application of digital hydraulic solutions is the lack of specific equipment available on the market. There is a need to develop a range of cylinders with multiple areas, rapid distributors, digital actuating elements, and control electronic components, all integrated into a configurable and user-friendly package.

The simulation of the digital hydraulic cylinder's operation confirms the possibility of effective adjustment of force and speed by selecting active sections and using constant flow rates and pressures. This work represents a first step in the development of the digital hydraulics concept, opening up perspectives for in-depth research in this field.

In the near future, reducing costs and increasing energy efficiency will become determining factors in the success of any industry. Currently, the hydraulic industry is not yet fully prepared to meet these requirements, as traditional systems are costly and energy inefficient. The correct choice of technical and economic solutions can transform hydraulic systems into the fastest and most efficient methods of power transmission. The energy savings resulting from modeling and simulating suitable solutions can improve the technical and economic performance of production lines, thereby contributing to cost reduction and supporting sustainable development.

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STEM Education and Mechatronic Applications: Mechanisms, Devices, and Systems in the Development of Youth and Students

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Abstract: *This article examines the essential role of STEM education in mechatronics, emphasizing its impact on developing youth and students. As nations recognize the necessity of preparing future generations for a technology-driven workforce, initiatives are being introduced to align higher education with Industry 4.0 demands. Through interdisciplinary projects and innovative methods, students gain vital skills in science, technology, engineering, and mathematics. The paper highlights successful educational programs and discusses the integration of STEM and mechatronic principles in curricula, promoting critical thinking and collaboration. It also reviews government initiatives in countries such as China, the United States, and Romania that aim to enhance STEM competencies, serving as catalysts for societal growth and innovation toward a prosperous future.*

Keywords: *STEM education, STEAM education, interdisciplinary projects, innovative learning, critical thinking, robotics, government initiatives, educational reform, global competitiveness, experiential learning*

1. Introduction. The importance and necessity of STEM education

STEM education (Science, Technology, Engineering, Mathematics) represents an integrated approach to four essential fields: science, technology, engineering, and mathematics. In an expanded version, STE(A)M includes the arts to encourage creativity and innovation. This interdisciplinary integration allows students to make connections between different fields and understand how they complement each other.
Through the STEM approach [1-4, 6, 7,14-17, 20], students can apply the knowledge they have gained in real-world contexts, directly impacting the development of critical thinking and problem-solving skills. Instead of isolating disciplines, STEM facilitates a holistic exploration of their interdependence. For example, understanding mathematical concepts becomes more accessible when applied in scientific experiments or engineering projects.
This practical approach not only strengthens theoretical knowledge but also stimulates creativity and innovation. Students learn how scientific principles influence new technological discoveries, how engineering drives innovation, and how mathematics supports these processes. This interdisciplinary perspective prepares them to effectively address complex challenges in industry and research.
A concrete example of STEM application in education is the use of mechatronic devices [5,18,19], such as mini weather stations, which allow students to collect and analyze real-time data. These educational projects not only improve technical skills but also contribute to the development of cognitive abilities such as problem-solving, statistical analysis, and error identification.
On the other hand, STEM education fosters innovation. Educational systems that do not promote a multidisciplinary approach can have a negative impact on the future of the industry and the ability to form innovative scientists and engineers. In this regard, a report from the University of Warwick highlights that the lack of multidisciplinary education "affects creativity in industry and the ability to produce technological leaders on a global scale" (STEM education).

2. STEM Education in universities and international competitions

In advanced economies, STEM education is an essential part of the university curriculum [1- 4, 6,7,9, 10-12,16,17, 20] and competitive educational programs. Universities in the United States, for example, are globally recognized for their research and innovations in STEM fields. Institutions such as MIT (Massachusetts Institute of Technology) and Stanford University place significant emphasis on interdisciplinary projects and industry collaboration. These universities offer specialized courses in robotics, artificial intelligence, and mechatronics, all integrated into their STEM programs.

• Prestigious university competitions

STEM-based academic competitions [8] are another method through which students in technical faculties can showcase their knowledge and skills. A remarkable example is the FIRST Robotics Competition (FRC), a global contest where student teams design and build robots to complete complex tasks. This competition not only provides valuable experience to participants but also offers the opportunity to innovate and work in teams.

In Germany, the Formula Student competition is one of the most prestigious platforms for engineering students. Teams from all over the world compete to design and build high-performance vehicles. This competition fosters collaboration between faculties and industry, contributing to innovation in mechatronics and intelligent transport systems.

• Public innovations and international recognition

Universities in industrialized countries often collaborate with the public and private sectors to support STEM innovations.

◘ A notable example is the DARPA Robotics Challenge, organized by the U.S. Department of Defense. This competition aims to develop robots capable of responding to emergency situations. Students, alongside researchers and technology companies, have the opportunity to innovate and contribute critical solutions within these contests.

◘ South Korea heavily invests in technology and STEM education, with its universities promoting robotics and programming innovation competitions. For instance, the World Robot Olympiad involves student teams competing in various disciplines, from robotics to artificial intelligence, frequently ranking high in global STEM competitions.

In countries with advanced economies, STEM education is crucial for developing the future skills of engineers and researchers. In addition to the United States and Germany, other nations such as Canada, Australia, New Zealand, and Japan have made significant strides in implementing STEM programs at universities and organizing specialized competitions.

◘ In Canada, top universities like the University of Toronto and the University of British Columbia are known for integrating STEM into research and education. These universities offer specialized programs in robotics, engineering, and mechatronics, providing students with opportunities to work on real-world projects in collaboration with industry. One example is the STEM Fellowship program, which promotes collaboration between students, researchers, and industry in data analysis and innovation projects in science and technology.

Canada also hosts competitions such as the Canadian Engineering Competition, where students demonstrate their technical problem-solving and innovation skills, gaining recognition nationally and internationally.

◘ In Australia, universities such as the University of Sydney and the University of Melbourne are recognized for advanced research in engineering and applied sciences. Competitions like RoboCup Junior Australia allow students to compete in robotics, applying STEM knowledge to build and program robots that perform various tasks.

◘ New Zealand has adopted a similar approach, with its universities actively promoting STEM research projects. An example is the Smart Ideas Challenge, organized by the University of Auckland, which encourages students to develop innovative solutions in green technology and robotics.

◘ Japan, known for its technological advancements, places significant emphasis on STEM education in technical and engineering faculties. Tokyo Institute of Technology and the University of Tokyo are two of the top universities offering extensive programs in mechatronic engineering and robotics. Competitions such as RoboCup Japan Open and the All Japan Robot-Sumo

Tournament allow students to develop their technical skills and innovate in areas such as artificial intelligence and robotics.
Moreover, Japan invests in public initiatives and STEM innovation contests, such as the Robot Development Project, which involves both researchers and students in the development of autonomous robots for industrial and social applications.

2.1. Educational projects based on mechatronics

A notable example of an educational mechatronics project, completed in Romania in 2024, is the Mini Weather Station (code MSM 001), developed as part of the MSSMM Master's Program «*Modeling and Simulation of Mobile Mechanical Systems*» at the Faculty of Industrial Engineering and Robotics (FIIR) - Bucharest. This project integrates essential elements from technology, engineering, and mathematics, using Arduino platforms and modules to build a functional device capable of collecting real-time meteorological data.
The Mini Weather Station (see Figure 1) was designed to be portable, easy to use, and capable of operating off-grid. The project is a successful example of STEM education application, allowing students to develop both technical and cognitive skills through the process of prototyping and practical testing.
The MSM 001 weather station includes Arduino-compatible modules, such as temperature, pressure, and humidity sensors, a real-time clock module, and a data storage module on microSD cards. These components enable students to monitor climate parameters in real-time and analyze the collected data, stored in CSV format, using specialized software such as MS Excel and KiCad. Additionally, the prototype is equipped with solar panels, ensuring energy independence, which stands as a positive example of integrating green technologies into educational projects.

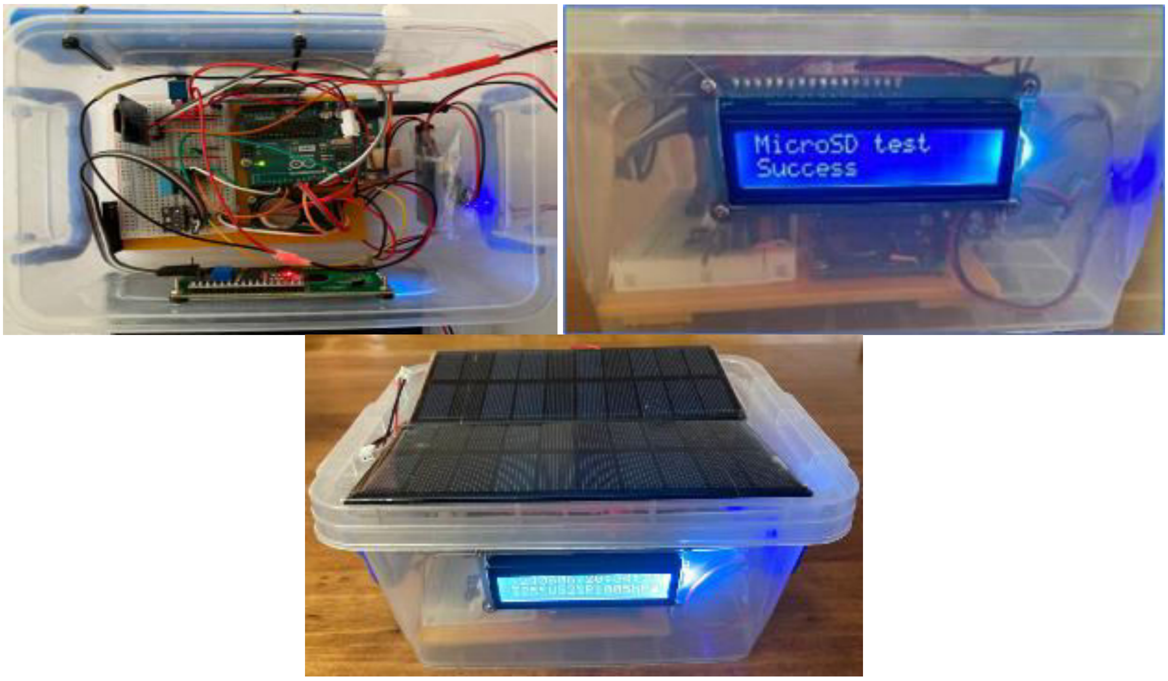

Fig. 1. Mini Weather Station - MSM 001 built on the STEM concept
(top view, side view, view with solar panel)

Through this project, students learn to apply knowledge gained in engineering, electronics, and programming to solve practical problems. This hands-on experience is crucial in mechatronics education, preparing them for the challenges of modern industry.

2.2. The role of robots and mechanisms in practical learning

Robots and mechanisms [12,13,18,19] play a central role in practical STEM education as they allow students to apply theoretical concepts in a tangible environment. Robot-based projects foster critical thinking, creativity, and problem-solving skills, enabling students to build and experiment with complex systems. This approach is part of the philosophy of STEM education, where students not only learn how to design and assemble mechanisms but also program and optimize them to perform specific tasks.
Educational programs based on robotics, such as FIRST Robotics, RoboCup, and university mechatronics competitions, contribute to the development of essential skills in the digital age. The projects often involve the integration of sensors and automated control systems, helping students understand how modern industrial processes work, including automation and intelligent production systems.
Mechanisms such as transmissions, pneumatic systems, or hydraulic systems are often used in these projects to simulate real-world processes encountered in industry. This combination of mechanical engineering and electronics stimulates multidisciplinary thinking, giving students a holistic view of how complex mechatronic devices function in real life.
An impactful European project is the **Guide of STE(A)M Education Practices - STEAM on edu**, funded by the European Union's Erasmus+ program. This guide is a valuable tool for any teacher wishing to apply the STEAM model. It provides detailed instructions for 12 study projects proposed in the guide, available at: https://steamonedu.eu/wp-content/uploads/2021/03/D4-Guide-of-STEAM-education-practices.pdf.
These 12 projects offer useful starting points for teachers interested in applying the STE(A)M approach in educational activities. Two of the proposed projects are:
(1) *Vision of the Future* and
(2) *Smart Home Sensor*.
Vision of the Future 26 involves a mini robot programmed with Scratch and Java for Arduino. In the image below (Figure 2), a presentation of the project from the aforementioned guide can be seen: https://steamonedu.eu/wp-content/uploads/2021/03/D4-Guide-of-STEAM-education-practices.pdf.

Fig. 2. "Vision of the Future," video available on YouTube

The ***Make it Open*** project, funded under the Horizon 2020 program, provides a kit for teachers with resources and examples for implementing various projects. It was one of the partners of the Bucharest Science Festival in Romania, 2023.
Arduino software has been widely adopted in STEM education programs worldwide. Its simplicity, accessibility, and versatility make it an ideal tool for introducing students to fundamental concepts in electronics and programming. Many educational institutions integrate Arduino into their curricula to teach topics such as electrical circuits, sensor interfacing, data logging, robotics, and IoT (Internet of Things) applications.

Arduino-based projects in STEM education range from simple experiments with LEDs and sensors to more complex projects like building robots, environmental monitoring systems, and smart devices.
Beginner Arduino kits for educational purposes are available on the market. These kits usually include Arduino boards, components, sensors, and educational materials such as tutorials, lesson plans, and project ideas. The beginner kits provide teachers with everything they need to introduce Arduino to students, regardless of their prior experience in electronics or programming. These kits offer hands-on learning experiences that engage students and encourage experimentation and creativity.

3. The benefits of STEM education applied to mechatronics

The application of STEM education to the field of mechatronics offers numerous benefits, enhancing both curricula and student competencies. These benefits can be summarized as follows:

1. **Improvement of the Mechatronics Curriculum:** STEM education contributes to updating and enriching the curriculum content to meet modern technological demands and increase its relevance to students.
2. **Multidisciplinary Teaching:** It leverages teaching content across multiple disciplines, combining science, technology, engineering, and mathematics, in alignment with national educational standards.
3. **Integrated Modern Principles:** It applies STEM/STEAM principles alongside up-to-date knowledge from mechatronics and contemporary technologies, promoting relevant and forward-thinking education.
4. **Engagement Activities:** It plans and organizes activities that actively involve students, parents, and the community to create a collaborative educational environment.
5. **Complex and Relevant Lessons:** It delivers periodic lessons on related sciences, emphasizing the importance of specific mechatronic concepts while ensuring age-appropriate content and participant safety.
6. **Interconnected Curriculum:** It ensures the completion of the Mechatronics curriculum while fostering connections with related disciplines for a holistic approach to science and technology education.
7. **Professional Development:** It supports the professional growth of other STEM/STEAM educators by sharing best practices and promoting effective teaching-learning methods.
8. **Tailored Projects:** It backs the development of projects that address the needs and interests of students, ensuring their relevance and applicability.
9. **Technological Applications:** It uses various complementary technological applications and diverse online resources to enhance the learning process.
10. **Increased Productivity:** It boosts productivity and learning opportunities through the use of modern technology.
11. **Improved Communication and Collaboration:** It enhances communication and collaboration within work teams, fostering essential skills for students' future careers.

• Development of Critical Thinking and Practical Skills

STEM/STEAM education promotes an active learning approach, encouraging students to engage in practical experiences that help them develop problem-solving and analytical abilities. For instance, the "FIRST Robotics" program in the United States, which encourages students to build and compete with robots, offers them the opportunity to apply theoretical knowledge in a practical and competitive setting. This learning method, focused on mechatronics and robotics, not only builds technical skills but also develops competencies such as collaboration, leadership, and creativity.
Susan Riley, an expert in STEAM education, emphasizes that "STEAM is an educational approach to learning that uses science, technology, engineering, arts, and mathematics as access points for guiding student inquiry, dialogue, and critical thinking." This definition highlights critical thinking as a key outcome of STEAM education.

• Creating Innovative Solutions through Interdisciplinary Projects
STEAM education enables the integration of various disciplines [5,10,12,13,18,19], and through interdisciplinary projects, it generates innovative solutions for complex problems. For example, projects like "Design Thinking," used by universities such as Stanford, foster innovative thinking among students, helping them collaborate and come up with ingenious solutions to intricate challenges. In this model, students not only learn technical concepts but also how to communicate and collaborate effectively, which is crucial in the modern workplace.

Globally, China is heavily investing in STEM education, recognizing the link between innovation and economic growth. This is reflected in teacher training programs that incorporate STEAM concepts to ensure students have a solid foundation and practical skills.

Similarly, in the United States, initiatives like "Educate to Innovate" reflect a national commitment to developing a competitive STEM workforce.

The large-scale introduction of the STEAM model into school curricula and extracurricular activities, supported by useful tools for teachers who have developed or will develop competencies to teach STEAM, could represent an important turning point for European education as well.

At the governmental level in Romania, the foundation for STEAM education is laid out in the "Educated Romania" project, which states: "Promoting STEAM education" includes cross-cutting strategic objectives related to "preparing and supporting teachers for teaching, learning, evaluating, and motivating students in the STEAM field."

The "Educated Romania" project has also been formalized through a package of educational laws, which includes two significant legislative acts:

● **Law on Pre-University Education No. 198/2023 (updated):** This law contains provisions aimed at improving the quality of education, including in the STEAM area. It includes measures to encourage student engagement in STEAM fields, as well as teacher preparation and support for teaching in this area.

● **Law on Higher Education No. 199/2023 (updated):** This law applies to higher education and aims to improve the academic and professional training of students. It contains specific provisions for the development of the STEAM field and the integration of Art into the teaching of STEM subjects.

Moreover, several heavily industrialized countries have launched initiatives or passed legislation to advance higher education, particularly in STEM and STEAM fields. Here are some notable examples from North America, Australia, New Zealand, the UK, China, and Japan:

☑ **United States:**

- **America COMPETES Act** (Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science): This act was reauthorized to increase funding for research and STEM education, specifically targeting advancements in engineering, AI, and quantum technologies. It also emphasizes collaboration between universities and industries.
- **Educate to Innovate**: A public-private initiative aimed at improving STEM education and fostering a competitive workforce, focusing on engaging women and minorities.
- **National Defense Education Program (NDEP)**: Provides scholarships and fellowships to students pursuing STEM careers, especially in defense-related industries.

☑ **Canada:**

- **Canada's Digital Charter**: This includes support for the development of a workforce skilled in new and emerging technologies like AI, cybersecurity, and quantum computing through partnerships between universities and tech companies.
- **STEM Skills Action Plan (2019)**: Focuses on integrating STEM programs at all educational levels, especially in post-secondary institutions. It encourages partnerships between universities and industries to provide practical learning experiences.

☑ **Australia:**

- **National Innovation and Science Agenda (NISA)**: This program aims to boost innovation and entrepreneurship in higher education by increasing the emphasis on STEM and industry partnerships. Funding has been allocated to research universities to foster greater collaboration with private industries.
- **Higher Education Support Amendment**: This legislation adjusts the funding model to support higher enrollment in STEM fields, which is seen as critical for Australia's economic future.

☑ **New Zealand:**

- **Tertiary Education Strategy 2020-2025**: Focuses on preparing students for future workforces, especially in STEM fields. The strategy promotes interdisciplinary education, including STEAM, and industry collaboration to better align with market needs.
- **PBRF (Performance-Based Research Fund)**: A major funding initiative that directs resources towards university research in high-demand areas, including STEM disciplines.

☑ **United Kingdom:**

- **Industrial Strategy**: The UK government launched an initiative to promote education in key areas like artificial intelligence, energy, and advanced materials. This includes significant funding for university research in STEM fields and partnerships with industries to commercialize research.
- **Turing Scheme**: Replacing the Erasmus program, this initiative focuses on sending students abroad, particularly for STEM-related opportunities, fostering global collaboration in research and education.

☑ **China:**

- **Made in China 2025**: A state-led initiative that emphasizes STEM education and aims to make China a global leader in advanced manufacturing, AI, and robotics. Significant resources have been allocated to university research and development programs in these fields.
- **Double First-Class Initiative**: This project seeks to enhance the quality of Chinese universities by focusing on specific disciplines, including STEM fields, and aiming to bring them up to world-class standards.

☑ **Japan:**

- **Society 5.0**: A government-led initiative that merges cyberspace with physical space. Universities are encouraged to innovate in fields like robotics, AI, and biotechnology. The education system is being restructured to better prepare students for these new industries.
- **Super Global Universities Program**: Focuses on enhancing the global competitiveness of Japanese universities, particularly in research and development in STEM areas.

4. Conclusions

The benefits of STEM and STEAM education are evident: they prepare young students not only for careers in science and technology but also develop their critical thinking and collaborative skills. The widespread implementation of these educational models, supported by government policies, can transform both European and international education, ultimately benefiting society as a whole by leading to generations of innovative and creative youth.
China, as a global leader in technology and innovation, has made substantial investments in STEM education to ensure that its students excel in science, technology, engineering, and mathematics. The Chinese educational system emphasizes proficiency in STEM subjects and encourages hands-on learning experiences.
The United States, with its strong tradition in research and development, prioritizes STEM education at all levels. Additionally, American universities in the STEAM fields are renowned worldwide.
National projects, such as “Romania Educated,” highlight the importance of this transition towards a skills-centered educational system focused on STEAM, ensuring a more prosperous future.
Moreover, Maia Bacovic and her team from the Faculty of Economics, University of Montenegro, Podgorica, emphasize the direct link between STEM competencies and societal well-being in their 2022 article, “STEM Education and Growth in Europe.” They state: “Statistical analysis [...] shows a strong linear association between scientific and technical education, production structure, income per capita, and productivity growth. [...] we found a significant contribution of STEM-educated workers to production growth.”
Currently, countries around the world recognize the importance of STEM education [1,4,6,7,14,15] and have undertaken various initiatives to advance this field. These efforts aim to prepare youth and students for the demands of the future workforce by aligning higher education with emerging technologies and modern Industry 4.0.

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Electrohydraulic Servo Actuators with IoT Capabilities

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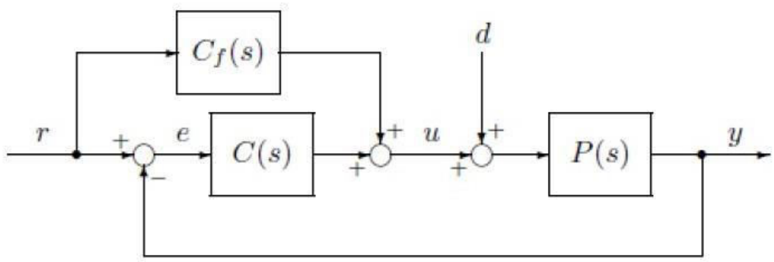
Abstract: *The following document details an electrohydraulic servo actuator system with Internet of Things (IoT) functionalities, highlighting its main components: control electronics, the servo amplifier, the power supply, the servo valve, the hydraulic actuator, and the feedback transducer. The system utilizes a two-degree-of-freedom (2- DOF) controller and IoT integration for monitoring and preventive maintenance. The system implementation is done using a Modicon M221 PLC and a Raspberry Pi single-board computer for the local server and monitoring. The conclusions emphasize the improvement of remote monitoring and system parameterization, suggesting future research directions for the development of cloud-based business models.*

Keywords: *Electrohydraulic actuator, IoT integration, 2-DOF controller, remote monitoring, PLC*

1. Preliminaries

An electrohydraulic actuator system comprises six key components: control electronics, which can be a computer, microprocessor, or guidance system, creating a command input signal; a servo-amplifier that provides a low-power electrical actuating signal, which is the difference between the command input signal and the feedback signal generated by the feedback transducer; a power supply, typically an electric motor and pump, delivering hydraulic fluid flow under high pressure; a servo valve that responds to the low-power electrical signal and regulates the hydraulic fluid flow to an actuation element, such as a piston and cylinder, positioning the controlled device; a hydraulic actuator, consisting of a piston and cylinder, to control linear motion and positioning; and a feedback transducer that measures the actuator's output position and converts this measurement into a proportional signal sent back to the servo-amplifier [1]. A general form of the 2-DOF control system is shown in fig.1 [2]. The key components of this system include the feedforward compensator $C_f(s)$, the serial compensator C(s) and plant process P(s). The set-point variable r represents the desired target, while the manipulated variable u is the output from the compensators that adjusts the plant. The controlled variable y is the output of the plant, which is affected by external disturbances d. Error e is the subtraction of y from r.



$$C(s) = K_P\left\{1 + \frac{1}{T_I s} + T_D D(s)\right\}$$

$$C_f(s) = -K_P\left\{\alpha + \beta T_D D(s)\right\}$$

Fig. 1. Two-degree-of-freedom control system

In this configuration, the feedforward compensator $C_f(s)$ directly processes the set-point variable r to anticipate and mitigate disturbances before they affect the plant. The serial compensator C(s) is part of the feedback loop, working to continuously correct deviations between the controlled variable y and the set-point variable r.
Hydraulic drives typically utilize two types of actuators: position-controlled linear actuators and speed- controlled rotary actuators. For position-controlled linear actuators, the feedforward path command is derived from the reference point's derivative, so α = 0. In contrast, speed-controlled rotary actuators require a feedforward path command that is directly proportional to the set-point value, thus ß = 0 for effective control [3].
A single-board computer (SBC) is a fully functional computer where the microprocessor, input/output functions, memory, and other features are integrated onto a single circuit board. It includes a fixed amount of built-in RAM and lacks expansion slots for peripherals. This straightforward design contrasts with the multiple configurations available in modern personal computers, yet its simplicity ensures reliability, making these ideal as embedded computer controllers for operating complex devices.

2. Controller implementation

The controller command is as follows:

$$u(s) = K_p \cdot err(s) \cdot \left[1 + T_d \cdot s + \frac{1}{T_i \cdot s}\right] + K_f \cdot [\alpha \cdot s \cdot sp(s) + \beta \cdot sp(s)] \qquad (1)$$

The FF compensator is calibrated depending on the physical parameter that the transducer's output value is proportional to (either proportional to the set-point (α = 0, ß <> 0), its derivative (α <> 0, ß = 0) or both (α <> 0, ß <> 0)).
The 2-DOF PID control algorithm was implemented using the Modicon M221 entry-level PLC [4]. The software development platform for this PLC is EcoStruxure Machine Expert-Basic, a free licensed programming software specifically designed for M221 controllers. Modicon offers performance and scalability suitable for a wide range of industrial applications, from entry-level tasks to high-performance multi-axis machines and high-availability redundant processes.
Regarding hardware implementation, a TM221CE24T controller was used, with 14 digital inputs, 2 analogue inputs, Ethernet and serial line ports, with 24 Vdc power supply. To interface the actuator with the PLC, a TM3AM6 analogue expansion module is required. The TM3AM6 module has 4 analogue inputs (±10 V, 0-10 V, 0-20 mA, 4-20 mA), 2 analogue outputs (±10 V, 0-10 V, 0-20 mA, 4-20 mA) and a 12-bit resolution.
A Raspberry Pi RPI4-MODBP 8GB [5] was used as the remote computer for a localhost server used for monitoring and parametrization of the controller, as part of the IoT system. The Raspberry Pi 4 Model B (RPI4-MODBP) with 8GB RAM is a versatile single-board computer, featuring 40-pin GPIO header, providing 26 GPIO pins that can be used as digital inputs or outputs, with support for I2C, SPI, and UART communication protocols, as well as a Gigabit Ethernet port.

3. IoT implementation for monitoring and parametrization

For monitoring and parametrization of the controller, a Pascal-based program was developed, using Lazarus IDE [6], that runs on a SBC in the same network as the controller. The application server runs in a terminal window (**fig. 2**) that features management of the current state of the IoT system (PLC on/off, web server on/off) and details about control system variables and controller parameters.
With this app open, a localhost web page can then be accessed to further monitor the system.

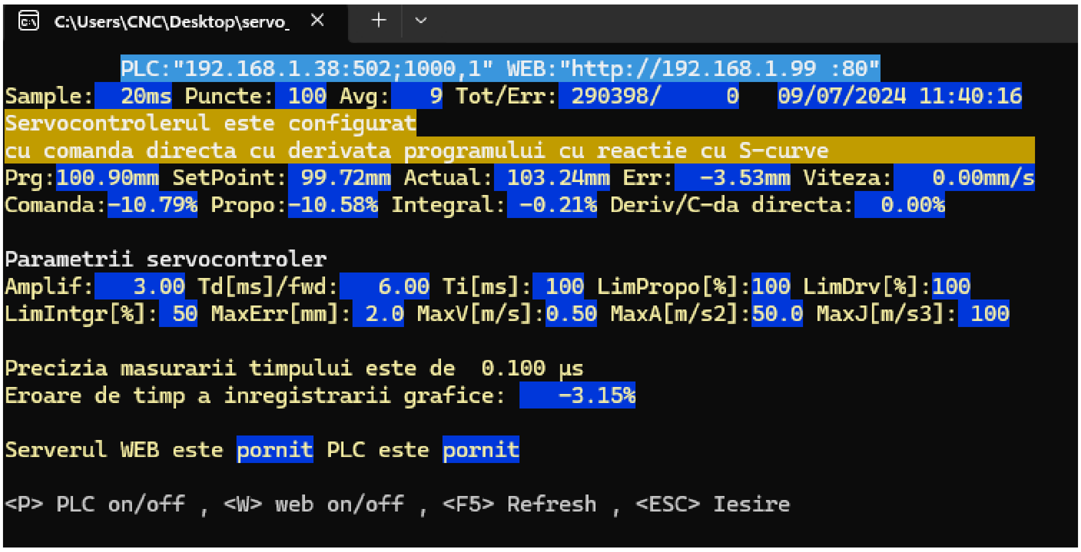


Fig. 2. Server’s terminal window

Inside this webpage, a user can either access a read-only window of the evolution of different measured values or access an administrator panel using a login feature. The administrator window, as shown in **fig. 3**, allows for variation of the 2-DOF controller parameters and configuration of the output graph, for showing multiple variables in the time frame.
The values are set via the controller's Ethernet interface using the MODBUS over TCP/IP protocol. MODBUS is a widely used communication protocol in industrial automation and is supported by many devices and controllers. Furthermore, implementing MODBUS over TCP/IP can be cost-effective compared to proprietary protocols or more complex communication standards. It leverages existing Ethernet infrastructure without requiring significant additional investment.

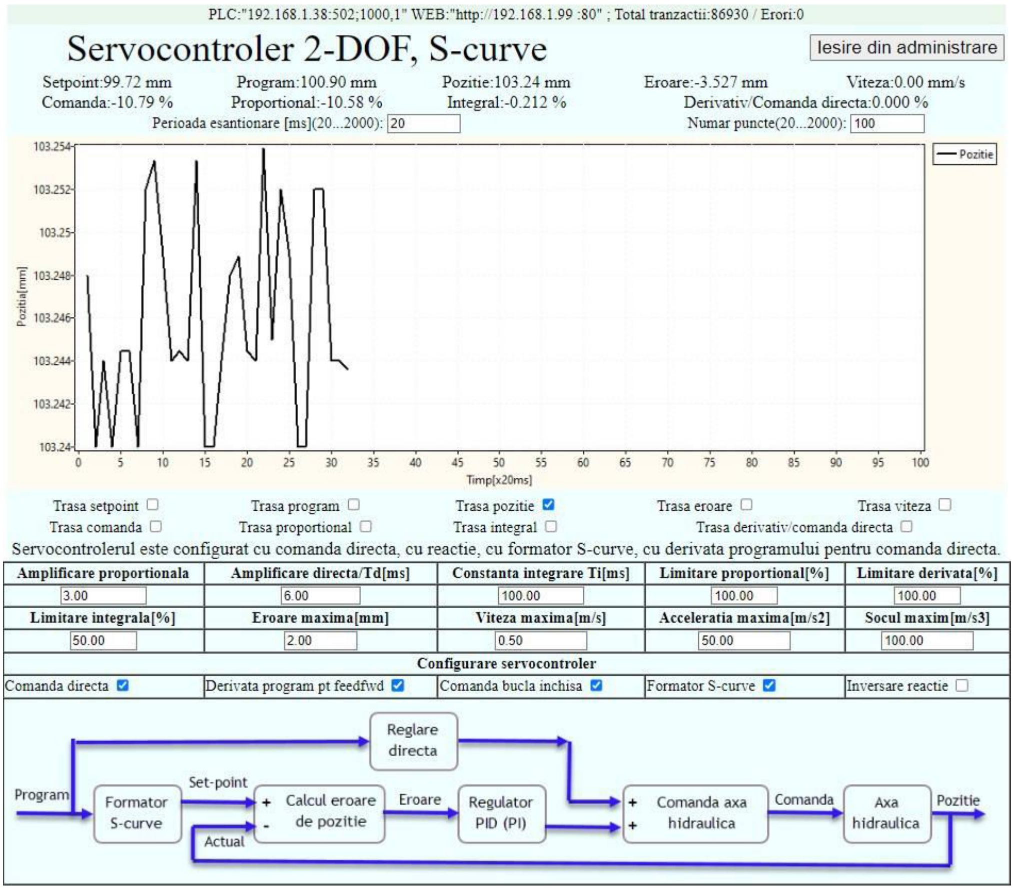


Fig. 3. Client browser window for the administrator

Fig. 4 shows the block diagram of the automated system for controlling a hydraulic actuator using a position transducer, PLC, and a single board computer [7]. The PLC receives input from the position transducer and controls the hydraulic system. The single board computer, which can run on Linux or Windows, connects to the PLC via MODBUS and manages configuration, HTTP server, and database functions. The system can be monitored and controlled remotely via HTTP clients through an internet- connected network.

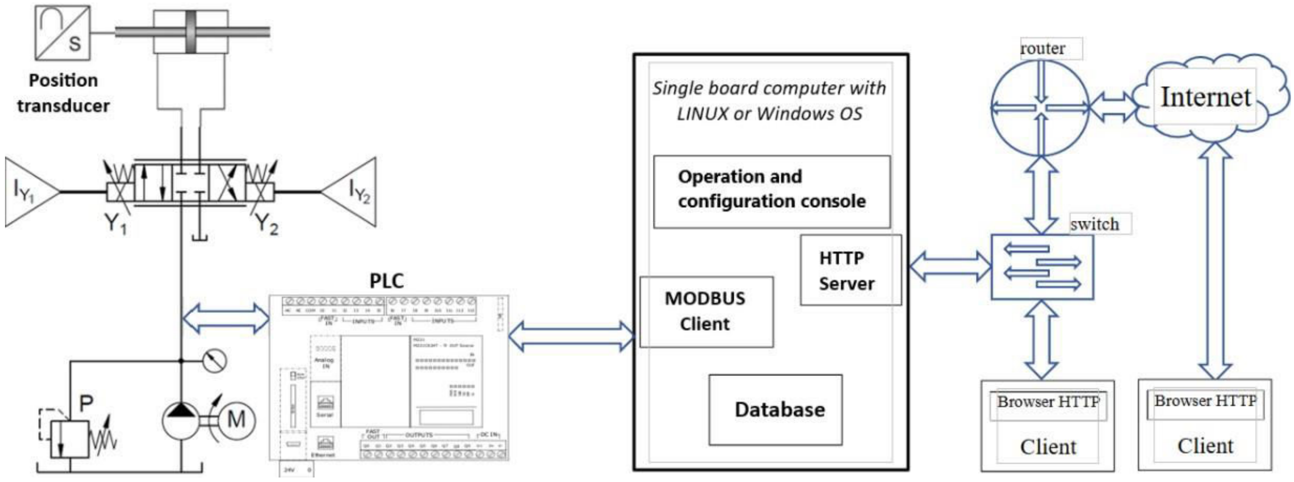


Fig. 4. Block diagram of the IoT system

4. Experimental setup

Fig. 5 and **fig. 6** illustrate the experimental stand, controller and other equipment used for the testing of 2-DOF controller on a hydraulic system. **Fig. 7** shows the functional diagram of setup.

Fig. 5. Experimental stand

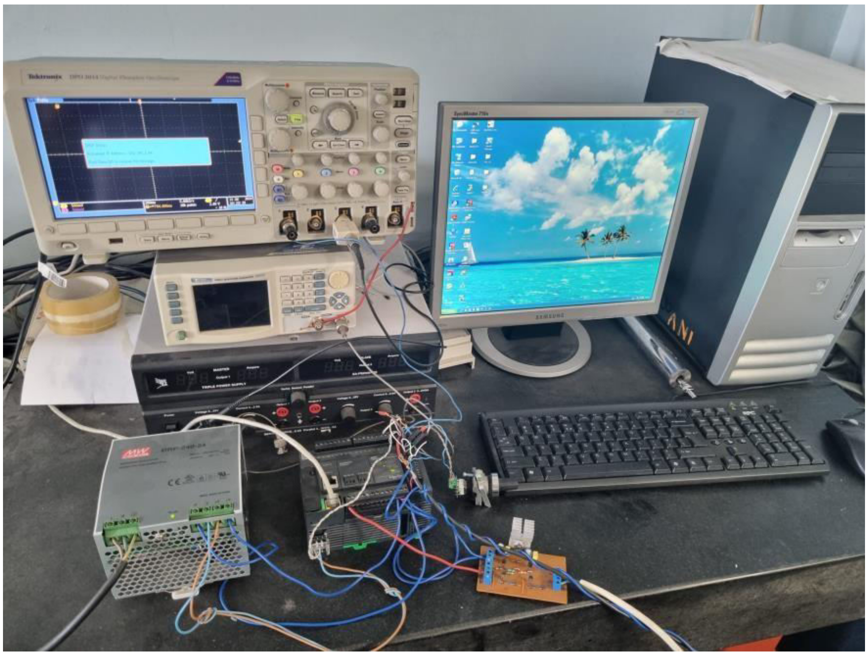


Fig. 6. Controller setup, with waveform generator and computer

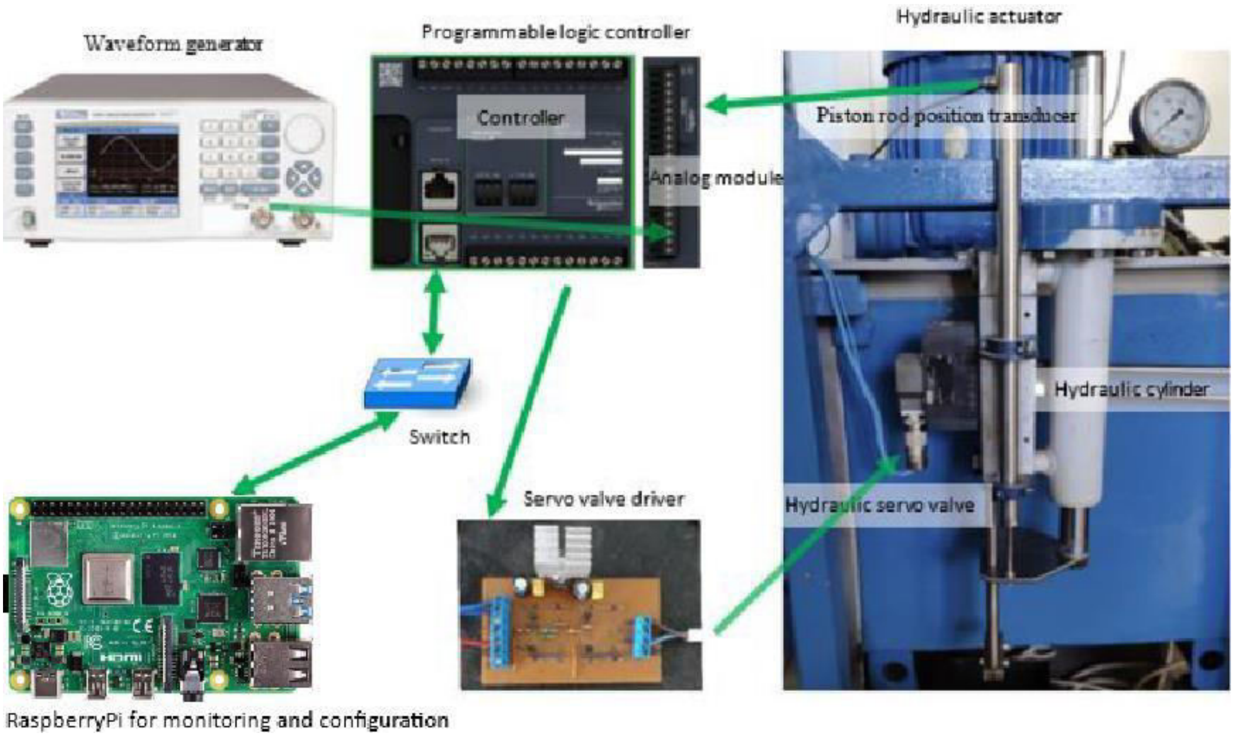


Fig. 7. Functional diagram of test stand

The hydraulic cylinder is actuated by an electro-hydraulic flow servo valve, which is powered by a hydraulic station capable of providing a pressure of 150 bar and a flow rate of 60 liters per minute. This setup enables a maximum speed of 0.66 meters per second and a maximum force of 1100 daN at the hydraulic cylinder rod. The position of the cylinder rod, with a maximum stroke of 200 mm, is monitored using an LVDT-type position transducer with a measurement range of 200 mm. Control signals for the linear hydraulic axis are generated by a WW5061-TABOR ELECTRONICS digital signal generator, facilitating the evaluation of both the static and dynamic performance of the hydraulic axis.

5. Results

The following pictures illustrate system response (cylinder rod position, error and velocity) when applying sinusoidal, step and triangular reference.

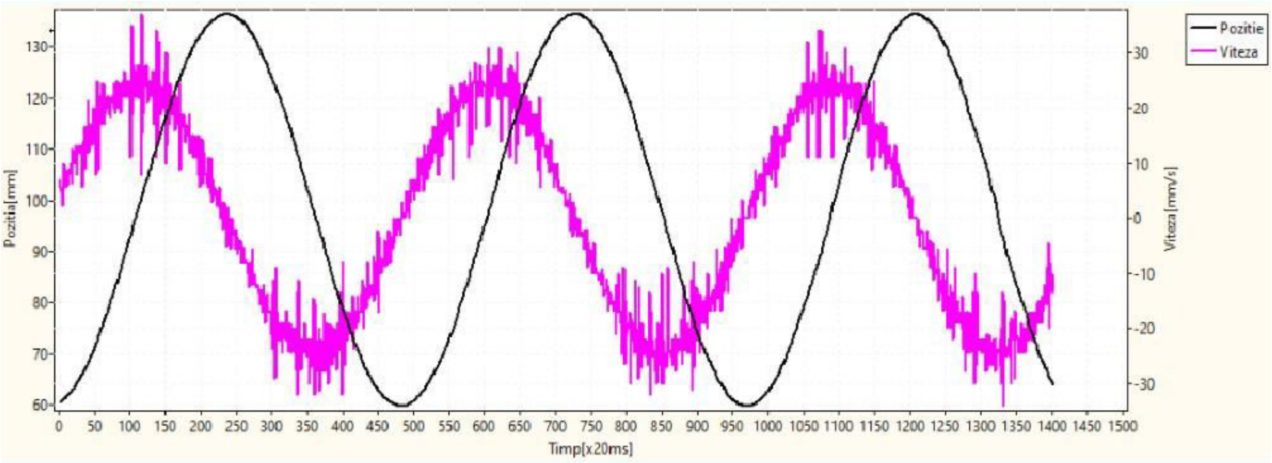


Fig. 8. Cylinder rod position (black) and velocity (purple) for sinusoidal signal

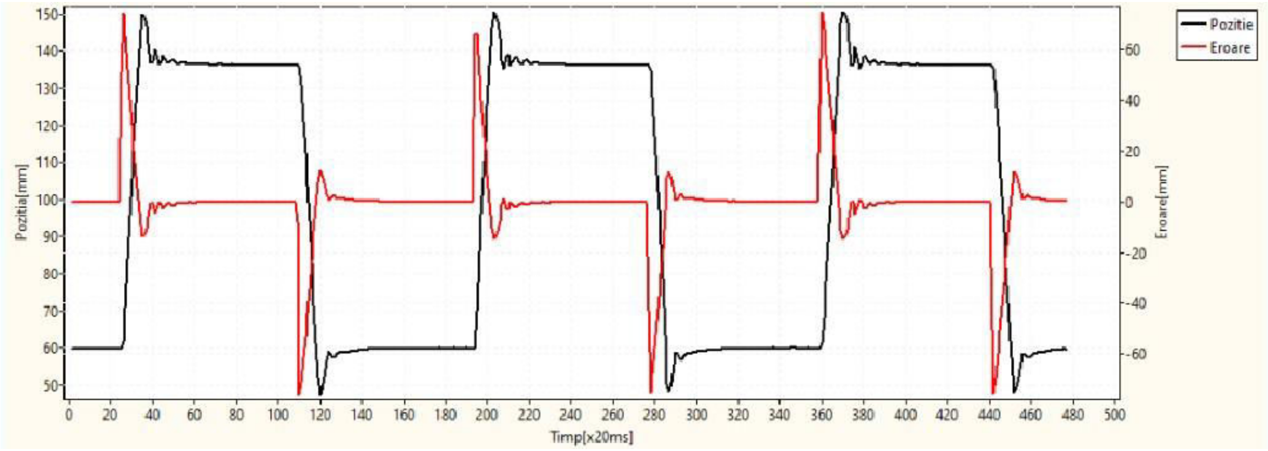


Fig. 9. Cylinder rod position (black) and error (red) for step signal

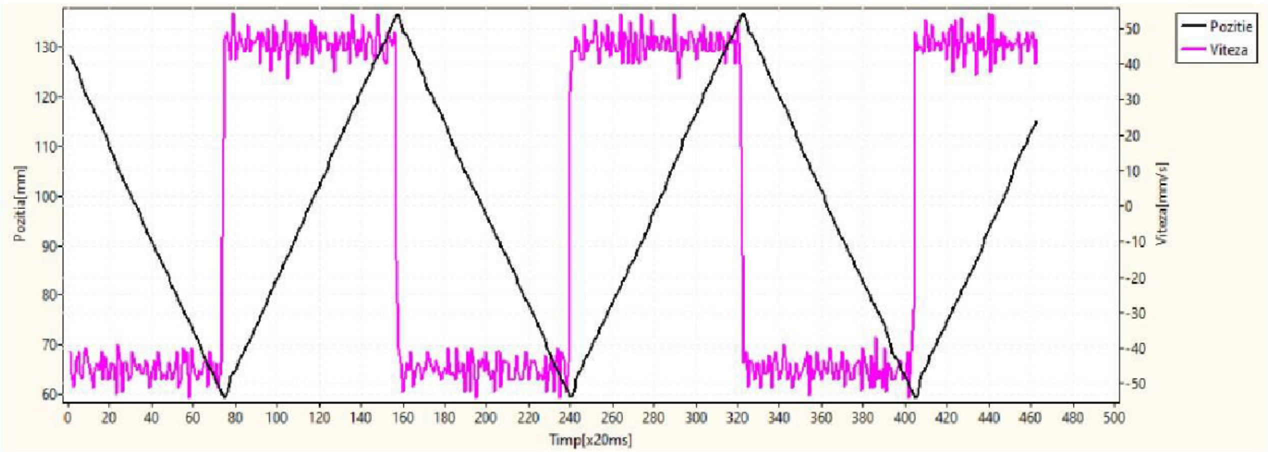


Fig. 10. Cylinder rod position (black) and velocity (purple) for triangular signal

For **fig. 8**, position shows a smooth sinusoidal pattern indicating periodic motion. The velocity data is noisy but follows a periodic pattern as well, peaking when the position changes the fastest, which is consistent with the derivative of a sine wave.

In **fig. 9**, the error spikes at the same time as the rapid transitions in position, which is typical as the system responds to changes and attempts to correct for deviations from the desired position.
For **fig. 10**, the velocity is highly variable and noisy but shows clear peaks at the points where the position changes direction, resembling a step-like pattern.

6. Conclusions

In the presented material, it was demonstrated how a linear hydraulic axis can be improved into an IoT system using open-source software and general use hardware. Thus, the client can monitor and parametrize the hydraulic axis from the network based on a dashboard, through any general-use browser. As a suggested direction for continuing the research, the development of new cloud - based businesses can be considered, offering access to the hydraulic axis through software applications commercialized in the form of software as a service (SaaS). Additionally, the IoT system could detect real-time operational anomalies of the hydraulic axis and can send alerts to users or trigger preventive or corrective actions. Another suggestion involves integrating a database into the client software, where values and process parameters are stored in real-time, allowing the monitoring of the system's evolution over time.

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Methods to Reduce and Control Risks Arising from Head Loss in the Transportation of Water through Pipes and Fittings Used for Firefighting

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***Abstract:** The article presents a series of cases transformed in methods, which can be used to reduce and control the losses of energy at water transportation through pipes and fire extinguishing equipment.*

***Keywords:** Pressure control, pipes, fire extinguishing, pressure drop*

1. Introduction

To enhance the efficiency of water transportation in firefighting systems, various methods for reducing hydraulic head losses have been investigated. One effective approach involves modifying the pipe roughness and utilizing polymer additives to decrease turbulent flow and velocity pulsations. By incorporating synthetic or natural polymer solutions, frictional resistance within pipes and hoses can be significantly reduced, leading to more efficient water flow and lower pressure drops. This technique addresses both the structural and fluid dynamic aspects of firefighting systems, offering a practical solution to common performance issues.
Furthermore, optimizing pipe design and suction conditions plays a critical role in minimizing pressure losses. Careful consideration of pipe diameter transitions and suction height can substantially affect the system's overall efficiency. Implementing strategies to reduce linear and local resistance, combined with the use of polymer additives, ensures that firefighting operations are more effective and reliable. These measures are crucial for maintaining operational effectiveness in emergency situations, highlighting the importance of both material selection and design optimization in firefighting systems.

2. Methods using polymer additives

The main methods to reduce the head losses in the transportation of water through pipes and fittings used in firefighting are:
- by modifying the absolute roughness Δn of pipes, hoses, etc., in order to choose the lowest possible values in service; this method is technically limited in relation to cost [1];
- by decreasing the velocity pulsations which have the effect of reducing the turbulent intensity; this can be achieved by: the use of synthetic or natural polymer additives; the use of additives such as suspensions of association materials and colloids, fibrous particles, suspensions of fiber-polymer mixtures (by injecting polymers into the layer near the inner wall of the pipe or in the center of the pipe) [2-6];
- use of specific firefighting methods [7,8];
- by optimizing load losses (linear and local) in the design phase;
- by the combined use of the methods presented.

2.1 Reducing load losses by modifying roughness

For cases where the flow is permanent $\partial u/\partial t=0$ with constant pressure and flow rate, by introducing dilute polymer solutions, the linear resistance coefficient decreases and thus the absolute roughness coefficient denoted by Δn decreases, becoming:

$$\Delta n = n_0 - n \tag{1}$$

which generates load loss reduction.

In the above assumptions, the head loss using Chézy's and Manning's relation for the hydraulic slope I is given by the relation [1]:

$$I = \frac{\bar{u}^2}{c^2 \cdot R} = \frac{Q^2 \cdot n^2}{S^2 \cdot R^{4/3}} = \frac{Q^2 \cdot n^2}{\bar{n}^2} \tag{2}$$

where

$$\bar{n} = S \cdot R^{2/3};\ c = \frac{1}{n} \cdot R^{1/6} \tag{3}$$

At constant flow, the pressure drop is [9]:

$$\Delta h_r = I \cdot l = \frac{Q^2 \cdot k^2}{A^2 \cdot R^{4/3}} \cdot l = C \cdot n^2 \tag{4}$$

where: R = hydraulic radius
C = constant
S = pipe cross section
Under these circumstances:

$$\Delta h_r = C \cdot n^2 = \Delta h_0 \cdot \left(1 - \frac{\Delta n}{n_0}\right)^2 \tag{5}$$

where: Δh_0 = pressure drop for water without additive content
Reducing pressure drop is due to:

$$\Delta(\Delta h_r) = \Delta h_0 - \Delta h = -C \cdot \Delta n^2 + 2 \cdot C n_0 \cdot \Delta n \tag{6}$$

Equation (6) shows that the function $\Delta(\Delta h_r)$ admits a maximum whose vertex, which is defined by the coordinates:

$$V(n_0, C \cdot n_0^2) \tag{7}$$

From a technical point of view, fire-fighting fittings (fire hoses, etc.), metal pipes, plastic pipes, etc., by their construction, allow a limit on the roughness values resulting from the technological processing

2.2 The influence of roughness on pressure drop

Experimental determinations carried out by Olsen and Eckart [5] have shown that an increase in the radial component of the velocity (due to the additional flow input) leads to a decrease in friction, and thus to a reduction in hydraulic head losses.
In this case, the determinations showed that the coefficient of linear hydraulic resistance is less dependent on the main flow.
The model evaluates the load losses due to friction in the vicinity of the solid walls; the roughness is modeled by means of cavities distributed at different distances through the damped eddies that are generated in the cavities.
The pressure drop is equal to the energy given up by the fluid unit at a reference cross section, i.e.:

$$\Delta h_r = \Delta E_c \cdot \frac{L}{d^*} \cdot \frac{1}{S \cdot \bar{u} \cdot \rho \cdot g} \tag{8}$$

where: L = the analysis distance in the flow direction
d* = the distance between two successive cavities
$\frac{L}{d^*}$ = the number of cavities per unit length
S = the cross-sectional area
ΔE_c = the energy transmitted in unit time, additional to one cavity
By analogy with Darcy's relation, we obtain [10-12]:

$$\lambda = \frac{8 \cdot \Delta E_c}{\pi \cdot \bar{u}^3 \cdot {d^*}^3 \cdot \rho} \tag{9}$$

2.3. Reducing load losses when using polymer additives

The intensity of axial turbulent fluctuations when polymer solutions are used increases compared to the case when water is not additivated, while the intensity of radial fluctuations decreases (in fibers, the phenomenon behaves the other way around) [5].

2.3.1. Mechanisms/theories to reduce pressure drop

There is controversy in the scientific world regarding the parameters that determine the onset of the charge loss reduction phenomenon (length scale or time scale) [5,6].
Such scales that characterize the macromolecule, are for length: the average radius of gyration of the macromolecule determined by the free compound chain model or the radius of gyration RG and for time, the relaxation time of the macromolecule.
Often solutions that have undergone mechanical degradation result in reduced flow friction, which is much smaller in larger diameter pipes than in smaller diameter pipes. This is most likely due to the fact that in larger diameter pipes the tangential wall stress is below the value required for most macromolecules to degrade.
Since both length and time scales are reduced by degradation, degradation experiments cannot distinguish between the two scales. There are theoretical motivations that argue in favor of the ratio of the time scales as the determining factor and none in favor of the length scale.
Microscale determinations confirm the change of the length scale in turbulent flow, with the entire energy spectrum being shifted to lower frequencies. Following the action of the centrifugal force in the vortex, macromolecules expand and can reach almost open conformations taking the shape and size of small vortices. Their size is determined by the velocity profile.
Related to the above, some theories consider additive interaction with small vortices. Indications of the smallest possible size of eddies in turbulent flow can be obtained for example, using Kolmogorov [1,6] length and time microsamples, with the following relations:
- length microsamples:

$$l = (\nu^3/u_d)^{1/4} \tag{10}$$

- time microsamples:

$$t = (\nu/u_d)^{1/2} \tag{11}$$

where: u_d = the energy dissipation rate per unit mass
ν = kinematic viscosity
The lowest vortices, in the high energy end of the spectrum, occur in turbulent flow near the wall, outside the viscous substrate, for which the tangential effort τ can be assumed to be approximately equal to the tangential effort at the wall τ_p. If $\bar{u}$ is the mean axial velocity, ρ – the density, d – the diameter of the pipe, the equation for the microscale of length [6] is:

$$l = \left(\frac{\nu^3 \cdot d}{2 \cdot \bar{u}^3 \cdot \lambda}\right)^{1/4} \tag{12}$$

which can be rewrite as:

$$l/d = 0.84 \cdot Re^{-3/4} \cdot \lambda^{-1/4} \tag{13}$$

The time scale corresponding to small eddies is given by the relation:

$$t = (\nu \cdot d/2 \cdot \bar{u}^3 \cdot \lambda)^{1/2} \tag{14}$$

which can be also rewrite:

$$t \cdot \bar{u}/d = 0.72 \cdot Re^{-1/2} \cdot \lambda^{-1/2} \tag{15}$$

Large vortices lose energy at the base of the viscous substrate and gain energy from the mean motion by stretching the vortices. Large vortices are not permanent formations; they are randomly generated, grow by extracting energy, reach a maximum, and gradually disappear to appear in another area.

The particle length of fibrous materials, which generate reductions in pressure drop, is much larger than the length scale of the energy dissipative vortices, so these particles will affect larger vortices that are farther away from the wall [6].

If the direct interaction between macromolecules and vortices is not possible, it has been suggested that the reduction in the linear hydraulic flow resistance coefficient is due to energy transfer from the vortices to the polymer molecules [6].

The correct determination of the relaxation time required for the macromolecule to regain its original shape and dimensions can be made using the theories of Rouse and Zimm [6].

In the region of charge loss reduction, the relaxation time of the polymer macromolecules is equal to or greater than the time scales of the smallest vortices. When the relaxation time of the macromolecules is larger than the time scales of the vortices, the macromolecules are likely to deform and thus absorb or dissipate energy from the smaller vortices.

Other theories consider that energy, cascading from the large to the small vortices, is partially transmitted to the polymer molecules towards the high-frequency end of the spectrum, which may lead to the alteration of the entire energy balance in turbulent flow [6].

There are theories that explain the mechanism of reduced charge loss reduction by the fact that polymer molecules can store strain energy and then release it to another region, thereby altering the energy balance [6].

Experimental evidence, based on flow visualization studies, has shown that in polymer solutions the structure of the near-wall layer is different and that the turbulence generation process is modified in the direction of decreasing turbulence intensity [5,6].

In turbulent flow, given the large variety of eddies with different energies, one can practically speak of a continuous distribution of eddies or an energy spectrum to which a frequency spectrum corresponds.

Determinations for turbulence emphasize that the reduction in pressure drop is not associated with an overall reduction in turbulence intensity [5,6].

Most of the results emphasize the attenuation of very small eddies at the high-frequency end of the energy spectrum, resulting in a shift of the entire energy spectrum to lower frequency domains, which shows that additives are more effective at suppressing small eddies [5,6].

2.4. Reducing firefighting pressure drop

Such situations can be identified in the use of fire hoses, water pipes for internal/external fire hydrant systems, the use of fire engines, etc.

2.4.1. Assessment and control of local head losses when increasing sudden increase in pipe cross-section

Consider the transition from a pipe of diameter d_1 to a pipe of diameter d_2 ($d_1<d_2$). It is assumed that the fluid motion is permanent, the upstream/downstream system is at the same level ($z_1 = z_2$) with respect to a given reference system, and the motion is turbulent [7,8].

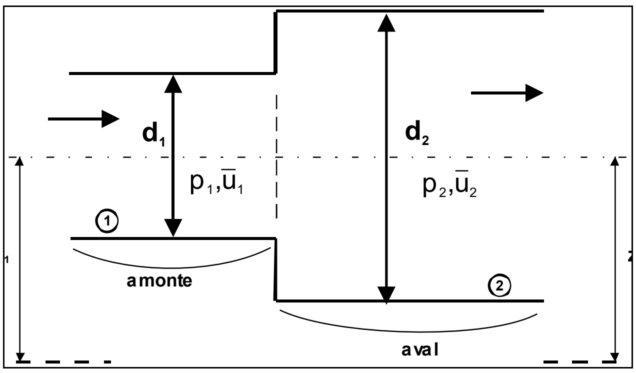

Fig. 1. Longitudinal section (upstream/downstream) in a pipeline section

With a sudden increase in cross-section, the local load loss coefficient (chapter 3) is:

$$\xi \cong (1 - S_1/S_2)^2 \tag{16}$$

The pressure drop between points (1) and (2) admits the maximum value:

$$\Delta p_{max} \cong 148.13 \cdot \bar{u}_1^2 \qquad (17)$$

where:

$$d_1 = 0.67 \cdot d_2 \qquad (18)$$

The relation shows that when switching from pipe diameter d_1 to pipe diameter d_2, ($d_1<d_2$) the pressure drop between points (1) and (2) is maximized; the method is also applicable with good approximation to the use of fire hoses [13,14].

$$(\Delta h_r)_{max} \cong 0.01 \cdot \bar{u}_1^2 \qquad (19)$$

2.4.2. Assessment and control of suction pressure drop from artificial/natural water sources

The suction height h_a expressed in m, for the supply of fire-fighting appliances from artificial/natural water sources (chapter 4) shall be [15-17]:

$$\Delta h_r \cong 10{,}33 - \left(\frac{p_a}{\gamma} + \frac{z}{900} + 1.21 \cdot \frac{\bar{u}_a}{2g} + h_a\right) \qquad (20)$$

where: p_a = the pressure at pump inlet;
γ = specific gravity of water;
z = altitude;
$\bar{u}_a$ = average velocity at pump inlet.
Δh_r = total value of head losses (linear and local)

From a technical point of view, h_a is limited and admits the maximum value 7.50m [18,19]. The decrease and control of total head loss Δh_r is achieved by:
- reducing linear head losses by using hose runs with the shortest possible lengths;
- reducing local load losses by using as few elbows, fittings, etc. as possible.

3. Sudden increase in cross-section of a circular pipe

3.1. Pressure drop assessment

The requirement of the problem is to determine for which ratio d_1/d_2 a minimum pressure drop is obtained when the cross-section of a circular pipe increases abruptly. For this purpose, consider the transition from section S_1 to section S_2 ($d_1<d_2$), under the assumptions:
- the movement of the quantity of water is considered to be permanent ($d\bar{u}/dt = const$) – the reporting is done in terms of the average velocity;
- the system characterized by the sections ($S_1< S_2$) is located at the same elevation $z_1 = z_2$, relative to a given reference system;
- the motion is considered to be turbulent Re >> 2300, for which the Coriolis coefficient $\alpha_1=\alpha_2=1{,}21$;
- neglects the influence of pipe roughness.

The continuity equation, applied to points (1) and (2), gives:

$$Q_1 = Q_2 \Leftrightarrow \bar{u}_2 = \bar{u}_1 \cdot \left(\frac{d_1}{d_2}\right)^2 \qquad (21)$$

Bernoulli's theorem written for (1) and (2) is:

$$\frac{p_1}{\gamma} + \alpha_1 \cdot \frac{\bar{u}_1^2}{2g} = \frac{p_2}{\gamma} + \alpha_2 \cdot \frac{\bar{u}_2^2}{2g} + \Delta h_r \qquad (22)$$

and

$$\Delta h_r = \xi \cdot \frac{\bar{u}_1^2}{2g} \qquad (23)$$

is the load loss for the sudden increase in section from S_1 to S_2, where:

$$\xi = \left(1 - \frac{S_1}{S_2}\right)^2 = \left[1 - \left(\frac{d_1}{d_2}\right)^2\right]^2 \qquad (24)$$

so that

$$\Delta h_r = \left[1 - \left(\frac{d_1^2}{d_2^2}\right)\right]^2 \cdot \frac{\overline{u}_1^2}{2g} \quad (25)$$

In these circumstances, we have:

$$\frac{p_1}{\gamma} + \alpha_1 \cdot \frac{\overline{u}_1^2}{2g} = \frac{p_2}{\gamma} + \alpha_2 \cdot \frac{\overline{u}_1^2}{2g}\left(\frac{d_1}{d_2}\right)^4 + \left[1 - \left(\frac{d_1}{d_2}\right)^2\right]^2 \cdot \frac{\overline{u}_1^2}{2g} \quad (26)$$

For simplicity, denote $0<(d_1/d_2)^2=x<1$ and the result is:

$$\frac{p_1}{\gamma} + \alpha_1 \cdot \frac{\overline{u}_1^2}{2g} = \frac{p_2}{\gamma} + \alpha_2 \cdot \frac{\overline{u}_1^2}{2g} x^2 + (1-x)^2 \cdot \frac{\overline{u}_1^2}{2g} \quad (27)$$

from where

$$\frac{\Delta p}{\gamma} = \frac{p_2 - p_1}{\gamma} = (-2.21 \cdot x^2 + 2 \cdot x + 0.21) \cdot \frac{\overline{u}_1^2}{g} \quad (28)$$

The first derivative is:

$$\frac{d}{dx}\left(\frac{\Delta p}{\gamma}\right) = (-4.42x + 2)\frac{\overline{u}_1^2}{2g} \quad (29)$$

which equalled to zero gives the value x=0,45 from which it follows that $d_1=0{,}67d_2$.
To determine the nature of the extreme, calculate:

$$\frac{d^2}{dx^2}\left(\frac{\Delta p}{\gamma}\right) = -\frac{2{,}21\overline{u}_1^2}{g} < 0 \quad (30)$$

where the extremum is a maximum.
In conclusion, pressure drop is optimal and admits expression:

$$\left(\frac{\Delta p}{\gamma}\right)_{max} = (\Delta h_r)_{max} = 0.302 \cdot \frac{\overline{u}_1^2}{2g} \quad (31)$$

4. Suction from natural/artificial water sources

4.1. Atmospheric pressure variation with altitude

For altitude values z≤10.500 m, the temperature decreases close to the function:

$$T(z) = T_0 - c_1 \cdot z \quad (32)$$

where: $z_0 = 0$;
$T_0 = 288$ K;
$C_1 = 0{,}0065^oC/m$, for Earth's atmosphere.
The state of perfect gases equation is:

$$p \cdot V = \nu \cdot R \cdot T = \frac{m}{\mu} \cdot R \cdot T \quad (33)$$

where:

$$\frac{p}{\rho} = \frac{R \cdot T}{\mu} = \frac{R}{\mu} \cdot (T_0 - c_1 \cdot z) \quad (34)$$

or

$$\rho = \frac{p}{\mu} \cdot \frac{1}{T_0 - c_1 \cdot z} \quad (35)$$

For the terrestrial gravity field, where $U=g \cdot z+c_2$, c_2 is a constant and the mass forces is derived from a force function U [20]:

$$dU + \frac{dp}{\rho} = 0 \quad (36)$$

or

$$g \cdot dz + \frac{\mu}{p} \cdot (T_0 - c_1 \cdot z) \cdot dp = 0 \quad (37)$$

Separating the variables and integrating, we obtain:

$$-\frac{g}{c_1}\cdot\ln(T_0 - c_1\cdot z) + \mu\cdot\ln p = const \quad (38)$$

and if you put the condition p=p_0 for z=0, then:

$$\frac{p}{p_0} = 1 - \left(\frac{c_1\cdot z}{T_0}\right)^{g/c_1\cdot\mu} \quad (39)$$

Expanding the right-hand side of the relation (39) serially and neglecting all but the first two terms, we obtain:

$$p = p_0\cdot\left(1 - \frac{g\cdot z}{\mu\cdot T_0}\right) \quad (40)$$

which will be [20]:

$$\frac{p}{\gamma} \cong 10.33 - \frac{z}{900} \quad (41)$$

4.2. Suction from natural/artificial water sources

The suction height denoted by h_a, where (P) is taken generically as the p.s.i. centrifugal pump, for specified working conditions, is as follows.

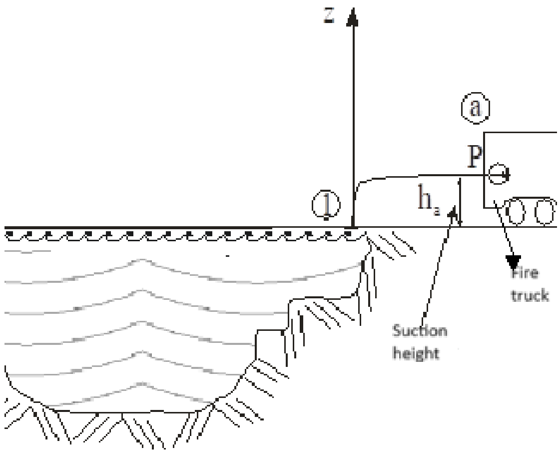

Fig. 2. Suction in the case of a p.s.i. fire truck

Applying Bernoulli's theorem between points (1) and (a), we have:

$$\frac{p_i}{\gamma} + \alpha_i\cdot\frac{\bar{u}_1^2}{2g} + z_i = const, i \in \{1, a\} \quad (42)$$

or

$$\frac{p_1}{\rho g} + \alpha_i\cdot\frac{\bar{u}_1^2}{2g} + z_1 = \frac{p_a}{\rho g} + \alpha_2\cdot\frac{\bar{u}_a^2}{2g} + z_a + \Delta h_r \quad (43)$$

if: z_a-z_1=h_a, $\bar{u}_a$>>$\bar{u}_1$, $\bar{u}_1$=0, p_1=p_{atm}, α_1=α_2=1,21, then [21]:

$$h_a = \frac{p_{atm}}{\rho g} - \frac{p_a}{\rho g} - \alpha_2\cdot\frac{\bar{u}_a^2}{2g} - \Delta h_r \quad (44)$$

or

$$h_a = \frac{p_{atm} - p_a}{\gamma} - 1.21\cdot\frac{\bar{u}_a^2}{2g} - \Delta h_r \quad (45)$$

It is technically necessary and sufficient that:

$$h_a \le \frac{p_{atm} - p_a}{\gamma} - 1.21\cdot\frac{\bar{u}_a^2}{2g} - \Delta h_r \quad (46)$$

where: Δh_r= total suction path pressure drop [m]
Substituting the relation:

$$\frac{p_{atm}}{\gamma} \cong 10.33 - \frac{z}{900} \quad (47)$$

in relation (45), we have:

$$h_a \cong 10{,}33 - \left(\frac{p_a}{\gamma} + \frac{z}{900} + 1{,}21 \cdot \frac{\bar{u}_a^2}{2g} + \Delta h_r\right) \quad (48)$$

in which: p_a= suction pressure at pump inlet [N/m^2];
γ= specific weight of water [kg/m^{2}s^2];
z= altitude [m];
ūa= average suction velocity at pump inlet [m/s];
Δhr= total amount of pressure drop [m].
Linear pressure losses are defined by:

$$\Delta h_{lin} = \lambda \cdot \frac{1}{d} \cdot \frac{\bar{u}_a^2}{2g} \quad (49)$$

and local pressure losses are defined by:

$$\Delta h_{loc} = (\xi_1 + \xi_2 + \xi_3 + \xi_4) \cdot \frac{\bar{u}_a^2}{2g} = \sum_{i=1}^{4} \xi_i \cdot \frac{\bar{u}_a^2}{2g} \quad (50)$$

where: λ= coefficient of linear hydraulic resistance;
l= suction path length [m];
d= diameter of the suction path [m];
$\bar{u}_a$= average suction water velocity [m/s];
ξ_1= coefficient of local pressure drop for sorb;
ξ_2= coefficient of local pressure drop in elbows;
ξ_3= coefficient of local pressure drop for connections;
ξ_4= coefficient of local pressure drop at pump inlet.

5. Dependence of h_a on specified parameters

5.1. Variation-h_a versus altitude-z

This variation depends on:
- the higher the value of this parameter, the lower the height h_a from which the suction is to be performed.

5.2. Variation-h_a versus suction pressure-p_a

This variation depends on [22]:
- the suction head is dependent on the atmospheric pressure; at the vacuum operation, the pa pressure becomes a suction (absorption) pressure for a period of time that the transition to the discharge regime for the truck is made, in the sense that the valves for the discharge can be gradually opened;
- in the case of vacuum, the suction pressure must be much higher than the water vaporization pressure (p_a>>p_v), since the practical suction head is negative for temperatures between 72ºC and 100ºC; in such cases, the pump truck must be placed at a lower level than the water source (flooded system); otherwise, cavitation is generated, which adversely affects the suction process and hence the pump efficiency.

5.3. Variation-h_a versus pressure drop-Δh_r

This variation depends on:
- the pressure losses consist of linear pressure losses (51) and local pressure losses (52):

$$\Delta p_{lin} = \rho \cdot g \cdot \Delta h_{lin} = \lambda \cdot \frac{l}{d} \cdot \frac{\bar{u}_a^2}{2} \cdot \rho \quad (51)$$

$$\Delta p_{loc} = \rho \cdot g \cdot \Delta h_{loc} = \rho \cdot g \cdot \sum_{i=1}^{4} \xi_i \cdot \frac{\bar{u}_a^2}{2 \cdot g} \quad (52)$$

- the total value of the pressure losses is [6]:

$$\Delta h_r = \Delta h_{lin} + \Delta h_{loc} = \left(\lambda \cdot \frac{l}{d} + \sum_{i=1}^{4} \xi_i\right) \cdot \frac{\bar{u}_a^2}{2 \cdot g} = \lambda^* \cdot \frac{l}{d} \cdot \frac{\bar{u}_a^2}{2 \cdot g} \quad (53)$$

The suction head h_a may also decrease due to head losses; therefore, it is necessary to reduce them by:
- using hoses of the shortest possible length between the water source and the longitudinal axis of the centrifugal pump;
- reducing local pressure losses by reducing the number of bends, tight coupling of connections, etc.

5.4. Variation-h_a versus suction speed-$\bar{u}_a$

This variation depends on:
- centrifugal pumps [23]

$$\bar{u}_a = (0.07 \dots 0.1) \cdot Q^{1/3} \cdot n^{2/3} \quad (54)$$

where: Q= aspirated flow [m^3/s];
n= centrifugal pump speed [rot/s].
which means:

$$\frac{\bar{u}^2}{2 \cdot g} \cong Q^{2/3} \cdot n^{4/3} \quad (55)$$

- h_a decreases with decreasing speed $\bar{u}_a$.
In these circumstances, the relationship (48) will be:

$$h_a = 10.33 - \left(\frac{p_a}{\gamma} + \frac{z}{900} + 1.21 \cdot Q^{2/3} \cdot n^{4/3} + \lambda^* \cdot \frac{l}{d} \cdot \frac{\bar{u}_a^2}{2 \cdot g}\right) \quad (56)$$

6. Conclusions

The use of polymer additives in firefighting water systems markedly decreases hydraulic head losses. By modifying turbulent flow characteristics and reducing velocity pulsations, these additives lower both the frictional resistance and pressure drops in the system. The reduction in small, high-frequency turbulent eddies, as influenced by the polymer solutions, leads to a more efficient water transport mechanism. This finding highlights the practical benefits of incorporating polymer additives for enhancing the performance and efficiency of firefighting operations.
Effective firefighting system design must address both pipe roughness and suction conditions to minimize pressure losses. Lowering pipe roughness and employing polymer additives can reduce linear and local resistance, while careful management of pipe diameter transitions and suction height further optimizes system efficiency. Ensuring minimal pressure drops through strategic design and material selection is essential for improving the overall functionality and reliability of firefighting systems in emergency scenarios.

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River Stream Order and Tree Branches or Roots: An Analogy Related to Water Retention Capacities

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Abstract: *Order concept for hydrological basin is presented and a comparison is made with shapes presented by both the branches and roots of trees and plant species, indicating that said order can be seen as an indicator of intersection or water retention capacities, level of water stress and species adaptation to climate change.*

Keywords: *Rainwater interception, water harvesting, tree hydrology, adaptation to climate change*

1. Introduction

The concept of river flow order can be effectively analogized to the branching patterns of tree limbs or roots, highlighting their similarities in water retention capacities. Both systems demonstrate how hierarchical structures contribute to their overall functionality and efficiency.

The order of a river's stream is determined by its position within the basin's drainage network. Smaller streams (first-order) combine to form larger streams (second-order), which in turn merge to create even larger streams (third-order), and so on. The complexity of the river system's order affects its ability to manage and retain water, influencing flood control, groundwater recharge, and ecosystem support.

Similar to river flow order, tree branches and roots exhibit a hierarchical structure. Primary branches and roots give rise to secondary and tertiary branches and roots, creating a complex network. Branching hierarchy plays a crucial role in the tree's water absorption and retention capabilities. Leaves and smaller branches intercept rainfall, while roots absorb and distribute water throughout the tree, maintaining overall hydration and health.

The main river channel can be compared to a tree's trunk, serving as the primary conduit for water flow and support. Smaller streams (tributaries) are analogous to secondary branches and roots, distributing water and nutrients throughout the system moreover, floodplains and wetlands in a river system are akin to the soil and root zones around a tree, acting as storage areas that help maintain water balance and prevent overflow or drought stress. By understanding this analogy, we can gain insights into how both natural systems optimize water management through their hierarchical structures. This knowledge can inform strategies for urban planning, forestry, and conservation, enhancing the resilience and sustainability of our environments.

Trees play a crucial role in water conservation, acting as natural sponges that capture and store water in their vegetation and root structure. This process helps minimize runoff and increase water infiltration into the soil. Trees intercept rainwater on their leaves and branches, reducing the speed and volume of water reaching the ground, which prevents soil erosion, improves water retention, and facilitates the recharge of underground aquifers. Through transpiration, trees release water into the air, contributing to cloud formation and precipitation. Tree roots act as filters, absorbing pollutants and preventing them from contaminating water sources. Trees like willow, ash, and poplar are especially effective at conserving water due to their ability to thrive in wet areas and their deep root systems that help filter and clean water [1].

Studies have shown that tree canopies can intercept up to 30% of precipitation, with canopy flow (through leaves and branches) being greater than stem flow (through the trunk) [2]. Trees absorb water and nutrients from their roots, and through evapotranspiration, they generate upward thrusts of water, distributing it against gravity to higher areas [3]. Research by Huber and Ramírez (1978) [4] proposed a method to estimate water consumption through transpiration, finding that transpiration rates vary with air temperature.

The concept of order can also be applied to tree roots. The variation in root order over time can indicate a tree's adaptation to climate change, as some species modify their root networks to cope with water stress, which occurs when water demand exceeds supply or when water quality is too low for use [5-8]. David et al. (2016) [5] compiled studies and found that Mediterranean trees have developed structural and physiological attributes to cope with drought. These adaptations aim to maintain a favorable balance between water lost through leaves and water absorbed by roots. Adaptations include:

- Regulating stomatal and hydraulic conductivity.
- Adjusting the photosynthetic and nitrogen capacity of leaves.
- Reducing leaf size and/or increasing leaf thickness.
- Limiting the leaf area index.
- Establishing a canopy with low tree density.
- Maximizing water absorption by exploiting deep water sources.

These strategies enable Mediterranean trees to thrive in arid conditions by efficiently managing water resources. Recent advancements have improved the mapping of tree roots using minimally invasive procedures. For example, More and Ryder (2017) [9] found that at 200 mm depth, the vertical location of tree roots in Australia was more accurately depicted by Ground Penetration Radar (GPR) scans than the horizontal location, with two out of three scans showing accurate root locations. Urban trees are often studied for their role in sustainable cities, providing environmental services like oxygen generation and water retention to reduce urban flooding, despite facing challenges like pollution, water stress, and drought [10-11].

2. Methodology

2.1 Order applied to rivers and trees

River stream order a is determined by its hierarchical position within a river basin. In exoreic basins, stream order provides insights into drainage capacity and river system flow dynamics. The method for determining stream order is as follows [12].

Order 1: The smallest streams with no tributaries.

Order 2: Formed by two first-order streams confluence.

Order 3: Formed by two second-order streams confluence of, and so on.

For example, in Figure 1, order 4 basin is shown, illustrating a more complex and interconnected system as order increases.

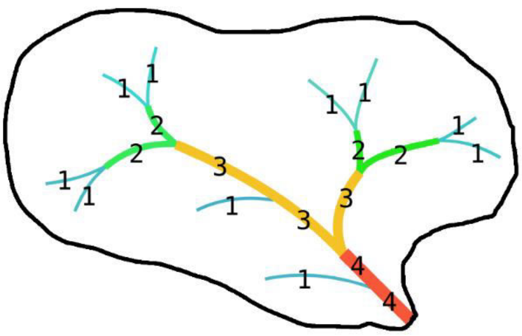

Fig. 1. Order 4 basin (Source: own design)

An analogy was made between order concept in a basin and branches or roots order for tree or bush, seeking to find correlations between this order and factors such as rainfall interception, evapotranspiration, and he adaptive certain species capacity to climate change or water stress in urban areas. This methodology aims to understand how the hierarchical natural systems structure can influence their functionality and resilience.

3. Application and Results

Consider hypothetical tree in Figure 2. By applying the definition of order to the branches of this tree, and assuming all branches have similar bifurcations, we approximate the tree's order to be 4. The complexity of this order increases if the tree is leafy rather than deciduous. This fourth-order can be interpreted as an index of the tree's potential to intercept rainwater. By analysing area of its leaves and branches, we can estimate the canopy flow, which contributes to rainfall interception.

Fig. 2. Hypothetical tree branches Order (Source: Google images © [13])

In Figure 3, tree roots are shown to have a 5 order, considering trunk as output. This higher order indicates a greater adaptive capacity for groundwater capture, suggesting that tree can efficiently manage water resources in its environment.

Fig. 3. Tree roots order (Source: Google images © [13])

4. Conclusions

This study draws an analogy between order concept in a river basin and the branches order or roots in a tree or bush. The correlation between these orders and various ecological functions such as rainfall interception, evapotranspiration, and adaptive capacity to climate change or water stress was explored. Understanding these relationships can provide insights into how natural systems maintain stability and resilience, especially in urban areas where trees face significant environmental challenges.

Trees intercept rainwater on their leaves and branches, reducing the amount and speed of water reaching the ground. This helps to prevent soil erosion, increase soil moisture, and recharge groundwater supplies. The order of the branches can indicate the tree's efficiency in intercepting rainfall.

Trees absorb water through their roots and release it into the atmosphere as vapor by means of evapotranspiration. This helps to regulate temperature and humidity levels, contributing to local climate stability. Higher-order root systems can enhance a tree's ability to access water and sustain evapotranspiration rates during dry periods.

Trees with more complex root and branch structures (higher order) are better equipped to adapt to environmental stressors such as drought and heat. These trees can efficiently manage water uptake and retention, making them more resilient to climate change.

In urban areas, trees face environmental challenges such as limited space for root growth, soil compaction, pollution, and heat stress. Understanding the order of tree branches and roots can help in selecting species and designing urban landscapes that maximize ecological benefits, such as improved water management and climate regulation.

By studying these analogies, urban planners and environmental scientists can develop innovative strategies to enhance the ecological functions of trees in urban environments. This research can lead to more effective urban forestry practices, such as selecting tree species that are better adapted to local conditions and designing green spaces that maximize environmental benefits. For instance, understanding how different tree orders affect water retention and evapotranspiration can inform the placement and maintenance of trees to reduce urban heat islands, manage stormwater runoff, and improve air quality. Moreover, integrating these insights into urban planning can promote biodiversity, create more resilient urban ecosystems, and provide residents with numerous health and well-being benefits. Trees contribute to cleaner air, reduced noise pollution, and cooler temperatures, which can enhance the overall quality of life in cities. Additionally, well-designed urban green spaces can foster social cohesion, provide recreational opportunities, and support mental health.

By leveraging the knowledge gained from these analogies, cities can implement more sustainable development practices, ensuring that urban areas remain liveable and resilient at climate change face and other environmental challenges. This holistic approach to urban forestry and green space management not only improves the immediate urban environment but also contributes to long-term sustainability and resilience, benefiting both current and future generations.

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Sustainable Development Goals - Scenarios Aimed at International Promotion through Pedagogy and Thematic Philately

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Abstract: *The Sustainable Development Goals continue to be in the spotlight and the order of the day, being considered some of the major initiatives regarding environmental protection that have appeared in the last period. Their impact on the life of local communities, as well as in the academic community, is a substantial one, they put pressure on those who make decisions to adopt policies, strategies, and good practices, responsible for the environment and the dynamic development of society. Beyond the various scenarios regarding the long-term sustainability of some measures and solutions, an impressive effort has been and must be made to reduce and prevent pollution of environmental factors and many other similar situations. In this sense, we sought to identify if there are solutions aimed at promoting work scenarios in the case of sustainable development objectives. What we have noticed, are several philatelic effects (postal stamps, FDCs and special envelopes, envelopes, and blocks, illustrated postcards, maxims, etc.) that have appeared in the last 7-10 years, internationally, most of them intended to emphasize and impose the (re)adaptation of scenarios to fight against environmental pollution and (re)define opportunities for community development on sustainable principles. Consequently, it matters not only what we propose to do, but also what each of us can do; or in this case, promoting the problems faced by the environment, and their associated solutions (from the perspective of sustainable development objectives), are a niche that deserves more attention.*

Keywords: *Environmental protection, sustainable development, thematic philately, international promotion*

1. Introduction

The Sustainable Development Goals (SDGs) that emerged under the auspices of the United Nations (UN) continue to be in the limelight and the order of the day. These are still considered to be some of the major and far-reaching initiatives that have appeared in recent times, about environmental protection and the adjacent measures for the viable support of future generations [1]. The impact, but especially their role, in the development of local communities and the academic community, is substantial.

These measures raise the awareness of the general public - investing in children and young people to ensure a more equitable, fair, and sustainable world for all [2] - who have access to information about the state of the environment and, at the same time, put pressure on all the actors who are in the position of making decisions to adopt policies, strategies, and good practices, which from the very beginning and until the end are responsible with the living environment and the current dynamic development of society [3]. It is certain that beyond the various scenarios regarding the sustainability of some long-term measures and solutions (after 1987) [4], an impressive effort has been, is, and still needs to be made to reduce and prevent the pollution of environmental factors [5] and many other similar situations. And, of course, to ensure a minimum standard of living, from a resource perspective, for future generations.

In this sense, we sought to identify if there are solutions aimed at promoting work scenarios in the case of sustainable development objectives. What we have noticed, from a purely philatelic perspective are several philatelic effects (e.g. *postage stamps*, *FDCs*, *special envelopes*, *blocks*, *postcards*, *maxims*) that have appeared in the last 7-10 years, at the international level, most of them being intended to emphasize the (re)adaptation of scenarios to fight against environmental pollution and to (re)define opportunities for community development on sustainable principles.

Being aware that there are numerous and varied solutions proposed to address the theme of sustainable development objectives, we believe that we must align ourselves through the present work also from the perspective of thematic philately, which promises, through the issues recently put into circulation, greater visibility in favor of the considered theme. Thus, we noticed that in recent years, several countries around the world have issued philatelic issues related to the objectives of sustainable development, which were designed not only to draw attention to this topic of general interest but also to promote the idea that our living environment needs help in its fight against the pollution we produce. Under these conditions, we believe that thematic philately also has a well-defined, clear, and rigorous word, in terms of promoting sustainable development objectives and transmitting similar messages with a pronounced applicative character. Consequently, it matters not only what we propose to do, but also what each of us can do; or in this case, promoting the problems faced by the environment through the philatelic invoice fund, and their associated solutions (particularly from the perspective of sustainable development objectives), are a niche that deserves more attention.

2. Materials and methods

The initiative to identify some philatelic materials started from several articles published a short time ago in a specialized blog in the field, namely Jurnalul Philatelic. Although those articles do not expressly present the idea of sustainable development, our approach was to see how this concept penetrated and was subsequently widely promoted. Starting from this and an article with a similar theme [6], to identify the pieces in question, we turned to a series of sites, with philatelic specifics, on the list of which we can find Colnect®, Delcampe®, Okazii®, eBay®, WOPA+®, etc. The indexing, analysis, and description of the identified pieces were made starting from the data provided by Colnect® and Delcampe® or published by the postal administrations.

Following the identification of the philatelic pieces in the topic addressed, due to the large number of results, we applied the following selection criteria, which can equally have a pedagogical effect:

- *thematic relevance*: the philatelic issues themselves should properly address issues related to sustainable development objectives or at least tangentially refer to them, providing information on this aspect of global billing;
- *the quality of the design of the pieces*: the visual appearance of the philatelic issues must be attractive and highlight the visual impact of the sustainable development objectives in the current context of the Information and Knowledge Society;
- *innovation, novelty, and originality of the exhibition*: philatelic shows that bring innovative elements or original approaches to the theme will be considered to highlight both the creativity and the impact of the message conveyed;
- *The educational content of the issued pieces*: philatelic issues should directly provide educational information on the effects of adopting sustainable development objectives at the local communities level, as on potential solutions for their successful implementation;
- *connection with other current events*: if the philatelic issue correlates with current events or with other awareness campaigns regarding environmental protection and the approach of similar action strategies, it can be positively evaluated and taken into account;
- *representation of diversity*: philatelic issues should reflect diversity and convey an eloquent and comprehensive message regarding the need to protect the environment and (re)define the community development context;
- *the effectiveness of the message transmitted*: philatelic issues must clearly and effectively communicate the message regarding the impact of the adoption of sustainable development objectives at the local/regional level;
- *availability of information*: philatelic issues should be accompanied by both additional information and descriptions providing context and details about the issue itself;
- *quality of philatelic material*: the use of quality materials for philatelic issues can be an additional selection factor.

All these criteria contributed decisively to the selection and promotion of the identified philatelic issues, which successfully address the issue of the objectives proposed at a global level for the sustainable development of communities, equally drawing attention not only to scenarios with a possible negative impact on the environment and the community but also on the scenarios emerging on the horizon.

3. Results and discussion

The acceleration of changes on all levels, as well as the impact between technology and the natural environment, calls for a new mentality regarding environmental issues, so an ecological education from the earliest age [7]. This approach is of major importance because the first forms of organization of knowledge by children, of the environment, appear in pre-primary education and continue in the primary classes by reintroducing the subject of Knowledge of the Environment, starting with the 1st grade.
In this sense, through interdisciplinary approaches and recourse to ways of working through projects, to focusing on transversal skills and key skills, to contents that include situations and phenomena from the current context, teachers become more than sources of information; they become facilitators of authentic learning, which students can put into practice in the future [8]. The teacher's role is configured and transformed into that of a partner in the learning process, a process in which students must engage with enough energy to be able to produce the much-desired changes and to develop skills appropriate to the world in which we live.
Themes related to ecology, recycling, and environmental protection (both in general and specific cases), combined with Romanian culture and tradition are very important [9], in the current context of managing non-renewable resources, and not only, that is why it is good to be addressed in educational institutions, in leadership classes or even in optional proposed classes, at the request of the institution and/or the community. Completing them with projects related to the identification of the community's needs and the careful study of the long-term strategy aimed at transformation on sustainable principles [10], along with the approach to sustainability (viability) issues in the curricular and extracurricular activities of educational institutions are only two perspectives worth considering [11]. These can have visible implications in the acquisition of ecological behavior norms specific to ensuring the balance between the health of the individual, society, and the environment, and the formation of a disapproving attitude towards those who violate these norms, respectively the formation of the necessary attitudes for the development of conscious and responsible activities that lead to improving the quality of the environment.
The concept of education for sustainable development (ESD) is essential in the modern world. This involves implementing the values of sustainable development in all facets of our lives, including the education system. Encouraging young people as promoters of sustainable development involves efforts to activate and empower them in economic, social, and environmental issues [12]. Because it is a fundamental concept for the population of general interest, sustainable development should be seen as both a philosophy and a list of measures to be taken by one individual and implemented by another. In other words, sustainable development must become a common state of mind for everyone [13]. In this sense, the World Commission on Environment and Development (WCED) gave the best-known definition of sustainable development in the report "Our Common Future" (1987), also known as the Brundtland Report; this definition says that "sustainable development is the development that seeks to meet the needs of the present without compromising the ability of future generations to meet their own needs". When we talk about sustainable development, we must remember the 17 Sustainable Development Goals (SDGs), which were assumed by our country and the other UN member countries in September 2015. Therefore, the nations of the world have committed the year to eliminate poverty and hunger, combat inequality and injustice, and take active steps to protect the environment by 2030.
At the level of Romania, for the implementation of the European provisions in the matter of sustainable development, the Department for Sustainable Development was established, by Government Decision No. 313/2017. The Department is financed from the state budget through the budget of the General Secretariat of the Government and has the following functions:

- coordinating the implementation activities of the 17 sustainable development objectives;

- planning and integration of the information communicated by the institutions with attributions in the field, for the formulation of proposals for measures to improve the efficiency of the processes developed by the public administration authorities,
- reporting to the Government, on the elaboration or implementation of the set of measures through sustainable development at the national level and coordination of activities;
- monitoring of sustainable development indicators established at the EU and UN levels, as well as specific indicators, adapted to Romania's conditions.

3.1 Sustainable Development Goals, 05/09/2016, Mauritius

From the perspective of thematic philately, under the theme entitled "Together for sustainable development", it appeared on 09.05.2016, at the UN Post Office of Mauritius, multicolored postage stamp (Mi MU#1162, Yt MU#1191 and Sg MU#1277), format 44.5 x 30 mm, with comb lace 13¾, printed by offset lithography (Fig. 1). It bears the value of 27 Mauritius rupees and exhibits under the official seal of the U.N.O. the emblem associated with the Sustainable Development Goals [14].

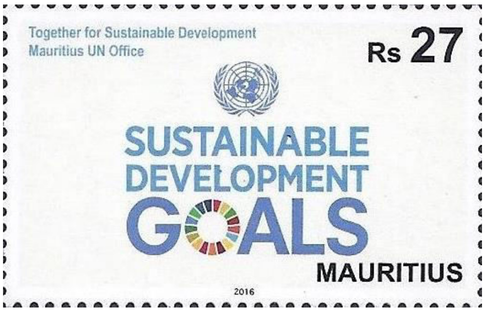

Fig. 1. Postmark of the philatelic issue "Sustainable Development Goals", 09.05.2016, Mauritius [14]

3.2 Sustainable Development Goals, 24.10.2016, U.N.O. Geneva

The 17 laced postage stamps (one for each of the Sustainable Development Goals), with 13¼ comb lace, issued on 24.10.2016 under the auspices of the U.N.O. Geneva included in a multicolored sheet (indexed in catalogs Mi NT-GE#973..989KB, Sn NT-GE#629a-q, Yt NT-GE#961..977, Sg NT-GE#853.. 869, WAD UN#229MS.16..245MS.16, Zum NT-GE#984..1000) with the face value of 17*1 Swiss francs (Fig. 2). Printed by the offset lithography technique, the postage stamps reached post offices and collectors in a print run of 28,000 copies [15].

Fig. 2. The complete sheet (with the 17 postage stamps and the related vignette) for the philatelic issue "Sustainable Development Goals", 24.10.2016, U.N.O. Geneva [15]

Awareness of environmental protection, as well as the significant impact of the 17 sustainable development goals among human communities, have increased in visibility in recent years, leading to sustained efforts to reduce the use of single-use plastics, promote recycling, develop more sustainable energy alternatives, as well as the definition of new strategic partnerships to achieve and adopt an appropriate ecological education. The education itself referred to, but also individual and collective actions are essential to reduce pollution and protect the environment.

3.3 Global Goals for Sustainable Development, 04/12/2017, Papua New Guinea

As part of the "Chairmanship of the Asia Pacific Economic Cooperation (APEC)" series, the four multicolored laced stamps contained in the 105 x 75 mm mini-sheet reproduced in Fig. 3 - top image (Mi PG#2265..68KB, Yt PG#BF227, Sev PG#2148ms) appeared on 12/04/2017 at Papua New Guinea post offices. In addition to these, the booklet (Mi PG#BL203, Yt PG#BF229, Sev PG#2149) saw the light of day in which all 17 sustainable development goals are explicitly highlighted (see Fig. 3, bottom image) [16].

Fig. 3. Mini-sheet (with the 4 postage stamps and no vignette) and sheet for the philatelic issue "Global Sustainable Development Goals", 04.12.2017, Papua New Guinea [16]

3.4 Other philatelic issues representative of the Sustainable Development Goals

Worldwide, there are several materials of a philatelic nature (*postage stamps*, *envelopes on the first day of issue*, *blocks and sheets*, *envelopes*, *illustrated postcards*) that promote the idea of sustainable development, of which we mention only a part, respectively:

a) full multicolored sheet "Adhesion of Tunisia to United Nations, 60th Anniv." (Mi TN#1892-1911KB, Sg TN#1870a, Sn TN#1627, Yt TN#1798-1817, WNS TN#040MS-16) issued on

11/12/2016 at Tunisian Post Offices, with lace comb 13½, printed by offset lithography at the face value of 20*500 Tunisian miles [17];

b) full multicolored sheet "Solidarity Stamp 2019. Agenda 2030" (Mi ES#5384KB, Ed ES#PP81) appeared on 25.09.2019 at the Post Offices of Spain, with comb lace 13½ x 13, later printed at the Fábrica Nacional de Moneda y Stamps-Real Casa de la Moneda (RCM-FNMT) by offset lithography at the nominal value of 8*1.40 Euro [18];

c) multicolored postage stamp "75th Anniversary of the United Nations" (Mi MC#3509, Sg MC#3399, Sn MC#3025a, Un MC #3270, Yt MC#3254) appeared on 23.10.2020 at the Post Offices in Monaco, in 30 x 41 mm format, with 13¼ lace, later printed by offset lithography in an edition of 40,000 copies at a nominal value of 1.40 Euro [19];

(a) (b)
(c) (d) (e)
(f) (g)

Fig. 4. Various philatelic materials representative of the "Global Sustainable Development Goals", for the reference period 25.09.2019 - 30.05.2022 0-[22]

d) A multicolored postage stamp from the series "International Year Basic Science for Sustainable Development" (Mi PT#AT134, Yt PT#D249), appeared under the imprint of the designer Hélder Soares at the Post Offices of Portugal on 30.05.2022, in unlaced format 55 x 30 mm, later printed by offset lithography and digital printing at Copidata S.A. [20];
e) multicolored postage stamp (Mi CH 2806, Sn CH#1862, Yt CH#2731, WADP CH#028.22, Zu CH#1918) issued under the imprint of designers Andrea Münch and Markus Läubli, at the Post Offices of Switzerland on 05.05.2022, in 28 x 33 mm format, with comb lace 13½ x 13¼, later printed at Cartor Security Printing by offset lithography at face value of 110 Swiss cents [21];
f) multicolored slip from the "Intern. Year of Basic Sciences for Sustainable Development” (TG#2022.09.01-135) issued at the Post Offices of Rep. Central African on 01.09.2022 [22], printed by offset lithography at the face value of 3,300 West African CFA francs.

4. Conclusions, perspectives, and proposals

Environmental pollution in all its forms represents a significant global problem, with a negative impact on the development of human communities at the local and regional levels. This unpleasant situation is mainly generated by socio-economic activities and can be addressed by reducing the use of single-use plastics, more efficient management of the resulting waste, and the involvement of all entities with a decision-making role. Actions to prevent environmental pollution must be taken now to protect the planet and ensure a sustainable future for future generations.
Sustainable development as a concept seeks and tries to find a stable theoretical framework for decision-making in any situation where there is a human-environment relationship, whether it is the environment, the economic environment, or the social environment. Although initially sustainable development wanted to be a solution to the ecological crisis determined by the intensive industrial exploitation of resources and the continuous degradation of the environment and sought, first of all, the preservation of the quality of the environment, nowadays the concept has expanded to the quality of life in its complexity, and from an economic and social point of view. This last aspect also emerges from the promotion carried out at the international level through the prism of materials specific to thematic philately. Thus, the current objective of sustainable development is also given by the concern for justice and equity between states, not only between generations.

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Annex

Fig. 5. Circulated envelope with the postmark "Sustainable Development Goals",09.05.2016, Mauritius 0

Fig. 6. Illustrated postcard stamped "Solidarity Stamp 2019. Agenda 2030", 25.09.2019, Spain 0

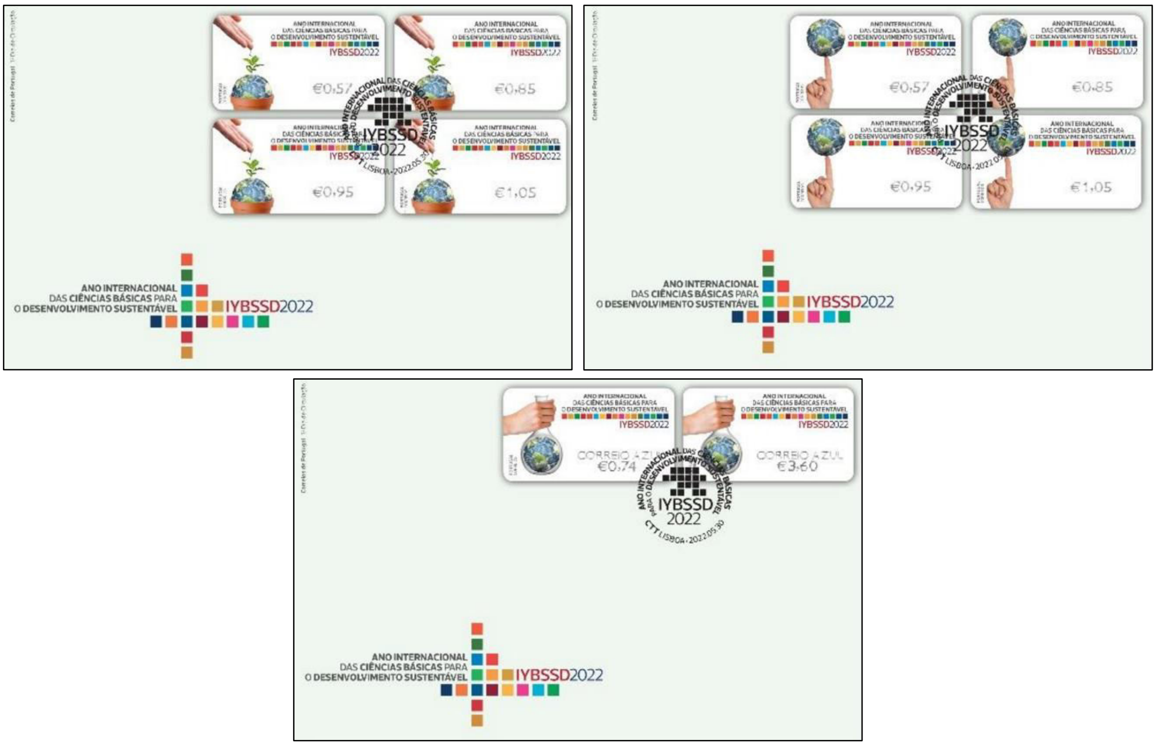

Fig. 7. Postmarked FDCs "Intern. Year Basic Science for Sustainable Development", 30.05.2022, Portugal 0-**Error! Reference source not found.**

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