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Intelligent Hydraulic System for Comparative Functional Testing of Biodegradable Working Fluids

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Abstract: *In the hydraulic field and especially in mobile hydraulics, the effect of oil losses on the environment (soil, water) is profoundly negative. In this context, the use of biodegradable fluids, with low impact on the environment, is one of the research directions lately developed. While some systems are made ever since the design phase so that they work with biodegradable fluids, most of the existing ones have been designed without taking into account this aspect. However, in the case of systems of previous generations, it is possible to use biodegradable oils as a working fluid following research on the compatibility of components with the fluid. The article presents a first step in this direction, by creating a stand that tests the effects of operation with biodegradable oil of simple hydraulic systems. The disadvantage of the large time required for testing can be mitigated by creating an intelligent data acquisition and transmission system, which eliminates the need for permanent monitoring by a human operator.*

Keywords: *Intelligent hydraulic systems, biodegradable hydraulic fluids, endurance tests*

1. Introduction

One of the most important components of hydraulic systems is the working fluid; its nature is different depending on the application, but also on the historical period. The most common - mineral oils - began to be used in hydraulic installations in 1920, although they were available since the early 20th century. The working fluids used in hydraulic systems suffer cyclically significant variations in speed, pressure and temperature; in addition, they are in contact with various materials and may be exposed to electromagnetic fields or even nuclear radiation, and so on. Such difficult fluid use conditions impose specific requirements: lubrication capacity, acceptable viscosity under all operating conditions, stable physical and chemical properties, low compressibility, limited foaming tendency, compatibility with materials in the system, etc.

There is currently a wide variety of working fluids that are chemically divided into several classes, but no fluid meets all the characteristics necessary for a given hydraulic transmission. In order to satisfy as many requirements of the hydraulic system as possible, the working fluid is added accordingly. Additives were introduced into mineral oils in the 1940s to improve the chemical and physical properties of hydraulic oils, especially anti-corrosion and anti-flammable ones. Over time, the problem of pollution and environmental degradation has arisen, mainly in agricultural land and the seas and oceans. At the beginning, there appeared the biodegradable lubricants used in the maritime industry since 1985, as an alternative to mineral oil products, which degrade slightly, slowly and inappropriately. Their advantages are rapid biodegradability and environmental protection due to the low eco-toxicity of chemicals entering the soil.

Although it seems an easy solution to a problem, the use of biodegradable oils cannot be recommended as a quasi-general solution; in some applications, a compatibility study with hydraulic systems is required in order to avoid malfunctions caused by improper use. As the tests that are most often performed are endurance tests, it is recommended to make intelligent stands that can operate without being constantly monitored by an operator. The stands for endurance testing of hydraulic fluids are based on the principles of intelligent hydraulics, consisting of pumping groups, pressure distribution and regulation groups, electronic controller, computer block with sensor and appropriate software, data acquisition, transfer and processing system, including the control block. The technological support for transferring and digitizing the entire system is the Internet of Things (IoT). IoT smart devices allow connecting via the Internet with other devices, services and automated systems, thus forming a network of objects. Intelligent hydraulics involves the analysis of processes and, to a certain extent, the making of the necessary decisions [1, 2].

2. Tested fluids and working methodology

As shown above, in some cases a test of the compatibility of biodegradable fluids with the other components of the hydraulic system is required; this applies when the system was not designed to work with such fluids, but it is desirable to replace mineral oils. The compatibility study is done starting with the most important components of the system; the work order would be power generators, distribution and control equipment, and hydraulic motors. The working methodology is a complex one, which verifies both the behavior of the equipment and the working fluids after long-term operation in load.

The fluids tested are the following:

a) ***KAJO-BIO-Hydrauliköl HETG 46***, from LUBRICON (Australia)

It is a hydraulic fluid based on vegetable oils, slightly biodegradable, environmentally friendly. The additives used provide excellent properties related to resistance to oxidation, corrosion, low temperature and extreme pressure. The density is 918 kg/m^3, the kinematic viscosity at 100ºC is 10 cSt.

b) ***Shell Naturelle Fluid HF-E 46***, from Shell Deutschland Oil GmbH

It is a hydraulic fluid with a density of 921 kg/m^3 and the kinematic viscosity at 40ºC is 47.2 cSt.

c) ***Lubrifin H46 EP***, from Total Lubrifin

It is a mineral oil that has been used as a benchmark. It has a density of 871 kg/m^3, and the kinematic viscosity at 40°C is between 41.4 - 50.6 cSt.

The test procedure involves performing commands that simulate the actual operation of a hydraulic system: performing double strokes of a linear hydraulic motor requires the actuation of an electrically operated directional control valve to supply alternately the two chambers of a cylinder. The loads on the two directions of movement were performed (simulated) with two pressure valves. The working frequency of 0.1 Hz was chosen so that the rhythm does not influence the operation and at the same time does not favor the appearance of faults. In this situation, the action of the thin slots in the devices on the working fluids, the diametrical clearances in the devices and the variation of some functional parameters over time will count.

For each of the 3 types of hydraulic oil, a stand was made with a minimal structure, but able to ensure the performance of the tests. The hydraulic devices used are identical in terms of hydraulic design, performance and manufacturer.

The proposed work sequence allows the following tests to be performed:

- Verification of the realization of the functional hydraulic schemes; it consists in checking the fluid flow in the two directions that simulate the chambers of a hydraulic cylinder.
- Dimensional verification of some components of the hydraulic equipment used to make the stands. To this end, the clearances between the spool and the body at the directional valves and the flow losses at 100 bar through the directional valves were checked. The measured data are included in the database.
- Measurement of functional parameters; the pressure drop on the directional valves and the flow variation are measured.
- Checking the purity of the working fluid before the start of the test program and during its running.
- Checking the kinematic viscosity of each working fluid.
- Carrying out an endurance program that adjusts the working pressure to 150 bar, the switching frequency to 0.1 Hz and a number of 600,000 cycles. Tests 1....5 are repeated every

200,000 cycles, following which some comparisons will be made and the necessary conclusions will be drawn.

3. Description of the constructive solution of the stands

3.1 Electro-hydraulic structure of the stands

Figure 1 shows the hydraulic operation diagram of the stands. The three stands are structurally and functionally identical.

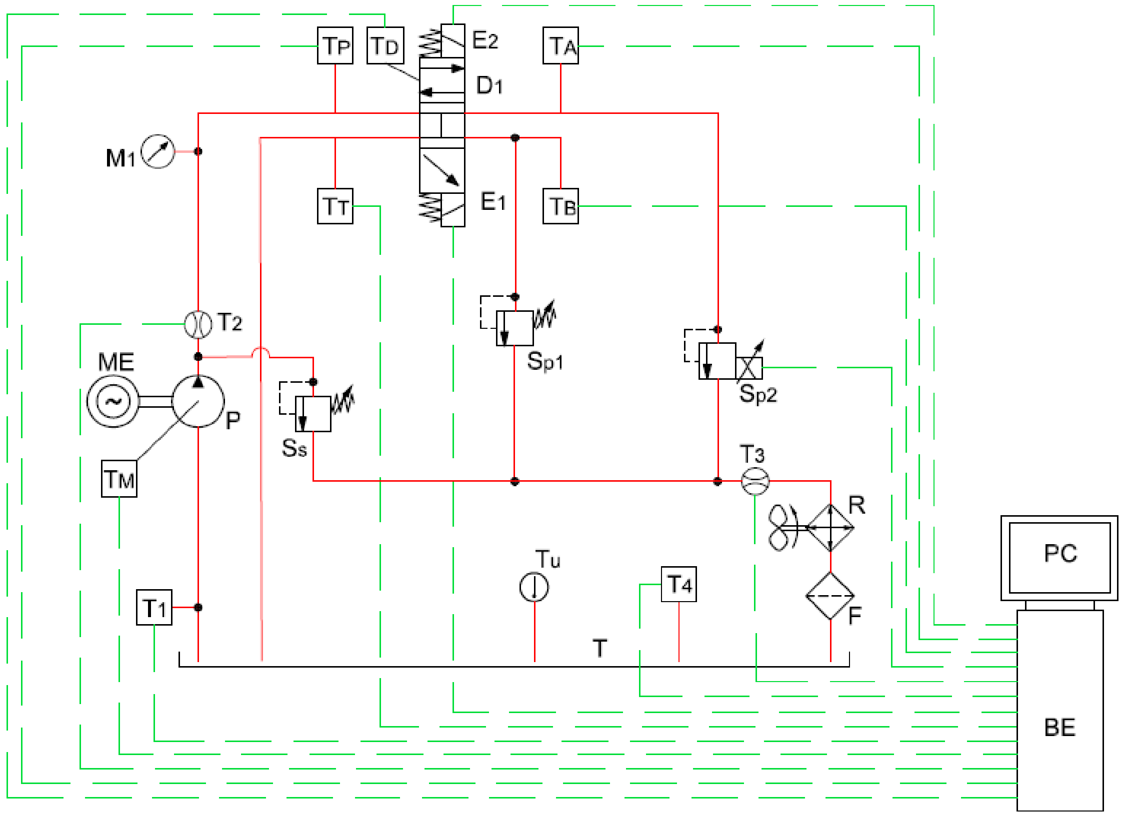

Fig. 1. Functional diagram of a hydraulic test stand

The hydraulic pump symbolized with P is driven by an electric motor ME, supplying the installation with the working fluid. The pump flow is measured with the flow meter T2. The pressure achieved in the system either by the pressure valve with manual adjustment Sp1 or by the electrically controlled proportional pressure valve Sp2, is measured with the pressure transducers TA and TB respectively. The T1 transducer measures the pressure on the suction path. The TD1, T4 and TM transducers monitor the operating temperatures of the pump, tank oil and directional valve D1. The flow difference between transducers T3 and T2 represents the loss of internal flow of directional valve D1. Directional valve selects which branches of the hydraulic circuit are active for the test. All commands and output signals are managed by the electronic block BE, which is directly connected to a PC.

The SS pressure relief valve ensures that the upper critical limit pressure is not exceeded in the hydraulic system. The heat exchanger R, allows the working fluid to cool when it reaches high temperatures, exceeding 60ºC. Filter F retains particles in the working fluid; such particles would increase the wear of the hydraulic equipment.

These identical stands study the changes in properties that occur in different types of working fluids and the degree of wear of hydraulic devices during operation. The electric motor is started from BE, which drives the hydraulic pump. By switching the directional valve to one of its fields, the desired working (test) valve is selected. In the first phase of the tests, the operating frequency was set to 0.1 Hz, which means that every 10 seconds the position of the directional valve spool changes. The working fluid is subjected to various loads created by manually adjustable valves or proportional valves. These loads range from 10 bar to 200 bar [3].

3.2. Computer system of working fluid test stands

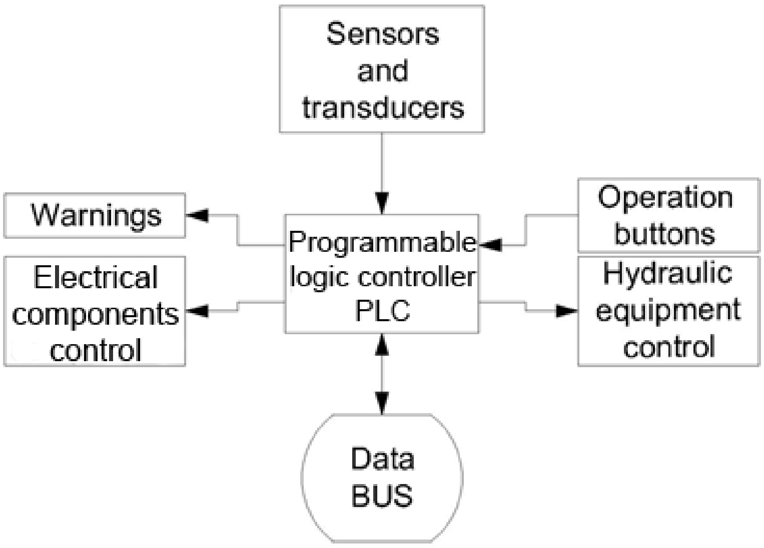

Fig. 2. Hardware structure of the data acquisition and control system of a designed test stand

The data acquisition and control system consists of transducers and sensors, electro-hydraulic converters specific to the control equipment (electromagnetic actuators) of the stand, as well as the operator console containing operation and control buttons and optical and acoustic signals of the system. These components are interfaced with the programmable logic controller PLC by electronic modules for the conversion of analog or digital electrical signals into standard electrical signals; in the case of analog signals, we work in the ranges -10 V… + 10 V, 4… 20 mA, and in the case of digital signals - in relay contacts, as to the input and output signals. The PLC reads/writes these signals and converts them to numeric or Boolean values (true/false). Another signal processing that is performed at the level of the programmable logic controller consists in scaling the numerical values in values corresponding to the measured or commanded physical parameter [4].

In addition, at the PLC level, digital/Boolean signals can be filtered to eliminate noise. Other functions performed by the PLC are to automate the testing process (e.g., starting the electric motor in the star or triangle position, selecting the hydraulic circuits specific to the tests performed, etc.), and also to exchange data with the higher hierarchical system via the data bus (see Figure 3).

The functional block diagram of the computer system for control and monitoring of stands is shown in Figure 3. The PC operating system communicates via the internal data bus (there can be RS485 serial bus or Ethernet) with the programmable logic controllers at each stand, with transducers and execution elements on the test stands. The software running on this PC allows the local operation of the system of test stands, as well as communication via LAN or IoT networks and Internet, with the database server running a DBMS (Data Base Management System) software, which allows storage and accessing of data specific to the tests performed [5, 6].

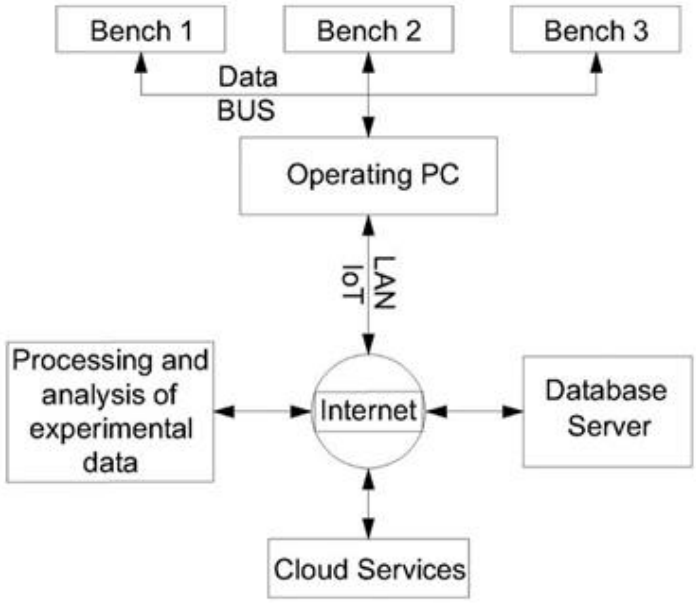

Fig. 3. Hardware structure of the computer system

The processing and analysis of experimental data can be performed on any PC connected to the Internet that has access to the database server, with dedicated software applications.
An alternative to database and experimental data processing may be the acquisition of Cloud Services to implement these features [7].

4. Results and conclusions

The results obtained so far, after performing an (incomplete) number of work cycles, allow the following conclusions to be drawn:

1. Following the first verification it was found that the biodegradable fluids can make the hydraulic scheme of the 2 stands (the third stand has as working fluid the H 46 hydraulic oil), at the test pressures of 5 bar; 50 bar; 100 bar, and 200 bar. No difference was found between the sizes measured simultaneously on the three stands; in other words, so far biodegradable fluids have had behavior and effects similar to those of conventional hydraulic oil in hydraulic systems.
2. The proposed and materialized scheme of the stand was validated by the proper operation of the three hydraulic assemblies.
3. Operation with a frequency of 0.1 Hz (directional valve control at 10 s) did not cause any malfunctions.
4. The degree of contamination of the working fluids is similar in all three cases, at the same time, and it is maintained in the accepted operating parameters; indirectly, it confirms that the use of biodegradable fluids does not cause wear different from that caused by mineral hydraulic oil.
5. The tests will be continued until the proposed number of cycles is reached (600,000); following that, at the end of the testing process a complete presentation of the results will be made.

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