Kinematic and Dynamic Irregularities of Roller Pumps

Part II. Numerical Research, Results and Analysis

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Abstract: *In this work some theoretically found results, concerning typical irregularities of roller pumps, are given. The impact of some main geometric sizes on the character of changing of a given working camera's flow rate, as well as the possibility for using approximate equations for the determination of the coefficient of kinematic flow rate's irregularity, are indicated. The phase characteristics of a roll's rotation, indicating the existing of a transitional and unsteady periodical process, depended by the kinematic characteristics of rotation, have been presented. Graphs, representing the change of the existing forces, acting on the pump's rolls, and adjusted pump's shaft torque, both them limited in the range of one full rotation, have also been given.*

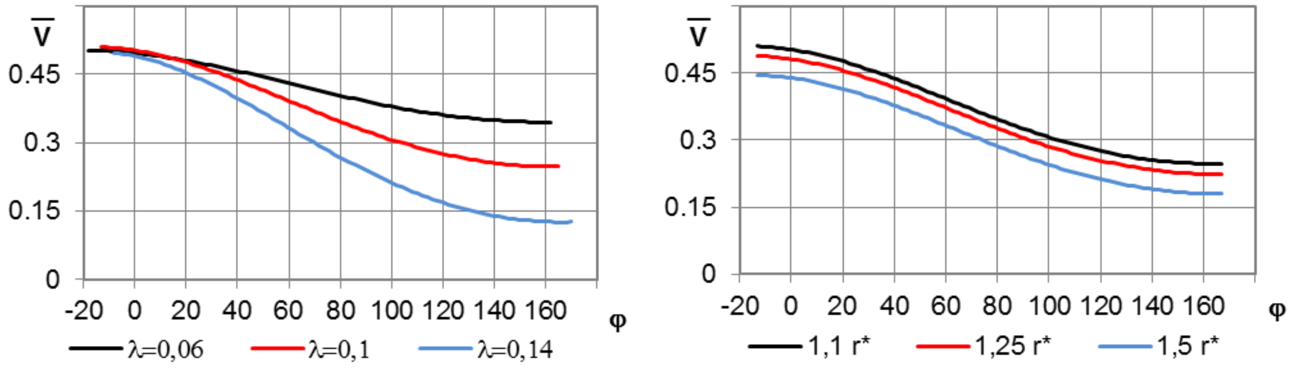
Keywords*: Roller pump, kinematic and dynamic irregularities.*

1. Introduction

In the first part of this work the equations, describing some of the main irregularities of roller pumps: kinematic – determining the flow rate's irregularity; dynamic – determining the loading on the main working elements of these pumps, have been established. These equations ensure the providing of theoretical research, concerning the evaluation and analysis of the work processes of this type of pumps. The main purpose of this work is to use the already established (in the first part) theoretical models and equations, so that numerical research, concerning the determination of the character and parameters of the appeared and periodically existing processes, as well as the change of the occurred irregularities of a roller pump's working characteristics, to be accomplished.

2 Numerical research and results, concerning the kinematic irregularities

In fig. 1 it is given the change of the dimensionless volume of a working camera, for different values of the eccentricity and radiuses of the rolls (with r* the roll's radius is indicated), while it has been connected to the high pressure pump's canal.



a) **b)**

Fig. 1. Change of a working camera's volume as a function of the rotor's angular of rotation

In fig. 1a it can be clearly seen that the character of the volume's changing stays similar for different values of the eccentricity λ and with the increasing of λ the change of the relative volume also start to increase, which can be considered as a result of the increased pump's total working volume. If the roll’s radius is being increased, while the other geometric sizes stay constant, the line $\overline{V} = f(\varphi)$ moves down, which is a result of the decreased pump’s total working volume.

In fig. 2 it can be seen the change of the dimensionless flow rate of a given working camera, while it has been connected to the high pressure zone.

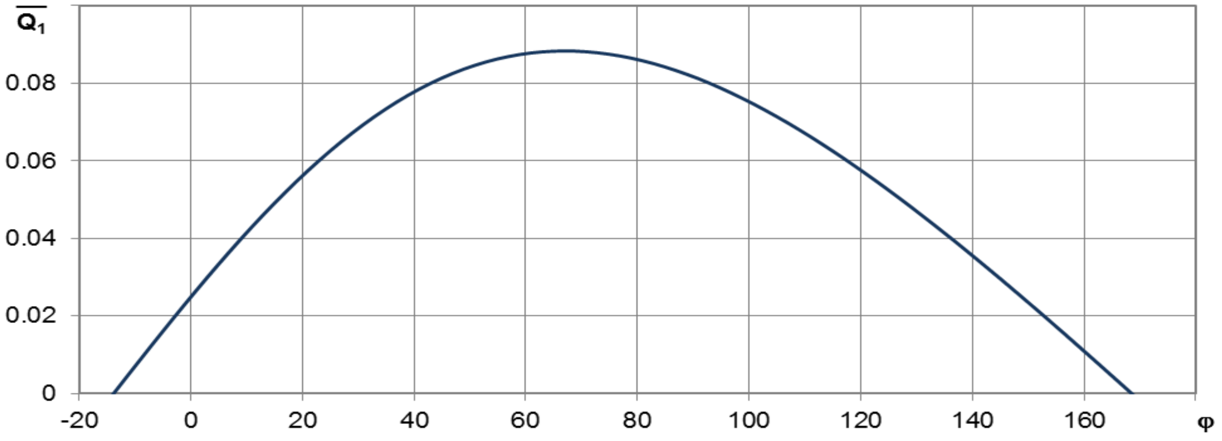
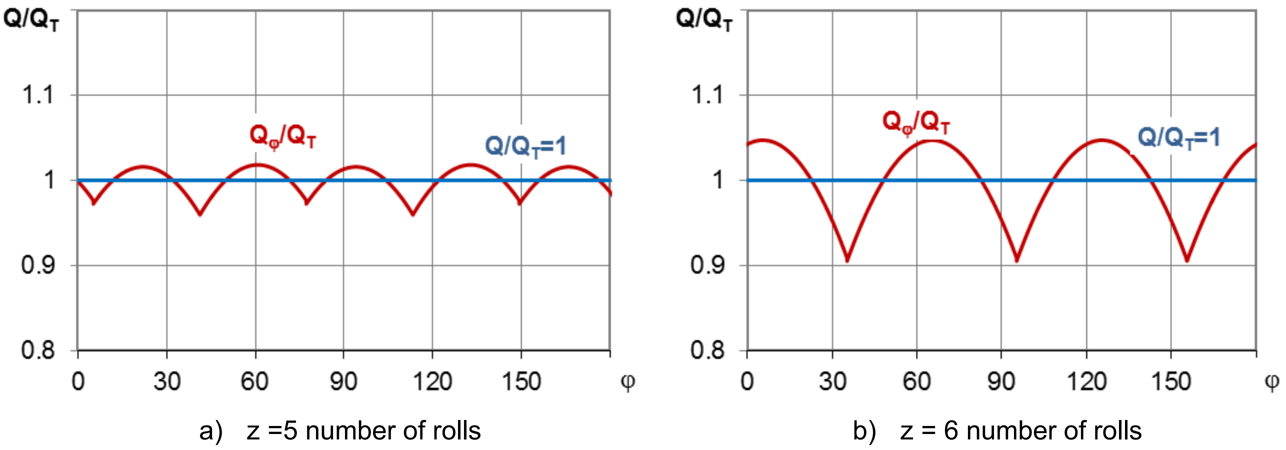


Fig. 2. Change of a given working camera’s flow rate

It can be seen that the flow rate, ensured by a working camera, is characterized by too high irregularity, which has a significant impact on the total flow rate’s kinematic irregularity for the investigated type of roller pumps. The location of the function’s maximum is not exactly in the middle of the high pressure move, and it is dislocated in left. The increasing of the pump’s flow rate to $\overline{Q}_{1,\varphi} = \overline{Q}_{1,\varphi\max}$ becomes more intensive, compared to its decreasing to $\overline{Q}_{1,\varphi} = 0$.

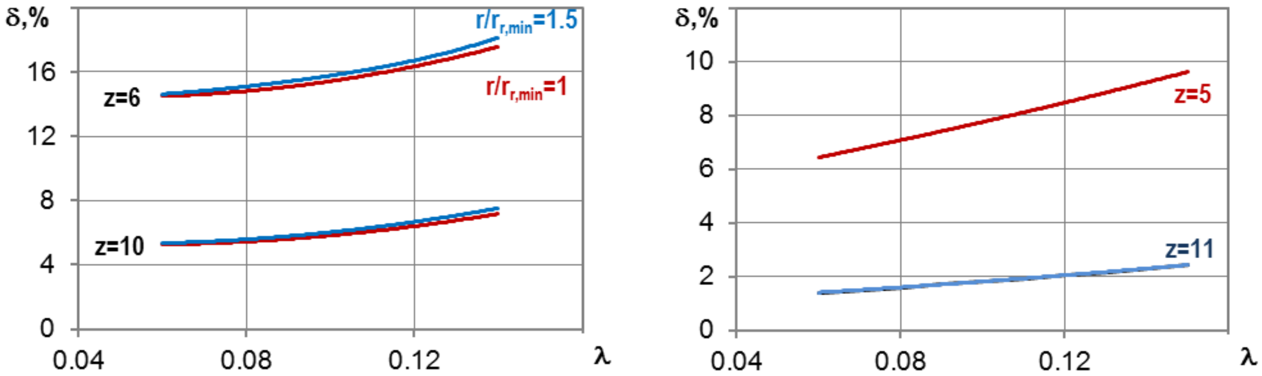
It is interesting for the graph, representing the change of the momentary theoretical flow rate - Q_{φ}, for pumps having different number of rolls, to be seen. A well-known fact is that the number of rolls, being even or odd, has a significant impact on the working process for all the volumetric hydraulic machines with analogical kinematic of their main working elements. The graphs, given in fig. 3, show the change of a pump’s momentary flow rate, when the pump consists of an odd ($z = 5$) or even ($z = 6$) number of rolls. It can be seen, that for the odd number of rolls the difference between the maximal and minimal flow rate has a significantly less value than in case the pump is with an even number of rolls. This is the main reason for the less kinematic irregularity of the theoretical flow rate in case of a pump with an odd, instead of even, number of working cameras.



a) z =5 number of rolls b) z = 6 number of rolls

Fig. 3. Change of the momentary theoretical flow rate of a roller pump with an odd and even number of rolls

As it can be expected, the number of rolls has the most significant impact on the pump flow rate's irregularity. For an even number of the working cameras the coefficient δ of the flow rate's kinematic irregularity has a significantly higher value than in case of an odd number of these cameras. The impact of the main geometric parameters – relative eccentricity and diameter of the rolls, on the coefficient of irregularity is minor. Practically, the roll size doesn't influence the flow rate's irregularity. With the increasing of the pump's relative eccentricity, for a given number of rolls, the kinematic irregularity of the flow rate will also increase. The value of this increase will be limited in a given range, however it will be higher (given as an absolute value) for the pump with less number of rolls. For pumps with more than 10 rolls, when the relative eccentricity is being increased the coefficient of irregularity will also increase, but this increase (given as an absolute value) will be less than 1%.



a) at even number of rolls

b) at odd number of rolls

Fig. 4. Change of the coefficient of irregularity of the theoretical flow rate of roller pumps with an odd and even number of rolls

The evaluation of the kinematic irregularity (in finding a solution of engineering problems) can be accomplished by using approximate equations, ensuring the estimation of δ. For rotary volumetric pumps with similar kinematic of their main working elements (pistons, vanes, etc.), it is recommended that: $\delta \approx \frac{500}{z^2}$ - for pumps with an even number of rolls; $\delta \approx \frac{125}{z^2}$ - for pumps with an odd number of rolls. This can be clearly seen in fig. 5.

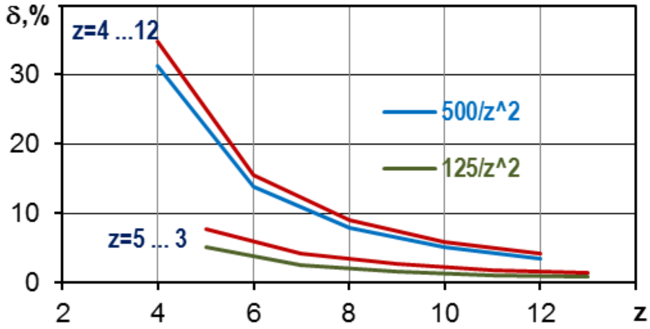


Fig. 5 Comparison between the values of the coefficients of kinematic irregularities, found by using the established precise and approximate equations

3. Numerical research and results found for the investigated dynamic processes

This part of the work consists of results, found for given concrete problems and having different level of coherence between each other, but both are based on the established in the first part equations - (16)÷(21). For finding a solution of these problems the required algorithms, programs and numerical procedures, used to accomplish the simulation and to investigate the existing processes, have been developed in Matlab. The accomplished numerical experiments represent the next stage of progress to the research given in [2], where the investigated roller pump has the following parameters: $z = 6$, $\Delta p = 0.4\ \mathrm{MPa}$, $k = 0.01\, r_r\ \mathrm{Nms/rad}$, $g = 9.81\ \mathrm{m/s^2}$, $m = 0.02\ \mathrm{kg}$, $R = 0.045\ \mathrm{m}$, $r = 0.0415\ \mathrm{m}$, $r_r = 0.009\ \mathrm{m}$, $b = 0.0381\ \mathrm{m}$, $e = 0.003\ \mathrm{m}$, $\omega = 500\pi\ \mathrm{rad/s}$, $\mu_1 = \mu_2 = 0.02$.

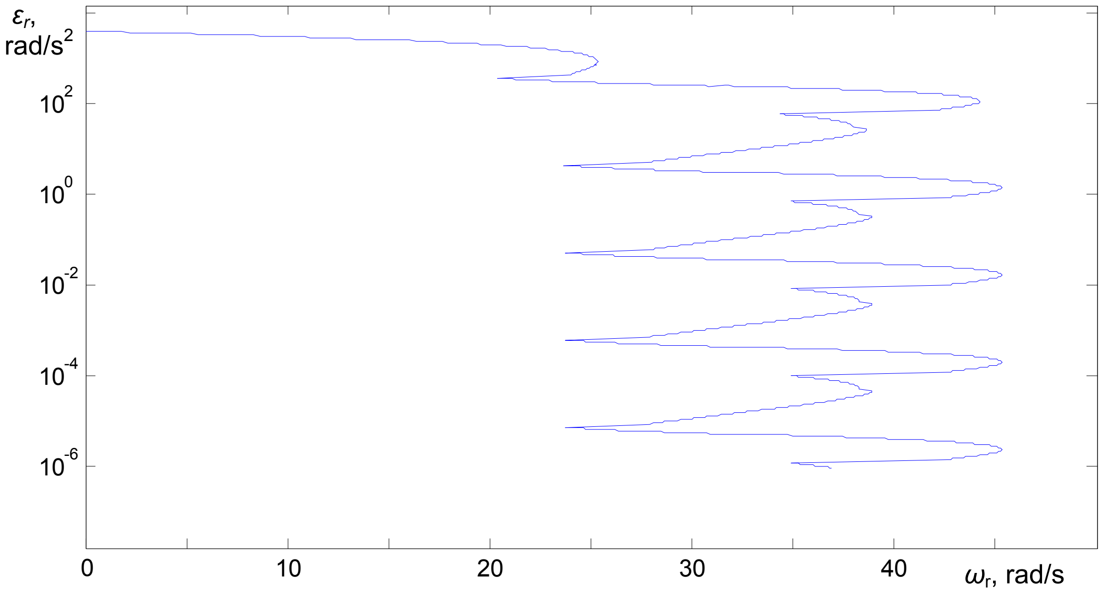


Fig. 6. A phase characteristic $\omega_r = \omega_r(\varepsilon_r)$

A significant part of the investigation of a given dynamic process is the structuring and analyzing of its phase characteristics. Fig. 6 shows the relation between the angular velocity and acceleration, and fig. 7 – the relation between the angular of rotation and angular velocity. Looking at the graphs, it can be seen that a transitional process and steady periodical process of changing the roll's angular velocity exists.

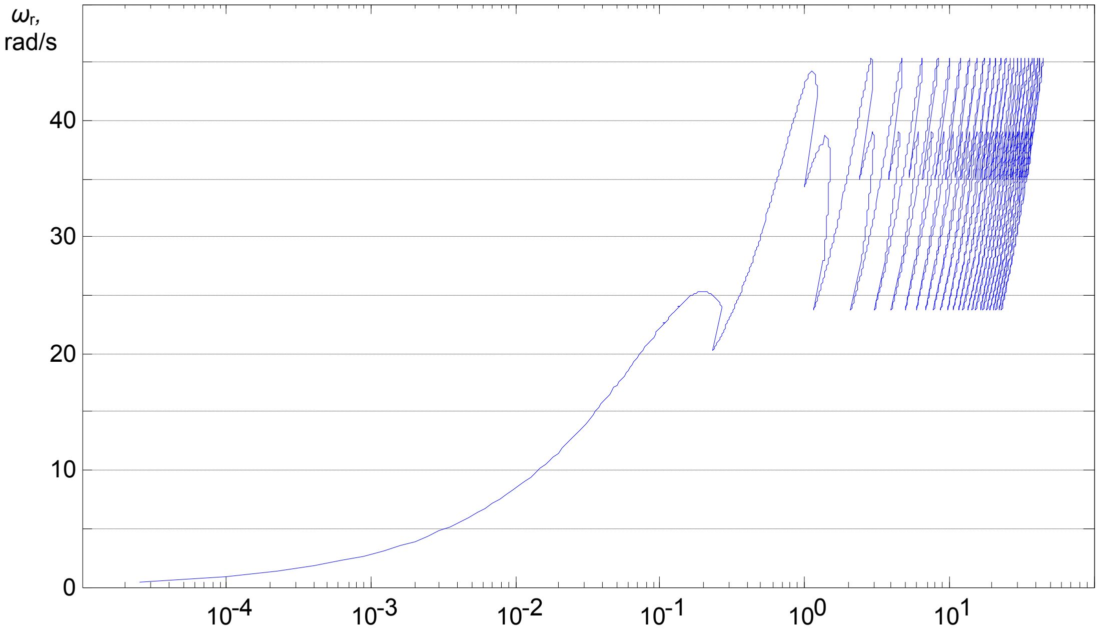


Fig. 7. A phase characteristic $\varphi_r = \varphi_r(\omega_r)$

For the visualization of the transitional process the angular acceleration (in fig. 6) and the angular of rotation (in fig. 7), are given together in a same logarithmic scale. The periodicity of changing to the angular velocity, in the defined regime, is being characterized with a constant value of its amplitude. The angular acceleration, found for different significant values of the initial velocities (fig. 6), get steady rapidly to the levels of keeping the fluctuations of the roll's angular velocity ω_r in a given constant interval. This leads to the ensuring of a periodicity of the roll angular of rotation's value - φ_r, achieved at the same speed of rotation (fig. 8), but belonged to a range of values with continuous one-direction increase (fig. 7).

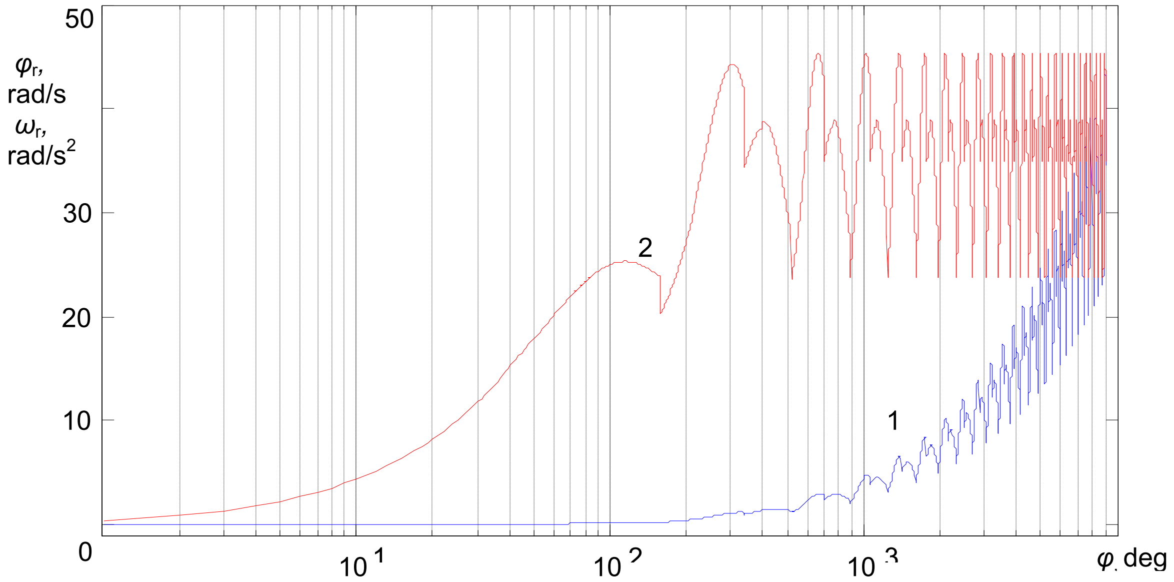


Fig. 8. Change of the angular of rotation φ_r (1) and roll's angular velocity ω_r (2) according to the rotor's angular of rotation φ

The graphs, given in fig. 9, represent the normed, in terms of the maximal force of pressure - F_{max}, equations, concerning the forces with the most significant impact on the mechanical state of the pump rolls:

$$\overline{F} = \frac{F}{F_{max}}, \ \overline{N}_1 = \frac{N_1}{F_{max}}, \ \overline{N}_2 = \frac{N_2}{F_{max}} \text{ and } \overline{\Phi} = \frac{\Phi}{F_{max}},$$

when the rotor is being rotated three times.

For the same period of time it is given and the graph representing the relation between the roll's angular velocity - ω_r, normed with respect to its maximal value:

$$\overline{\omega}_r = \frac{\omega_r}{\omega_{r,max}}.$$

The so given dimensionless equations, ensuring the accomplishment of a scale overlay (fig. 9), where parameters, having different dimensions, can be implemented. This will lead to the simplification of studying and analyzing the investigated processes. The results, found in this research, confirm the results found in [2], according to which the change of the angular velocity - ω_r, for a steady pump's work regime, has a cyclic character with a period of 2π and a phase, which is coincident to the centrifugal inertia force – *Φ.* As a significant element in the graph of ω_r, the "jumping" decrease of the angular velocity's value, during the incursion in sealing sections and the "jumping" increase – during the leaving of these sections, can be recognized. It has to be indicated that, if the roll's mass inertia moment has a constant value, the periods of incursion and leaving are related (respectively) to the exporting and importing of kinetic energy. In the graph of ω_r, given in fig. 9, the additional possibilities for ensuring of a quantitative view for the values of "jumps" – the decreases in the velocity's value are significantly higher, compared with the increases, can be seen. In terms of mathematical considerations the interruptions in the graph of the function $\omega_r = \omega_r(\varphi)$ represent ambiguities, implementing an additional cyclic irregularity of the work processes in the investigated pump. Their studying is being an object of an additional research, which does not correspond to the purpose of this work.

The "jumping" change of the reactions N_1 and N_2 is presented in [2], where it has been defined as a shock/hit interaction between the roll and respectively the stator and rotor. Applying the hypothesis for the existing of ideal plasticity, i.e. the velocity of reflection, occurred after the hit's realization, is equal to zero, then during the roll's incursion through the sealing sections the relative velocity of the hit interaction between the roll and stator will be twice bigger than the one between the roll and the rotor.

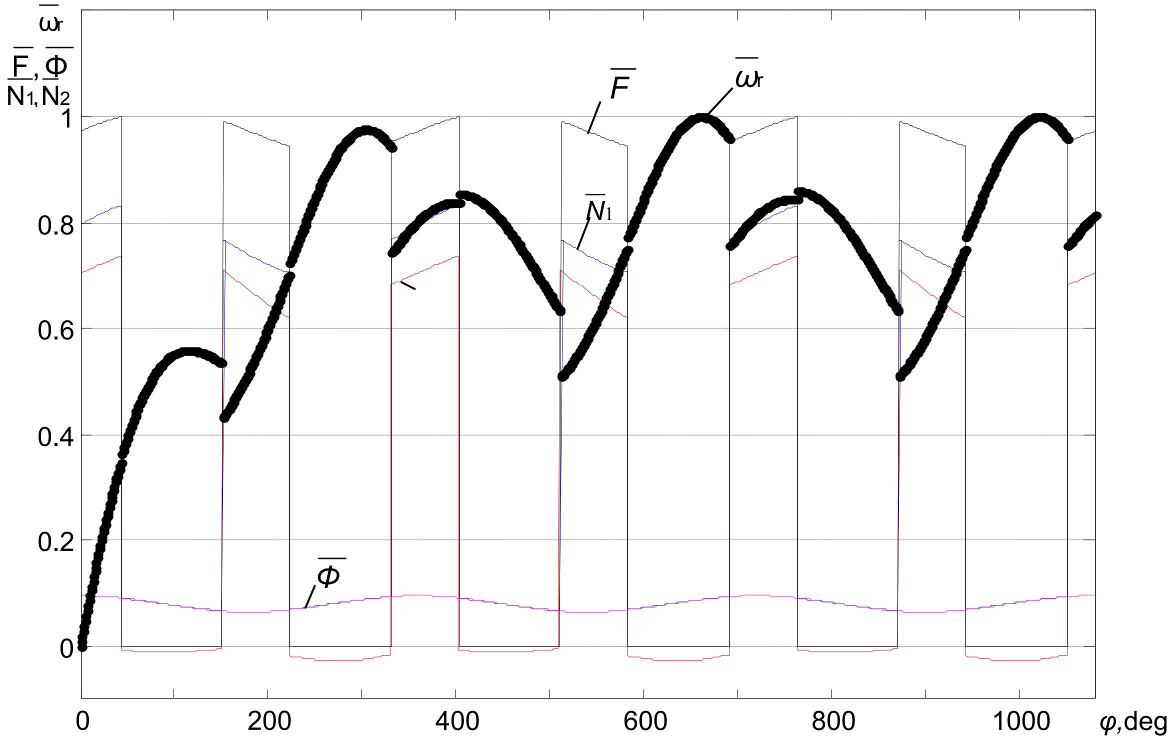


Fig.9. The change of the normed values of the roll's angular velocity $\overline{\omega_r}$ and the forces $\overline{F}$, $\overline{N_1}$, $\overline{N_2}$ and $\overline{\Phi}$ belonging to the first three rotations of the rotor.

During the pump is working, the occurred irregularities will not only affect the rolls, but they can also be referred to other pump's main working elements. The irregularities, concerning respectively the stator and rotor, represent the appearance of dynamicity in the reactions of the pump's fastening elements and the torque's characteristic - $M_R = M_R(\varphi)$. The rotor torque's degree of irregularity can be evaluated by the coefficient of dynamicity:

$$k_d = \frac{M_{R,max} - M_{R,min}}{M_{R,mid}},$$

where $M_{R,max}$ and $M_{R,min}$ are respectively the maximal and minimal values of the function $M_R = M_R(\varphi)$, and $M_{R,mid}$ is the function's average value:

$$M_{R,mid} = \frac{M_{R,max} + M_{R,min}}{2}.$$

Based on the equations, established in part I of this work, the possibility for accomplishing the graph - $M_R = M_R(\varphi)$, is given by the equation, estimating the reduced moments, in terms of the rotor's axis:

$$M_R(\varphi) = \sum_{i=0}^{z-1} N_{2,i}(\varphi + i\beta)\overline{O_rC_i}(\varphi + i\beta),$$

where $O_rC_i(\varphi)=e\cos(\varphi)+\sqrt{(R-r)^2-e^2\sin^2(\varphi)}$ is the distance between the rotor's axis of rotation and the i^{th} number of a roll, and $N_2(\varphi)$ is the projection of the main vector of forces on the tangent. In figures 10 and 11, the graphs of the functions $M_R=M_R(\varphi)$, found for one full rotation of the pump's rotor, in case of an odd (z=7) and even (z=8) number of rolls, where all the other main parameters are having fixed constant values, are given.

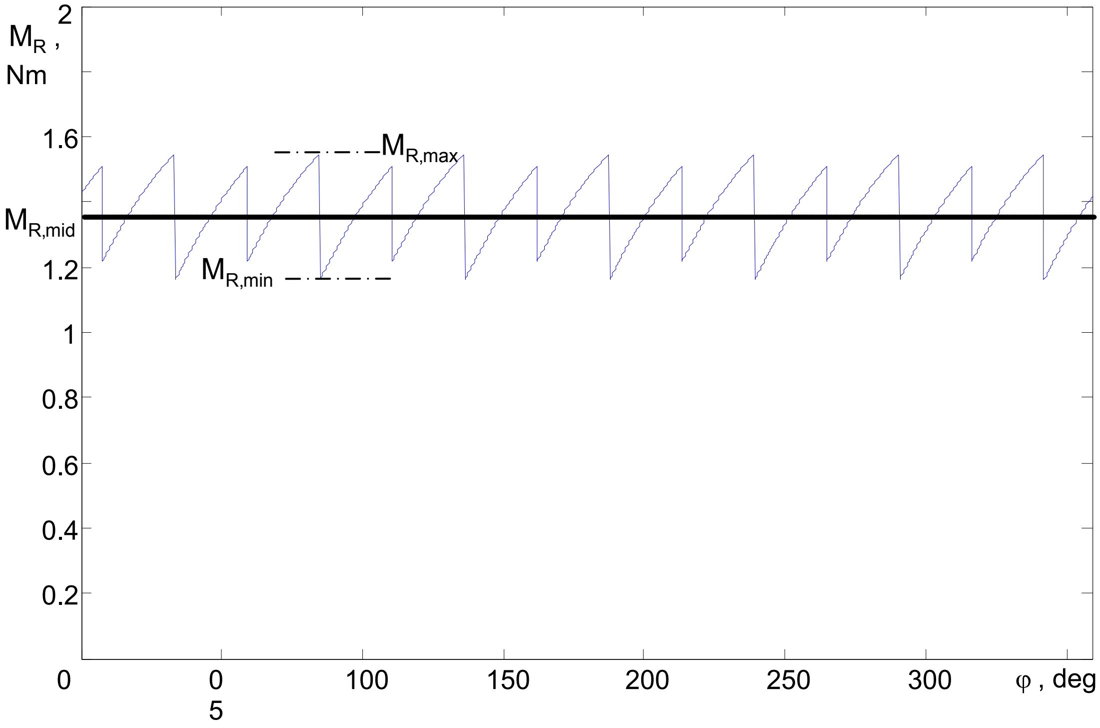


Fig.10. Torque's characteristics $M_{R,mid}$ at z=7

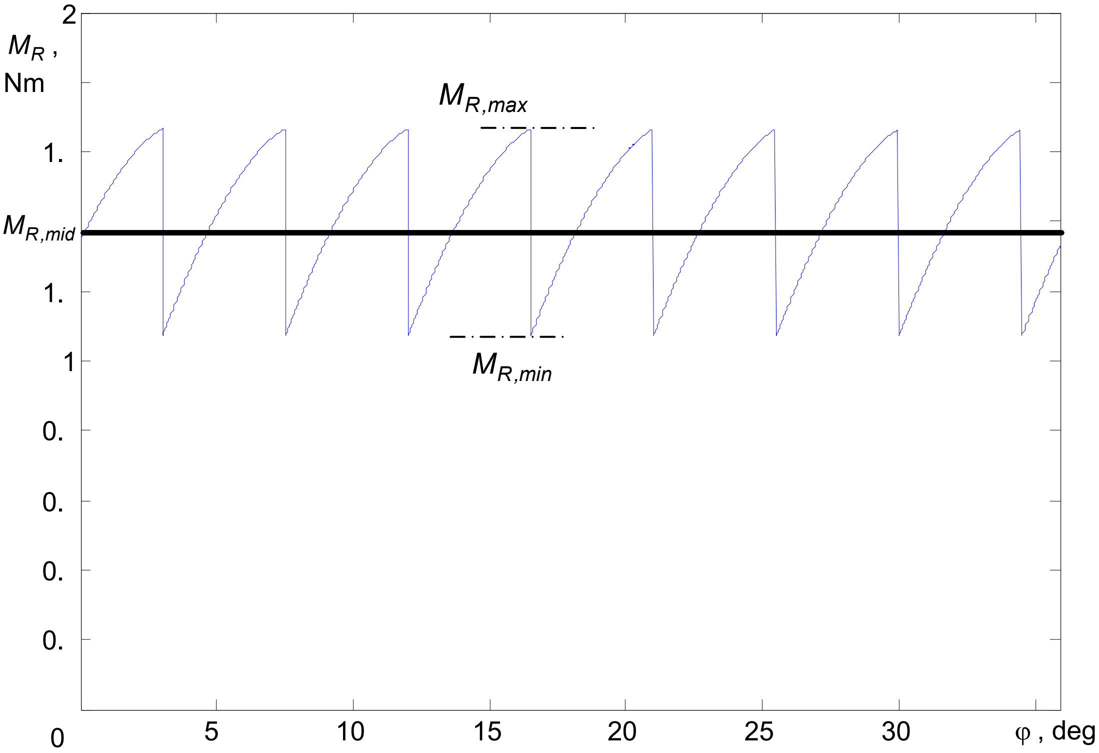


Fig.11. Torque's characteristic $M_{R,mid}$ at z=8

The difference in the values of the coefficient of dynamics k_d is significant, which fully correspond to the information, given in some high-reputed specialized editions. In the case of an odd number (z=7) of rolls, it is found that: $k_d = 0.2844$ - at $M_{R,max} = 1.5464$Nm, $M_{R,min} = 1.1614$Nm and $M_{R,mid} = 1.3539$Nm, and in case of an even number (z=8) of rolls, it is found that: $k_d = 0.4313$ - at $M_{R,max} = 1.6659$Nm, $M_{R,min} = 1.0748$Nm and $M_{R,mid} = 1.3704$Nm. As a significant the difference between the frequencies of the existing irregularities, occurred in the range of one full rotor's rotation, can be considered. It is necessary to indicate, that for an even number of rolls the frequency is multiple to the number of rolls z, while for an odd number of rolls, it is multiple to their doubled number – 2z.

Conclusions

Analyzing the accomplished theoretical research, concerning some typical for the investigated type of roller pumps irregularities, the following more important conclusions can be given:

- The impact of the relative eccentricity and roll size on the character of changing to the flow rate of a work camera – fig. 1, is determined;
- According to the graph, given in fig. 5, it can be seen that for the approximate evaluation of the flow rate's kinematic irregularity the approximate equations for estimating the coefficient δ, can be used. The using of these equations is recommended in case of volumetric pumps with a similar kinematic of their working elements (pistons, vanes, etc.);
- In figures 6 and 7, the phase characteristics of the roll rotation for a given roller pump, are given. The analysis of these results indicates the existing of a transitional and steady periodical process, related to the kinematic characteristics of the roll's rotation (fig. 8);
- According to the graph of the normed forces and angular velocity, given in fig. 9, it can be concluded that the "jumping" ambiguities" in the change of the angular velocity will match the ambiguities of the forces, occurred during the roll's transition through the transitional sealing sections;
- By using an appropriate modification of the proposed mathematical model (1), (2) and (3), the diagram of the rotor's torque (fig. 10 and fig. 11) is being found. In addition to that, the coefficient of rotor's dynamic (1), in case of an even and odd number of rolls, is determined.

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