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Study of the influence of the design parameters of the wet end of the gear pump on the force factors, acting in the gear pump with external gearing, using the software package MATLAB 2018a

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Abstract. The main advantages of gear pumps with external gearing in comparison with other types of positive displacement pumps are presented. The problem of calculating the loads, acting in gear pumps with external gearing, is considered. Examples of the application of calculation methods for solving a wide range of engineering problems in the energy, shipbuilding and aircraft building, shipbuilding and automobile industries are given. The advantages of using modern calculation methods for scientific research are considered. An example of introducing a virtual laboratory workshop for conducting experiments with electrical equipment is presented. The description of the program made in the numerical computing environment for the implementation of algorithms MATLAB R2018a for the calculation of the scalar and the direction of the force acting on the driven gear is given. The advantages of the developed program are presented. The results of the study of the effect of the presence of chamfer on the sleeve and eccentricity on the scalar and the direction of the acting force are presented. The results of research obtained using the developed program have been analyzed.

1. Introduction

External gearing gear pumps are widely used in various sectors of the economy due to their indisputable advantages in comparison with other types of pumps [1, 2]. To all their major advantages the ease of use, good weight and dimensional characteristics, low cost and reliability are given. Among all the tasks of designing pumps, the task of calculating the loads acting on the driven gear stands apart, being the starting point for designers to choose the dimensions, weight and pump parameters. In that matter when referring to the pump design optimization, it is necessary to know the load as precisely as possible in order to get the optimum choice for bearing type and size. Therefore, it highlights the relevance of the study of the parameters affecting the amount and direction of the load, in order to "predict" the direction and module of the acting loads during the pump operation. Classical approaches to the study of the influence of factors changing the module and the direction of the load
during the pump operation are relatively labor-intensive and involve the manufacture of prototype models and stands, what leads to additional material costs and increasing the complexity of the research process. Furthermore, the development and manufacture of stands and the testing process itself take some time.

A modern engineering approach to the problem of studying loads and parameters affecting them involves the use of numerical modeling and techniques of programming. Examples of the application of modern computing methods for calculating the loads, acting in displacement pumps are presented in [3-4], in the flow parts of dynamic pumps in [5-7]. However, modern methods of calculation and programming techniques, described in [8-10], are being actively implemented in all areas of engineering and industries - in the energy sector [11], in the automobile sector [12], in the shipbuilding and aircraft industries [13-15]. Furthermore, numerical methods of calculation and programming techniques can greatly reduce the research time and difficulty, increasing their efficiency and allowing the research results demonstration more visibly. A study for a two-phase fluid in the flow part of an axial pump using the STAR CCM + software package is given in [16], a study of pump operation at various levels of cavitation in [17], a study of vortex and hysteresis effects in the intake device of a centrifugal multi-stage pump in [18]. Numerical modelling techniques are also actively used to calculate the parameters and operating conditions, dimensions and masses of diverse machines and mechanisms. Examples of the calculation and flow optimization in impeller pumps are given in [19-20]. The numerical modelling techniques have been actively disseminated in the field of experiments, allowing to reduce the material costs of the purchase and maintenance of experimental stands, simplify and expedite the process of experimentation and, in case of need, conduct it again or repeat. An example of comparing the results of a physical experiment with the results of a three-dimensional hydrodynamic simulation of the cavitation process in a centrifugal pump is given in [21]. For conducting experiments with electricity and electronics, LabVIEW virtual laboratory practice is actively applied. The LabVIEW software package provides a wide range of elements, a sort of operation modes for the studied electrical circuits; so the visual perception of information on the monitor screen is identical with laboratory installation. Due to the possibility of conducting virtual electric experiments, the risk of injury caused by failed experiments is entirely excluded, which, of course, ensures the full safety of such experiments. However, the lack of sensation of real physical experience is the significant shortage for these calculation software packages, which may negatively affect the training of specialists for working with electrical equipment in the real production conditions. Examples of the application and the description of the calculable software packages LabVIEW are given in [22-25]. Nowadays, it is safe to say that numerical modelling techniques and programming methods are crowding out the traditional methods of calculation "step by step" in all areas of science and technology.

2. Modern software for research

In the case of study, the programming method was chosen as the one for studying the influence of the design parameters for the flow part of a gear pump on the direction and magnitude of the fluid force. For this purpose, two subprograms have been developed in MATLAB language in the MATLAB R2018a software package: «For One Position of Teeth» and «For All Positions of Teeth». The «For One Position of Teeth» subprogram calculates the resulting force $P_{rez}$, the resulting force projections $P_x$ and $P_y$ (output is an array $3 \times z$ size, where $z$ is the number of gear teeth) for one gear position. The geometrical characteristics of gears (number of teeth $z$, radius of outside circle $R_a$, radius of base circle $R_b$, face width of tooth $B$), eccentricity $e$, angles, assigning the gear sleeve geometry, and nominal pressure $P_{nom}$, are given as the inputs. All angles are laid off from the horizontal (180°) clockwise, the horizontal – 0°. The «For All Positions of Teeth» subprogram doesn’t work without the «For One Position of Teeth» subprogram, which is the internal loop of this subprogram. The inputs for the «For All Positions of Teeth» subprogram are the outputs of the «For One Placing of Teeth» subprogram (an array of forces' scalars $3 \times z$ size). The corner segment $\left[\frac{-e + B}{2}, \frac{e + B}{2}\right]$ is split into n
segments, \( n+1 \) points of division. The parameter \( u \), which determines the angle of rotation of the gear, is variable (figure 1):

Consequently, inside the «For All Positions of Teeth» subprogram, the simulation of gears rotation on the angular segment \( \left[ \frac{-f_0}{2}; \frac{f_1}{2} \right] \) is running, which allows to determine intermediate load values and calculating the angle of action of the maximum load on this gear with a given flow path geometry. The 2 arrays of \([1 \times (n + 1)]\) size each are created inside the subprogram, which contain the angle and the scalars of the resultant force are written.

The program has the following advantages:
1) Versatility - the ability to change the inputs and to calculate the forces for pumps with different characteristics and geometry of the flow part.
2) The program is a platform for the study of the dependence of the magnitude and direction of eccentricity and chamfer on the direction and magnitude of the force acting on the gear.
3) A significant reducing the time and labour-intensity for the load's calculating.

As for the design parameters for research were chosen the chamfer on bushing and eccentricity in the pump body. It was decided to research the influence of the presence of chamfer on bushing and eccentricity in the pump body on the scalar and the direction of the fluid force. 4 variants of the geometry of the flow part were considered:
1) Without including chamfer on the bushing with eccentricity \( e = 0 \) \( \mu m \);
2) Without including chamfer on the bushing with eccentricity \( e = 16 \) \( \mu m \);
3) With including chamfer on the bushing with eccentricity \( e = 0 \) \( \mu m \);
4) With including chamfer on the bushing with eccentricity \( e = 16 \) \( \mu m \);

A variant of the bushing with chamfer is shown in the figure 2:
The variant of the flow part, with including chamfer on the bushing, assumes that not only the first and last teeth form an «infinite» drift between the gear and the pump body, but also an intermediate one (figure 3):

The drift $h_0$ between 3, 4, 6, 7 teeth and the bushing is considered as «small», others drifts are considered as “infinitely great”.

All dimensions and parameters required for inputs to the program were taken from the NSh32U pump.

The magnitude of the eccentricity $e = 16 \mu m$ was taken from practice (displacement of the center of the gear during the pump operation).

The drift size $h_0 = 40 \mu m$ was also taken from practice.

3. Results of the research

The results of the calculation of the direction and scalars of the force acting on the driven gear without including chamfer and with $e = 0$ μm (var 1), without including chamfer on the bushing with eccentricity $e = 16 \mu m$ (var 2), with including chamfer on the bushing with eccentricity $e = 0 \mu m$ (var 3), with including chamfer on the bushing with eccentricity $e = 16 \mu m$ (option 4) are presented in Table 1:

| Variant of flow part | Average angle of acting force $\beta_{cp}$,˚ | The scalar of acting force $P_{cp}$, N |
|----------------------|---------------------------------------------|--------------------------------------|
| 1                   | Without including chamfer on the bushing with eccentricity $e = 0 \mu m$ | 259,2 | 12 656 |
| 2                   | Without including chamfer on the bushing with eccentricity $e = 16 \mu m$ | 283,5 | 15 215 |
| 3                   | With including chamfer on the bushing with eccentricity $e = 0 \mu m$ | 264,3 | 11 290 |
With including chamfer on the bushing with eccentricity $e = 16 \mu m$

The averaging was carried out to the angle of the acting force, the scalar of the resulting force was calculated by the 2 average scalars, stand for the average angle of acting load. Diagrams with information about the magnitude and direction of the force at different points of the pitch arc, and the averaged load scalar are shown in figure 4 and figure 5:

**Figure 4.** The average module and direction of load without including chamfer diagram with a) $e = 0 \mu m$ and b) $e = 16 \mu m$

**Figure 5.** The average module and direction of load with including chamfer diagram with a) $e = 0 \mu m$ and b) $e = 16 \mu m$

### 4. Conclusions

Based on the research results, we can make following conclusions:

1) In a radial arrangement of gears ($e = 0 \mu m$), the presence of unloading chamfers on the bushings reduces the fluid force acting on the driven gear by $\approx 11\%$.

With an eccentric arrangement of gears ($e = 16 \mu m$), the presence of unloading chamfers on the bushings leads to a more significant reduction by $\approx 25\%$. 
Consequently, the use of chamfers to reduce the acting force is more economically reasonable with an eccentric arrangement of gears.

2) Without chamfer on the bushing the presence of eccentricity significantly affects the scalars of force - with the eccentricity \( e = 16 \, \mu m \), the force increases by \( \approx 17\% \).

With chamfer on the bushing, the eccentricity has practically no effect on the changing of the scalars of force (with eccentricity, the acting force changes by \( \approx 1 - 3\% \)).

3) With a radial arrangement of gears, it is possible to "predict" the direction and scalar of the average acting force. With an eccentric arrangement of gears, it is very difficult to "predict" the direction of action of the average force, because the magnitude of eccentricity has a significant impact on the direction of acting force.

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