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To cite this article: V Devisilov and E Sharai 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **492** 012025

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Hydrodynamic filters in hydraulic fluid cleaning system of hydraulic drive

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Abstract. The paper deals with prospects for the use of hydrodynamic filters in the hydraulic fluids' system for the preparation and regeneration based on a review of the current state in the field of hydrodynamic filtering. The authors show the classification of known design schemes for hydrodynamic filters according to two characteristics: presence or absence of sludge liquid and methods for creating an additional force field. The authors note the advantages and disadvantages of each type's hydrodynamic filter. In this paper, the authors establish the dependence of the particles' separation efficiency caused by the rotation of the filter septum on the average median particle size of impurities. Upon reading the paper one realized that the prospects of using hydrodynamic filters to provide the required frequency of the hydraulic systems hydraulic fluid of hydraulic drives.

1. Introduction

One of the methods to improve the reliability of technical systems is to reduce the failure rate [1-4]. For hydraulic systems, the failure rate of equipment depends on a number of factors: the working fluid cleanliness class, operating conditions, and timely maintenance. Practice shows that increasing the reliability of the elements of the hydraulic system by 80% depends on the purity of the working fluid. The presence of mechanical impurities in the working fluids of hydraulic systems reduces the life of hydraulic actuators and can lead to sudden failures during device seizure, leakage, valve clogging, etc. Both the concentration of particles in the fluid and their size affect the wear process of hydraulic actuators. Particles of contamination enter the working fluid when pouring fluid into the tank; when worn rubbing surfaces; through hydraulic seals. Therefore, it is necessary to constantly monitor and promptly clean the working fluid of hydraulic actuators from mechanical impurities. Of the known methods of cleaning liquids from solid contaminants, only filtering can guarantee the required cleaning fineness.

Certain portions of hydraulic fluids are high viscosity mineral oils. High fluid viscosity and clogging of the filter material lead to the need to create a high-pressure drop across the filter septum and frequent filter regeneration. Therefore, it is advisable to use combined devices, such as hydrodynamic filters, providing highly efficient separation processes. Hydrodynamic filtration differs from the traditional one by the presence of an additional component of velocity v_t , tangent to the filtration surface (figures 1a, 1b). The hydrodynamic effect is the continuous removal of the



accumulated layer of sediment from the surface of the filtering material [5-7]. Realization of this effect requires high tangential speed v_t flow rate relative to filtration rate v_0 . Within reasonable limits of the ratio of these velocities, a hydrodynamic effect arises for large particles of pollution exceeding 300 μm . To reduce the size of particles that can be removed from the surface of the filter septum, a combination of hydrodynamic filtration with an additional force mechanism is used (figures 1c, 1d). In this case, forces, usually centrifugal and vibration have an additional effect on the particle of pollution near the filter septum and do not allow it to settle on the filter surface.

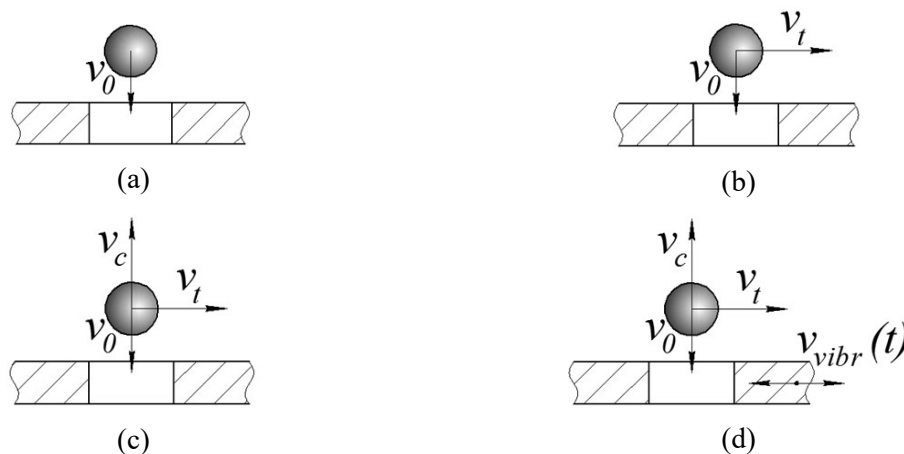


Figure 1. Filtering circuit: a) customary; b) hydrodynamic; c), d) hydrodynamic with force action.

The area of application of hydrodynamic filters is quite wide. The advantage of these devices is that with guaranteed observance of the purity of the liquid, determined by the cell size of the filter material, they have the ability to self-purification, which increases the regeneration time and service life [8].

2. Basic types of hydrodynamic filters

There are several types of hydrodynamic filters, differing in the organization of output streams, and in the method of flow swirl, which provides for the creation of an additional force field. Conditionally, they can be divided into the following groups:

2.1. Sludge liquid or without sludge liquid

The first class of hydrodynamic filters is characterized by the sludge fluid or without sludge fluid and includes two groups of filters: full-flow and part flow [8]. The full-flow filters (figure 2a) pass through the filter septum all the liquid that has arrived for purification. The advantage of this mode of operation is obvious - this is the absence of sludge fluid. However, the self-cleaning ability of such filters is lower than part-flow filters (figure 2b). They are used where full collection of impurities is necessary, with low viscosity of the medium being cleaned with low obliteration properties or with a slight difference between the density of the solid and liquid phases.

In part-flow hydrodynamic filters, a part of the filtered fluid (usually 10–15%) is by passed along the filter septum to flush accumulated sediment from its surface, and then is dumped along with the contaminants into the tank for the filtered fluid or is disposed of after proper decontamination as waste.

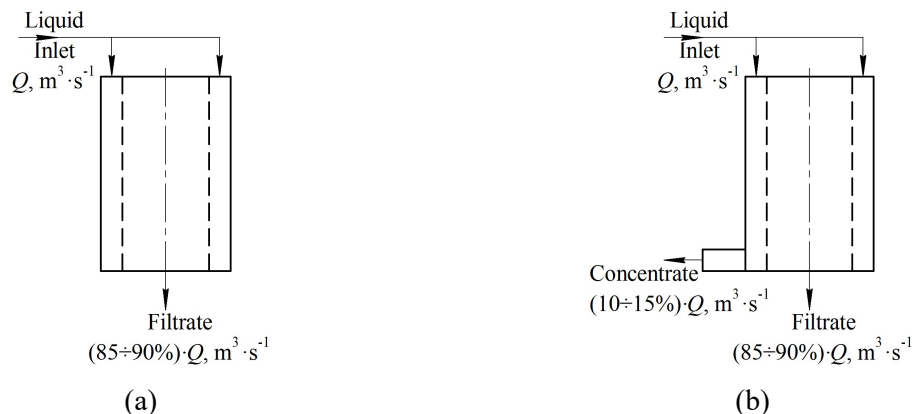


Figure 2. Hydrodynamic filter circuit: a) full-flow filter; b) part-flow filter.

2.2. Creating way a force field

The second classification group includes hydrodynamic filters containing elements of its design to create an additional swirl flow, which reduces the load on the filter material by separating part of the contamination by a centrifugal mechanism. Five types of hydrodynamic filters can be distinguished: with a rotating filter septum; with rotating and vibrating filter septum; with a rotating filter septum with a protective shell; with a filter element with a large curvature of the surface; with special twisting devices.

The greatest effect of swirling flow allows to obtain devices with a rotating filter septum, as they allow you to adjust the rotational speed depending on the properties of the medium being cleaned and thereby obtain the greatest force on the stream to be cleaned with minimum filter sizes [9] (figure 3). The combination of rotation of the filter septum with vibration along the axis of rotation increases the self-cleaning ability of the filter due to the destruction of the accumulated sediment layer and its simultaneous removal from the surface of the filter septum by centrifugal and hydrodynamic forces [10,11] (figure 3b). However, the flow in the channel formed by the casing and the filter septum is close in its structure to the Couette-Taylor flow, which, as is well known, can be unstable [12-15]. With the advent of macro-vortex structures in the working area, particle separation deteriorates due to the uneven distribution of radial and longitudinal velocity along the length of the channel; part of the filter septum can be excluded from work due to the circulation of secondary currents. In addition, the presence of vortex structures increases the hydraulic resistance in the filter. Therefore, for hydrodynamic filters with a rotating filter septum, it is necessary to choose the optimal operating conditions for which the flow in the working channel will be irrotational and stable. The proposed design with perforated protective shell, located between the housing and the filter septum. The presence of a rotating perforated shell allows the separation of not only coarse, but also fine particles of dirt, because in the annular gap between the filter septum and the perforated protective shell, the liquid rotates like a solid body with a constant angular velocity, which prevents the penetration of fine particles of dirt to the surface of the filter material [16, 17]. Thus, the rotating perforated shell allows you to increase the service life of the hydrodynamic filter by self-cleaning the filter septum and reducing the particle size separated by centrifugal forces, compared to the rotating filter septum with a similar frequency, but in the absence of a protective perforated shell. However, this design, complicated by the presence of additional moving elements, does not solve the problem of vortex formation in the working annular channel and requires the selection of operating parameters that ensure a steady flow [18-20].

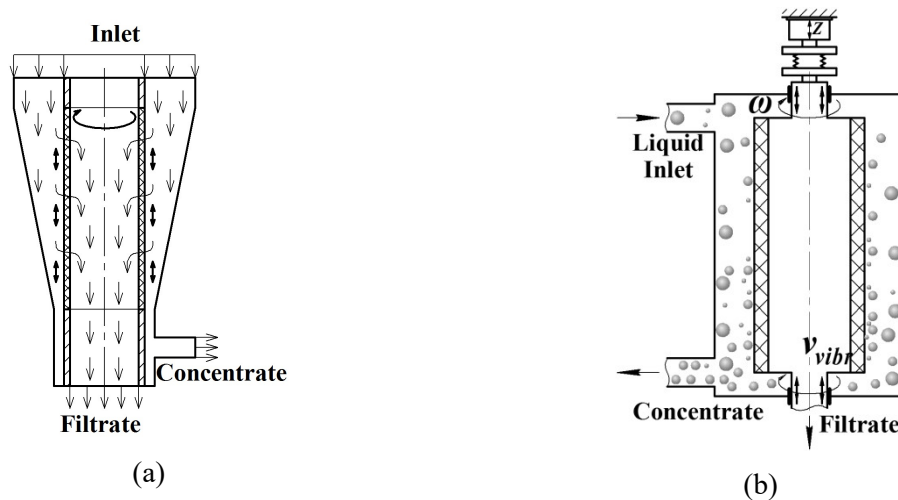


Figure 3. Hydrodynamic vibration filter circuit: a) with rotating filter septum; b) with rotating and vibrating filter system.

3. Calculation of the centrifugal separation's efficiency in a hydrodynamic filter

As a result of mathematical modeling of hydrodynamic and separation processes occurring in a hydrodynamic vibration filter using modern CAE programs, the dependence of the particle separation efficiency due to the rotation of the filter septum on the average particle size of contaminants at the rotation frequency $f_{rot} = 5$ Hz and particles density $\rho_p = 2500$ kg/m³ for non-Newtonian pseudoplastic fluids subject to the rheological power dependence of Oswald de Ville:

$$\tau = m|\dot{\gamma}|^{n-1} \dot{\gamma}, \quad (1)$$

where

τ – shift voltage;

n – flow index ($n < 1$);

m – consistency index;

$\dot{\gamma}$ – sliding velocity.

Evaluation of separation efficiency was carried out according to the expression:

$$\eta_{dm} = \frac{N_{rot}}{C_p} 100\% \quad (2)$$

where

C_p – particles count in the raw liquid;

N_{rot} – particles count dimension d_m , separated with centrifugal mechanism.

As a result of the calculations, it was established that at the frequency of rotation of the filter septum $f_{rot} = 5$ Hz centrifugal mechanism captured from 60 to 100 % medium sized particles 200...400 μm , from 20 to 60 % sized particles 150...200 μm , and from 10 to 20 % sized particles 60...150 μm depending on the flow index n (figure 4). A further increase in the frequency of rotation of the septum will increase the centrifugal contribution to the overall mechanism for cleaning fluid. However, there is a limit to the growth of the cleaning efficiency of the centrifugal mechanism, due to the loss of stability of the flow in the annular gap of the filter. The purpose of further research is to determine the limits of flow stability and the choice of optimal operating parameters of the filter.

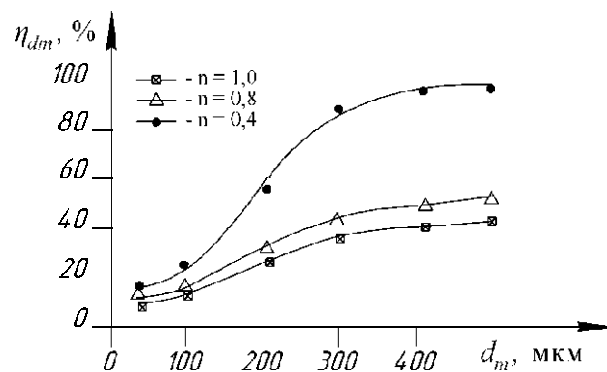


Figure 4. Separation efficiency dependence of the centrifugal mechanism on the average particle size of dirt particles at a frequency of rotation $f_{rot} = 5$ Hz and particles density $\rho_p = 2500$ kg/m³.

4. Conclusions

To ensure uninterrupted and reliable operation of hydraulic systems, it is necessary to clean working fluids from mechanical impurities in a timely manner. The proposed mechanism for cleaning highly viscous non-Newtonian fluids by filtration with a combination of the action of force fields reduces the load on the filter material by separating some of the contaminants by centrifugal forces, and increases the service life of the filter due to its ability to self-regeneration.

Acknowledgments

This paper was made according to State Order of the Ministry of Science and Higher Education of the Russian Federation (No 10.7766.2017/8.9).

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