Hydrodynamic filters in hydraulic fluid cleaning system of hydraulic drive

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

View the article online for updates and enhancements.
Hydrodynamic filters in hydraulic fluid cleaning system of hydraulic drive

V Devisilov¹ and E Sharai¹,²
¹Bauman Moscow State Technical University, 5 Second Baumanskaya Street, Moscow, 105005, Russian Federation
²E-mail: e9.sharay@yandex.ru

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 \( \mu m \). 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](image1.jpg)

**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.
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 2. Hydrodynamic filter circuit: a) full-flow filter; b) part-flow filter.
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/m$^3$ for non-Newtonian pseudoplastic fluids subject to the rheological power dependence of Oswald de Ville:

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

where

- $\tau$ – shift voltage;
- $n$– flow index ($n<1$);
- $m$ – consistency index;
- $\gamma$ – sliding velocity.

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

$$\eta_{dm} = \frac{N_{rot}}{C_p} \times 100\%$$

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 from10 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 3. Hydrodynamic vibration filter circuit: a) with rotating filter septum; b) with rotating and vibrating filter system.
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).

Published under licence in Materials Science and Engineering by IOP Publishing Ltd. Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

References

[1] Conrad F, Hilbrecht B and Jepsen H 2000 Design of low-pressure and high-pressure tap water hydraulic systems for various industrial applications (No. 2000-01-2614) SAE Technical Paper

[2] Livingstone G and Cavanaugh G 2015 The real reasons why hydraulic fluids fail Tribology & Lubrication Technology 71(7) p 44

[3] Badakh V, Tarasenko T, Puzik O and Kravushkina K 2013 Functional units based on cavitation effects for hydraulic systems of vehicles Transport engineering and management Vilnius: Lithuania pp 50–54

[4] Onischchenko D, Pankratov S, Zotov A, Osipkov A and Poshekhonov R 2017 Study of influence of hydraulic thermoelectric influence of hydraulic thermoelectric generator resistance on gasolie engine efficiency International journal of applied engineering research 12 (5) pp 721–727

[5] Yim S and Kwon Y 1997 A unified theory on solid-liquid separation: Filtration, expression, sedimentation, filtration by centrifugal force, and cross flow filtration Korean Journal of Chemical Engineering 14(5) pp 354–358

[6] Kim Mand Zydne A 2006 Theoretical analysis of particle trajectories and sieving in a two-dimensional cross-flow filtration system Journal of membrane Science 281(1-2) pp 666–675

[7] Al-Malack M and Anderson G 1997 Use of crossflow microfiltration in wastewater treatment Water Research 31(12) pp 3064–72

[8] Finkelstein Z 1986 Primenenie I ochistka rabochih zhidkostej dlya gornyh mashin

**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/m$^3$. 

![Graph showing separation efficiency dependence](image_url)
[Application and cleaning fluids for mining machines] Moscow: Nedra Publ.

[9] Aleksandrov A, Devisilov V, Sharai E and Kiselyova D 2018 Effect of geometric parameters of working channel of hydrodynamic filter with protective baffle on medium flow structure Herald of the Bauman Moscow State Technical University, Series Natural Sciences2 (77) pp 23–38 DOI: 10.18698/1812-3368-2018-2-23-38

[10] Devisilov V and Sharai E 2018 Particle Separation in an Annular Converging Channel with an Inner Rotating Permeable Baffle High Temperature56 (4) pp 576–580 DOI: 10.1134/S0018151X18040053

[11] Devisilov V and Sharai E 2016 Numerical study of the flow structure in a hydrodynamic filter Theoretical Foundations of Chemical Engineering50 (2) pp 209–216 DOI: 10.1134/S0040579516020044

[12] Ostilla R, Stevens R, Grossmann S and Verzicco Rand Lohse D 2013 Optimal Taylor–Couette flow: direct numerical simulations Journal of fluid mechanics719 pp 14–46

[13] Montavon C, Grotjans H, Hamill I, Phillips H and Jones I 2000 Mathematical modelling and experimental validation of flow in a hydrocyclone In: 5th International Conference on Cyclone Technologies Warwick, UK 31 pp 175–186

[14] Bunyawanichakul P, Kirkpatrick M, Sargison J and Walker G 2006 Numerical and experimental studies of the flow field in a cyclone dryer ASME Journal of Fluid Engineering 128 (6) pp 1240–1250 DOI: 10.1115/1.2354523.47

[15] Varaksin A, Protasov M, Marinichev D and Vasil’ev N 2015 An Analysis of the Parameters of Flare Particles for Optical Diagnostics of Vortex Flows Measurement Techniques58 (6) pp 655–660

[16] Durand A 2003 Bioreactor designs for solid state fermentation Biochemical Engineering Journal13 (2-3) pp 113–125

[17] Mochalin I, Brazhenko V and Yashchuk O 2017 An experimental research of the efficiency of a fluid mechanical cleaning by a rotating filterJournal of civil engineering and management23 (3) pp 43–46

[18] Yahi F, Hammoune Y, Lecheheb S and Bouabdallah A 2015 Experimental investigation of the free surface effect on the conical Taylor-Couette flow system Topical problems of fluid mechanics (Prague) p 273

[19] Noui-Mehidi M 2011 Design optimization of a conical annular centrifugal contractor FDMP 7 (2) p 141

[20] Xiaofei X, Pu W, Lanxi X and Dapeng C 2010 Occurrence of Taylor vortices in the flow between two rotating conical cylinders Communications in Nonlinear Science and Numerical Simulationvol 15 (5) p 1228