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Klaudiusz KLARECKI*

Institute Of Engineering Processes Automation And Integrated Manufacturing Systems, Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice
*klaudiusz.klarecki@polsl.pl

THE IMPACT OF THE FILTRATION PARAMETERS FOR HYDRAULIC FLUIDS CONTAMINATION

Abstract: The article is focused on the filtration phenomena of hydraulic fluids. It describes the mathematical model of this phenomenon. It has been shown that the appropriate selection filtration in the hydraulic system requires not only the proper properties of the hydraulic filter. Just as important are:
- Flow rate through the filter.
- The value of particulates flux causing an increase in contamination of hydraulic fluid.

1. Introduction

Frequent opinions is that hydraulic drives are very unreliable. Most often the users themselves contribute to a hydraulics failure. According to the manufacturers of hydraulic components, more than 70% of failures are caused by dirty hydraulic fluids. It is worth asking if the hydraulic users are like naughty children and they destroy purposely their hydraulic drives? Maybe the problem of hydraulic fluid contamination depends not only on the user's procedures.

2. Filters and filtration

Pure hydraulic fluid starts with the design of hydraulic circuit. It involves the proper selection of filter and its appropriate arrangement in the circuit.

Into hydraulic drives usually mechanical filters are used. Mechanical filters are divided into:
- surface filters,
- depth filters.

The advantage of the surface type filter is that it can be regenerated. Depth type filters can collect more contamination particles (dirt holding capacity of depth filters are much more higher than surface filters), so its life time is significantly higher.

Suction strainers and fillers are type surface filters. Pressure line filters and return line filters are mainly depth type.

Typical mounting places for filters are:
- suction line,

- pressure line,
- return line,
- kidney-loop (off-line filtration).

Occasionally, hydraulic filters are installed in several places of hydraulic circuit. Pressure line filters are installed onto inlets of components which are sensitive to contamination to protect them. Besides, hydraulic circuit is equiped with a main return line filter or off-line filter. This is very effective but expensive solution of filtration.

The main features of hydraulic filter are:
- nominal flow,
- pressure losses,
- dirt holding capacity,
- Beta ratio.

Beta ratio $\boldsymbol{\beta_x}$ is a formula used to calculate the filtration efficiency of a particular fluid filter using base data obtained from multi-pass testing (Fig. 1). The formula used to calculate $\boldsymbol{\beta_x}$ is:

$$\beta_x = \frac{N_u}{N_d} \tag{1}$$

whereby:
N_u – particle count in upstream fluid,
N_g – particle count in downstream fluid,
x – particle size.

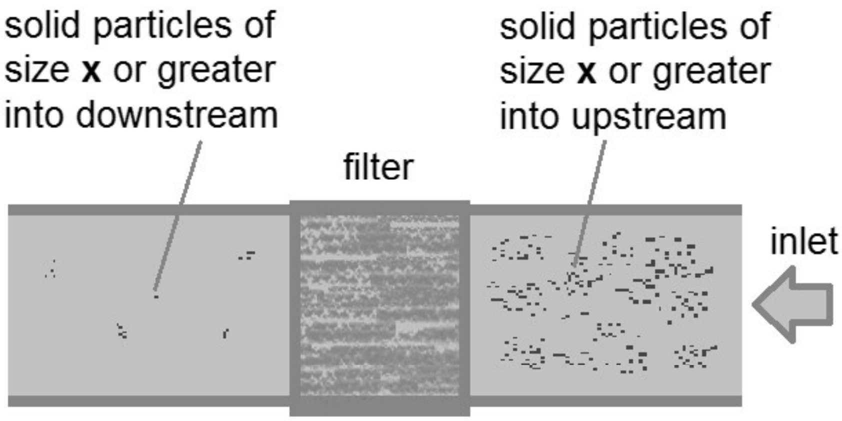

Fig. 1. Multi-pass testing

Particulate removal efficiency $\mathbf{n_f}$ can be seen as the probability of capturing particles flowing through the filter. The relationship between beta ratio and nf is given by the formula:

$$n_f = \left(1 - \frac{1}{\beta_x}\right) \cdot 100\% \tag{2}$$

3. Analysis of the impact of selected filtration parameters on the cleanliness of hydraulic fluid

For the analysis it has been adopted most common arrangement - with return line filter (Fig. 2).

Initially it was assumed that the cleanliness of the hydraulic fluid depend on the:
- filter efficiency,
- actual filter flow rate,
- tank volume.

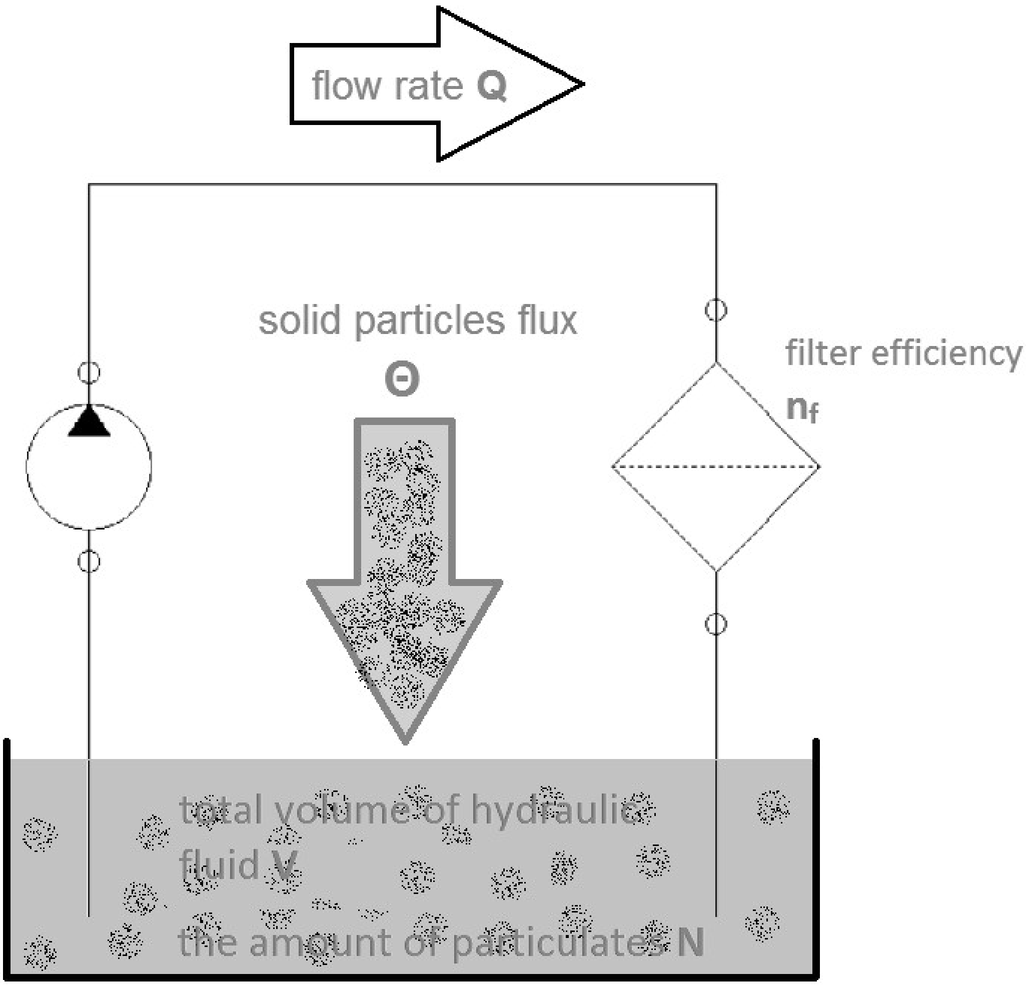

Fig. 2. Sketch of the analyzed hydraulic system

Model of filtration phenomena

Model of filtration phenomena was based on the following assumptions:
- filter efficiency is equal the probability of capturing particles with size x or greater,
- particulates are evenly distributed in the liquid,

- the inner and outer particulates with total flux **Θ** enters the hydraulic liquid, particulate flux is accepted as constant,
- particulates appear uniformly throughout the entire volume of hydraulic fluid.

The probability of capture contaminant particle over unit time **λ** can be accept as:

$$\lambda = \frac{n_f}{100\%} \cdot \frac{Q}{V} \tag{3}$$

Whereby:
Q – flow rate through filter,
V – total volume of hydraulic fluid into circuit.

Assuming a small value of λ, the formula for the number of dirt particles N in the hydraulic fluid can be written as follows:

$$\frac{dN}{dt} = -\lambda N + \Theta \tag{4}$$

Whereby:
Θ – solid particulates flux

It can be seen that formula (4) is same to describing the phenomenon of radioactive decay.

Combining (3) and (4) were obtained:

$$\frac{dN}{dt} = -\frac{n_f}{100\%} \cdot \frac{Q}{V} N + \Theta \tag{5}$$

In general, the factors that determine the number of particles of pollutants according to (5), are not fixed. For example, filtration efficiency may depend on the degree of filling of the filter. Also, the liquid volume in the system may be varied, e.g. due to leakages.

Determination of the number of pollutants, taking into account the variability of factors $\mathbf{n_f}$, **Q**, **V** and **Θ** most likely require the use of numerical methods to solve the equation (5). Further analysis was accepted a simplified model of filtration phenomenon in which factors have fixed values. According to the accepted simplification, the solution of equation (5) is particular integral in a particular as a:

$$N = N_0 e^{-\frac{n_f}{100\%} \cdot \frac{Q}{V} t} + \Theta \frac{V \cdot 100\%}{n_f \cdot Q} \left(1 - e^{-\frac{n_f}{100\%} \cdot \frac{Q}{V} t} \right) \tag{6}$$

Whereby:
ρ_{c0} – initial concentration of particulates.

For formulas (6) and (7) can enter the time constant filtration $\mathbf{T_f}$ as:

$$T_f = \frac{V \cdot 100\%}{n_f \cdot Q} \tag{8}$$

It should be noted that for the filtration times t >> T_f , the concentration of particulates approaching the values:

$$\rho_c = \frac{\Theta \cdot 100\%}{n_f \cdot Q} \tag{9}$$

From (9) it follows that for a given flux of particulates **Θ**, the particle concentration can be reduced by increasing filter efficiency $\mathbf{n_f}$ or increasing the flow through the filter **Q**.

Which way is more efficient? It will be analyzed in the example 1.

Example 1

Compare two hydraulic systems with 1000 dm^3 volume of hydraulic oil. First is equipped with a return line filter with $\beta_{10\mu m} = 300$. The off-line filtration with $\beta_{3\mu m} = 75$ filter is applied to second unit. Both systems work 24/7 in same environment with Θ = 1E+7 [1/s] flux of particles size 4 μm and above. Flowrate of main pump is 200 dm^3/min, flowrate of auxiliary pump is 50 dm^3/min (second unit). Initial fluid contamination was accepted as upper range of class 22 according ISO 4406.

Based on the item [2] were calculated beta ratios for particles with a size 4 microns. Beta ratio of filter with $\beta_{10\mu m} = 300$ was calculated 10, and for filter with $\beta_{3\mu m} = 75$ its beta ratio was 200. So the efficiencies of capture particles ≥ 4 microns are as follows:

- $n_{f1} = 90\%$
- $n_{f2} = 99,5\%$

The calculation results for Example 1 in accordance with formula (7) shown in Fig. 3.

Obtained results prove that the contamination of hydraulic fluid strongly depend on filter flow rate.

The calculated values of the particulates concentration in the steady state are as follows:

- return filter - $\rho = 3.33 \cdot 10^5$ particles / 100 ml,
- off-line filter - $\rho = 1.21 \cdot 10^6$ particles / 100 ml

For return line filter with $\beta_{10\mu m} = 300$ user can expect 19/.../... ISO cleanliness code (250.000 ÷ 500.000 range of particles number per 100 ml) . But for the off-line filtration with $\beta_{3\mu m} = 75$ probably value of ISO cleanliness code will be 21/.../... (1.000.000 ÷ 2.000.000 range of particles number per 100 ml).

It should be noted that in both filtration methods the cleanliness of hydraulic fluids is not met to ensure ISO class 18/16/13.

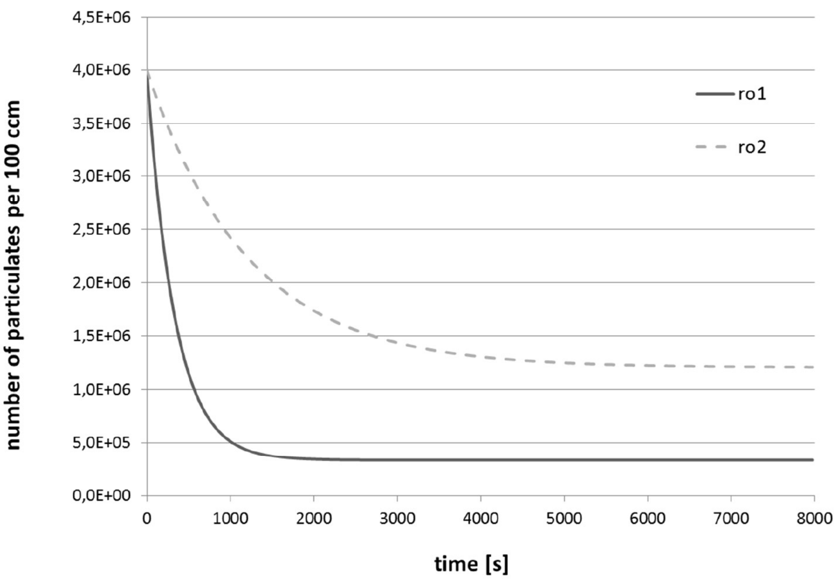

Fig. 3. The course of particulate concentration of pollutants of hydraulic systems from example 1

4. Conclusion

The considerations about the phenomenon of filtration in hydraulic systems were based on a model based on several simplifying assumptions, so that is possible get its analytical solution. A more adequate researches of filtration processes probably will require the adoption of numerical models and carrying out a series of experimental studies.

Thanks using analytical method was obtained proof of strongly relationship between filter flow rate and cleanliness of hydraulic fluid.

The calculation results indicate the importance of the knowledge of the particulates flux for proper design of filtration in a hydraulic system. Increasing the filter Beta Ratio does not bring significant changes of the cleanliness of the hydraulic medium. The results should not be interpreted as meaning that for hydraulic units are sufficient filters for higher particulate sizes "x".

The filters with acceptable Beta Ratio for particulates with high sizes ("x" above 10 microns) can't prevent hydraulic units from dust particles (with a size less than 4 microns), which can lead to accumulating of sediments into hydraulic elements.

A large amount of dust particles is causing the failures of valves and accelerated wear of cooperating parts. It also leads to accelerated degradation of the hydraulic fluid, and can promote the cavitation.

References

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