Statistical Analysis of the Pollution of a Hydraulic Oil Based on the Evolution of the Filter Clogging on the Pressure Pipe

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Abstract: *We present in this paper the results of an experimental study conducted on the analysis of the influence of clogging of a hydraulic filter, installed on the discharge pipe of a variable displacement pump, the operating pressure is 210 bar. The pump is used to supply hydraulic power to a finisher in the rolling mill at the iron and steel complex in Algeria. In this context, we tested the filter retention efficiency, whose mesh size of the filter element is 15 µm. The influence of the service time and consequently the number of pollutant particles retained per filter on the singular pressure loss ΔP of the filter were characterized. A statistical analysis conducted on the representative sample of ΔP values, followed by adjustment tests has been made. The statistical analysis carried out clearly shows that the evolution of the local pressure losses at the level of the filter follows a Beta law.*
Knowing such a distribution law of a variable is an advantage that will help to establish a predictive maintenance program, with the aim of acting in time, and this to remedy the failures, whose oil pollution is considered the main cause.

Keywords: *Hydraulic fluid, filter, pollution, pressure loss, statistical analysis*

1. Introduction

Hydraulics in general and industrial in particular is unavoidable in several areas such as the industrial sector. Indeed, it has a decisive place in the understanding, analysis and diagnostics of problems related to hydraulic systems. In addition, the control of these systems requires instrumentation that requires the designer and operator to a very advanced knowledge to carry out the hydraulic installations ensuring their operating safety.
The hydraulic fluid is considered the most important element for the proper functioning of a hydraulic mechanism. Hydraulic fluids used in high pressure systems are virtually incompressible, after the hydraulic system is primed with oil, it can instantly transmit power to all parts of the system. However, hydraulic fluids do not have the same properties, so do not have the same efficiency of energy transmission. The correct and proper choice of hydraulic oil depends on the application and operating conditions of the hydraulic system that the objective is to achieve better reliability.
According to studies already carried out, if one analyzes the failures occurring on the hydraulic installations, one notes that a large number of these come from the bad state of the hydraulic fluid, because the oil under pressure, circulating in the installation, loses its physicochemical characteristics [1] and carries all kinds of impurities that can be abrasive or non-abrasive. In any case, it is essential to eliminate them because they will cause breakdowns and abnormal wear of the components leading to leaks quickly. This is the role of filtration.
For the sake of efficiency of the filtration, it is then necessary to ask the question about the best possible location to install a filter as soon as all the other pollution prevention provisions have been taken (removal of pollution due to maintenance, transporting and filtering the air drawn in by the tank and any other external impurity).
For example, on the pump discharge pipe (high pressure), this filtration mode tends to become general but requires filter bodies and filter elements that can withstand the pressure of the circuit. These types of filters are often very expensive but the protection of the components against impurities is guaranteed.
The filtration efficiency is located on average around 10 µm and at times (3-4) µm if it concerns the protection of the servo-valves in particular.

Pressure filters are designed for direct mounting on pressure lines. They are generally mounted upstream of the control and adjustment devices of the hydraulic system. This filtration is effective:

- It protects the hydraulic components.
- Stops debris from pump wear.
- Acts as a safety filter in front of a sensitive component.

Generally, a hydraulic filter is characterized by its size, the mesh size of the filter element (x) in µm, [2] the retention rate (β_x) which is given by the formula (1) and the filter resistance or the permissible local pressure loss (ΔP_{adm}).

$$\beta_x = \frac{N_e(\geq x\ \mu m)}{N_s(\geq x\ \mu m)} \quad (1)$$

With

N_e: The number of particles before the filter of size ≥ x,

N_s: The number of particles after the filter of size ≥ x,

The singular pressure loss, located in a section of the pipe, is caused by a change of direction and intensity of the speed. The fluid flow has become locally (at the hydraulic component) a non-uniform or disturbed flow.

Such non-uniformity of speed can be caused by:

- a branch section of the pipe,
- a change of direction (elbow or distributor),
- a connection or connection (filter, valve),
- a measuring and control device (flow regulator, pressure limiter).

The flowing relation gives the singular pressure loss:

$$\Delta P = \xi \frac{V^2}{2g} \quad (2)$$

With

ξ: Coefficient that characterizes the resistance of the hydraulic component,

V: the flow velocity of the fluid,

g: the acceleration of gravity.

The pressure loss at the filter ΔP, is a kind of specific resistance related to the hydraulic component and its manufacturing technology, it characterizes the singular pressure loss at the filter, so it varies from one filter to one other [3]. It is also related to the quality of the oil passing through it, knowing that a large concentration of polluting solid particles circulating in the oil, which will subsequently be retained by the filter, affects the value of the local pressure loss. That is to say ΔP very sensitive to the increase in the number of solid particles retained [4]. The clogging phenomenon of the filters has become an issue for the maintenance of hydraulic installations. In this context, as we have already mentioned, the pollution of the oil in a hydraulic circuit is responsible for more than 70% of the failures of such a system. This phenomenon is the major concern of maintenance managers and technicians in general and that of precision hydraulic components in particular. As a result, researchers never stop running behind mathematical methods and models to implement it in order to establish a predictive maintenance plan to remedy the filter-clogging phenomenon, namely the evolution of the local pressure loss. To do this, considering ΔP as a variable in time, the knowledge of its law of its distribution is necessary for when can propose a powerful mathematical model describing the pollution process of the hydraulic oil used, it is the objective of this work

2. Methodology of work

The working methodology implemented for the realization of the present study, in order to carry out a statistical analysis on the pressure loss at the filter level is as follows:

The study concerns the monitoring of the evolution of the solid pollutant particles retained at the level of a filter, installed on the discharge line (pressure line) of a hydraulic pump with variable displacement, feeding the hydraulic circuit of the finishing machine located at the steel hot rolling complex in Algeria.

The operating pressure of the installation is 210 bar, the size of the particles to be removed to protect the valves and the rest of the hydraulic components installed is 15μm.
For that, we used an electronic particle counter of the CCS2 type, to allow us to count the polluting particles and to know the real purity class of the oil. It works according to the standards NAS-1638, ISO 4406-99 and ISO 4406-87. Counting is done online (the installation is running), once before the filter to be tested and a second after. On the ends of the filter is connected a differential pressure gauge for reading the pressure difference generated at the filter, the mesh size of the filter element are on average equal to 15 μm, the admissible resistance that the filter can bear is 2 bar. The Figure 1 gives the principle schema.

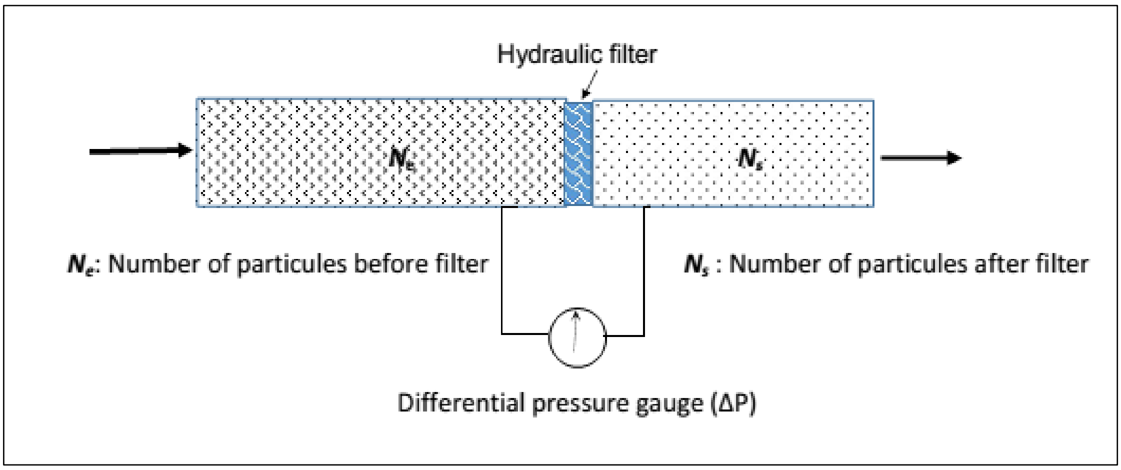

Fig. 1. The principle schema of experimentation

3. Results and discussion

According to the schematic diagram presented by the Figure 1, the measurement of the pressure loss ΔP, as well as the counting of the polluting particles upstream and downstream of the filter, and in order to be able to calculate the cumulative number of particles retained by the filter.
Experimental data are shown in the Table 1.

Table 1: The experimental data of locale pressure loss

No	Time ; (h)	Cumulative number of particules retained	ΔP ; (bar)	No	Time ; (h)	Cumulative number of particules retained	ΔP ; (bar)
1	0	2150	1.15	**16**	164	4480	1.70
2	12	2270	1.15	**17**	172	7125	1.76
3	24	2570	1.18	**18**	180	8200	1.65
4	36	2684	1.27	**19**	188	10588	1.75
5	48	2810	1.15	**20**	200	12780	1.88
6	56	2978	1.20	**21**	208	14025	2.10
7	64	3174	1.32	**22**	220	15848	2.20
8	72	3288	1.38	**23**	228	15900	2.25
9	80	3460	1.40	**24**	236	15820	2.00
10	92	3580	1.36	**25**	260	18700	1.98
11	100	3784	1.45	**26**	284	21800	2.00
12	112	3810	1.42	**27**	292	22540	1.98
13	120	4025	1.48	**28**	312	24400	2.18
14	132	4275	1.56	**29**	320	24670	2.24
15	140	3318	1.62	**30**	325	25460	2.20

3.1 Hypothesis

The assumptions considered for the preparation of the sample data are as follows:

- All the particles retained by the filter will remain stuck on the filter element during the whole analysis period.
- We do not consider the filter after a certain time as a source of pollution, that is to say, we neglect the measurements corresponding to values of (β_x) negative, which mean that the number of particles measured after the filter is greater than the one before the filter.

3.2 Analysis of the filter resistance evolution

The pressure loss ΔP at the filter varies with the service time, from the Figure 2, it is clear that ΔP increases with the increase thereof.

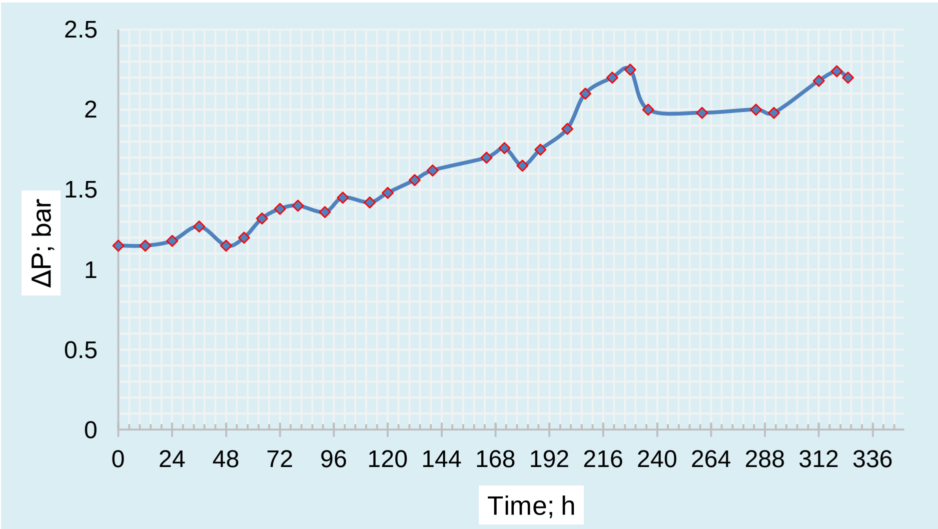

Fig. 2. The evolution of the pressure losses of filter

The only argument of this relation is the increase in the number of polluting particles circulating in the oil that have been stopped by the filter element, causing the reduction of its filtering surface. Therefore, according to the Figure 3, ΔP also increases with the increase of the retained particles number.

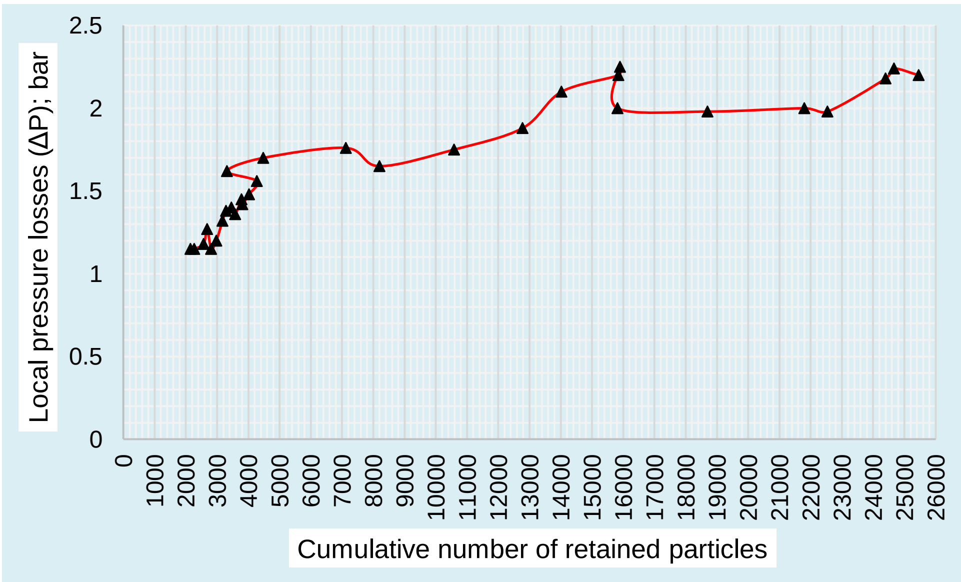

Fig. 3. The local pressure losses with the retained particles number

3.3 Statistical analysis of the pressure losses evolution

A statistical analysis of the representative sample of the ΔP values is considered very important, with the objective of carrying out future work on mathematical modeling and stochastic modeling in particular, in order to predict the evolution phenomenon of ΔP. In this context, MathWave statistical processing and analysis software (EasyFit 5.4) is used.
The density probability function f(x) and the cumulative distribution function F(x) adapted to the variation of the local pressure loss show that ΔP follows a Beta law, whose statistical parameters are: $\propto_1$= 5.2828,$\propto_2$= 5.9935, a= 1.25, b= 2.25, as shown in Figure 4 and Figure 5.
The probability density function:

$$f(x) = \frac{1}{B(\propto_1,\propto_2)} \frac{(x-a)^{\propto_1 - 1}\,(b-x)^{\propto_2 - 1}}{(b-a)^{\propto_1+\propto_2-1}} \tag{3}$$

Where
α1, α2 >0; Continuous shape parameters,
a, b; Continuous boundary parameters, (a<b).
$B(\propto_1,\propto_2)$ is the Beta function;

$$B(\propto_1,\propto_2) = \int_0^1 t^{\propto_1-1}\,(1-t)^{\propto_2-1}dt \tag{4}$$

The cumulative distribution function:

$$F(x) = I_z(\propto_1\,,\propto_2) \tag{5}$$

Where
$z \equiv \frac{x-a}{b-a}$,
I_z is the regularized incomplete Beta function, it is given by:

$$I_x(\propto_1,\propto_2) = \frac{B_x(\propto_1,\propto_2)}{\mathrm{B}(\propto_1,\propto_2)} \tag{6}$$

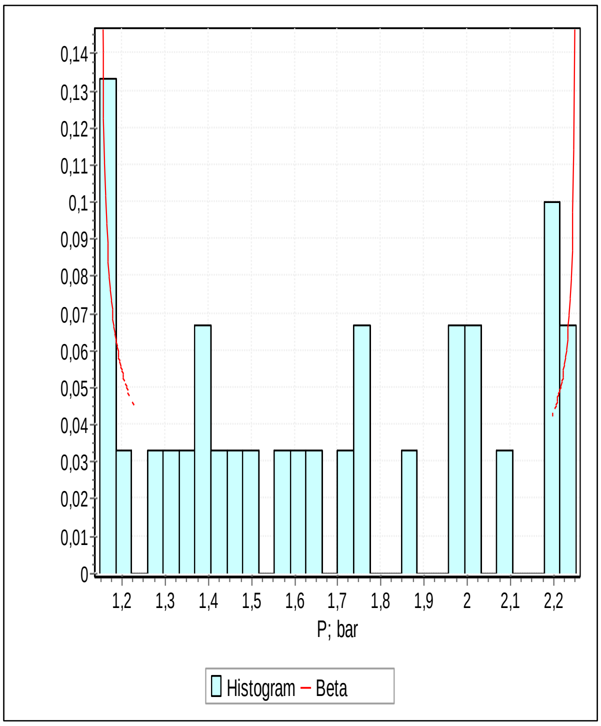

Fig. 4. The probability density function

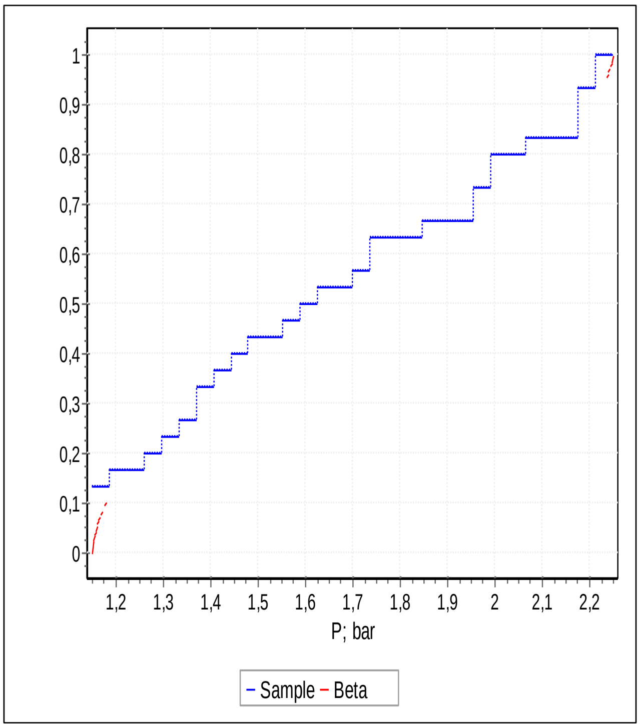

Fig. 5. The cumulative distribution function

The statistical tests of Kolmogorov-Smirnov [5] and Chi-Squared for risk levels of 10%, 5% and even 1% were performed on the ΔP sample, to ensure its adjustment to the Beta law are used. The Table 2 gives the tests results.

Table 2: The statistical test of sample

	The sample statistical test for a Beta law (α_1= 5.2828; α_2= 5.9935; a= 1.15; b= 2.25)					
	Kolmogorov-Smirnov test			**Chi-Squared test**		
Sample	Size = 30			Deg. of freedom = 4		
Statistic	0.1			1.0		
Probability value (P)	0.89608			0.9098		
a (Risk)	0.1	0.05	0.01	0.1	0.05	0.01
Critical value	0.2175	0.2417	0.2898	7.7794	9.4877	13.277
Reject?	NO	NO	NO	NO	NO	NO

It can be seen from the Table 2, that the statistical tests carried out are accepted for the three values of the degree of risk considered.

4. Conclusions

A first part of the present work has been dedicated to general notions on the importance of industrial hydraulics in general, and high-pressure installations in particular. The importance of the essential element in a hydraulic system namely the oil is described. The majority of anomalies disturbing the proper functioning of such a system are directly related to the degradation and contamination of the oil used.
The proper solution for oil contamination is to provide for the installation of filters. Therefore, the choice of location, type, size and even the quality of the filter is very important, in order to preserve the components of the installation, in order to improve the system performance by minimizing the number failures.
In a second part, an analysis of real data resulting from the operation of an industrial system (rolling mill), to describe the evolution of singular pressure losses, with respect to oil pollution was presented. In this context, the clogging of filter on the high-pressure pipe is analysed. The statistical analysis also took a part of our work, in order to rule on a distribution law describing the evolution of the pressure loss around the hydraulic filter, something interesting for the prediction of the possible breakdowns whose oil pollution will be the cause.

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