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PROGNOSTIC OF TRIBOLOGY PROCESSES IN HYDRAULIC EQUIPMENT

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Abstract: *The paper consider possibilities for performing of prognostic for tribology processes in hydraulic equipment. Oil contamination is the biggest threat to hydraulic system as solid particles in hydraulic oil. cause different serious problems. To extend lifespan of hydraulic equipment we used extrapolation procedure of prognostic process to assess remaining time to failure or risk of presence or occurrence of one or more failure modes in the future. This type of procedure can predict the next failure of technical system with significantly accuracy. Experimental tests were performed in laboratory conditions.*

Keywords: *tribology processes, hydraulic equipment, prognostic, extrapolation*

1. INTRODUCTION

When defining a strategy to maintain hydraulic systems we need to take into account their specific characteristics that dictate something modified approach in relation to other mechanical components and systems. Generally, for majority of of modern technical systems there is tendency to shift the focus of activities to the wider introduction of preventive maintenance activities and reduce the share of corrective maintenance. Hydraulic systems use preventive/proactive measures as an extremely important and there is a clear need and a lot of justification that they take dominant position within the defined maintenance strategy.

Introduction of a such approach in hydraulic system maintenance is significantly easier by the fact that the main cause of failure is recognized, clearly defined and described. That applies to all types and forms of contamination in the hydraulic systems that, in all conducted research and analysis, the cause of at least 70% of failures.

The term contamination in hydraulic systems include all processes that lead to temporary or permanent changes of exploitation characteristics of hydraulic oil (in terms of changes in its physical and chemical characteristics, and structural and functional degradation). The most significant contaminants of hydraulic systems are mechanical particles, water and products of oil degradation.

The biggest threat to the hydraulic system is the contamination by solid particles in hydraulic oil. They cause excessive abrasive wear, creating sheets on the surfaces of components, slow motion and could lead to stuck of moving parts. Solid particles can also have the effect of erosion on the valve command edges where disruption of command edge geometry resulted in decreasing of valves function efficiency [1].

Due to the multiple harmful effects on the system, the content of solid particles in the hydraulic oil should be restricted to a certain level. The level of contamination of hydraulic oil is defined by an appropriate standard [2].

2. PROGNOSTICS IN MAINTENANCE

Prognostics is a set of activities aimed at assessing the remaining time to failure for a particular technical system or risk of presence or occurrence of one or more failure modes in the future [3]. In this case, we will take the hydraulic system as a technical system.

Prognostics efficiency can be quite satisfactory for the failure modes that are relatively well-known and repeating time characteristics, followed by progressive degradation of key exploitation characteristics. In cases of failure modes with random and unexpected events, prognostics is a very difficult task with uncertain results.

Defining the Estimated Time To Failure - ETTF is done using the diagnostic parameters which are subject to condition monitoring of technical systems. Results of condition monitoring present a picture of the current condition and its monitoring over a longer period of time its possible to establish a database on condition history of technical system.

Prognostics output is to define the parameter values that determine the starting failure point or aggravation of exploitation characteristics of the system to the limit of its uselessness [3].

Compared to that maximum allowed value, we can define the set of limit values that represent landmarks and guidelines for all future maintenance actions. It’s been recommended to define three limits (three levels):

- level of compulsory stops,
- alarm level and
- warning level.

In addition, the level of compulsory stops and the alarm level are often encompassed in practice. Defining these values, or level increasing and decreasing, is done depending on a range of factors such as the characteristics and importance of technical systems, reliability, prognostics, production requirements, efficiency and organization of the maintenance function, the time for delivery of spare parts, etc.

Trend of changing certain failure parameters in the future can be predicted using extrapolation and projection procedures (figure 1).

Extrapolation represents curve adjustment (fitting) of specific failure parameter based on existing known parameter values (the current time and history of the technical system), also represents a relatively simple mathematical procedure.

Projection involves estimating of future parameter value and fitting a curve based on these estimated values. The projection includes mathematical modeling of the parameter behavior and defining the equations that will determine the speed and nature of the change of parameters in time for the defined exploitation conditions of the technical system and set limits for changes influencing factors.

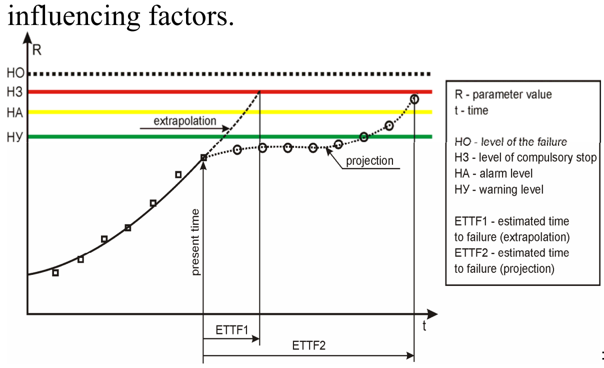

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Figure 1. Extrapolation and projection in prognostic [15]

Depending on the characteristics of a technical system, failure modes and its parameters, the difference between extrapolated and projected curve can be significant and therefore the difference in the values of the estimated time to failure (ETTF2 - ETTF1). If it is possible to perform projection or to define equations which describes behavior of diagnostic parameters in time, then results of projection is certainly more accurate than the extrapolation ones.

Prognostic can be implemented using one or more parameters of each individual failure modes. Multi-parameter analysis represents simultaneous data display of all parameters in a technical system. This concept has a very important role in prognostic because it enables the overview of mutual correlation and impact parameter and not their separate values.

The main problem with multi-parameter analysis is a way of presenting unified values of different parameters, considering that each parameter has a different unit of measurement and their numerical values can differ. It should also consider that in a number of parameters increasing trend shows deterioration (vibration, temperature, particles in the oil) but there are also those parameters in which zero value represents the failure (pressure or flow in hydraulic systems).

It is necessary to modify the presentation of parameter values where those are projected in the interval from 0 to 100% (regardless of the nature, value and unit of measure) during prognostic. In that case, 0 denotes the initial value of the parameter that corresponds to the new technical system while 100 is the value of the parameter that indicates failure condition.

The parameters that influence the rate of deterioration of failure modes or appearance of new modalities (e.g. load, speed, temperature...) are called influental factors. Each influential factor in general is a symptom of failure modes, but also has an impact on other existing modalities as well as a appearance of new modalities. The parameters that have the characteristics of influential factors must be considered separately, as they may lead to a situation where due to a failure modes with a relative low speed of deterioration occur one or more new failure modes, which have a significantly higher rate of deterioration and lead system to failure in a much shorter time interval.

Initialization of each failure modes should always go back to its cause, which represents a group of parameter values that are the subject of monitornig and defining initial point of the failure modalities, when using multi-parametric analysis techniques. Prognostic accuracy of initialization failure modes depends on whether the techniques used extrapolation or projection to define the trend of change in the value of related parameters in the future (figure 2).

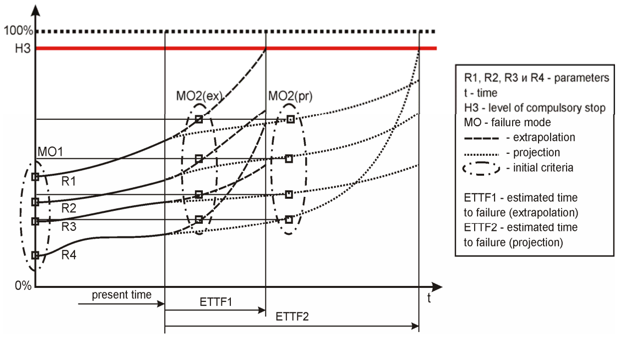

Figure 2. Prognostic of initialization failure modes [3]

The prognostic process involves the implementation of four main phases [4]:

- preparatory activities,
- prognostic of existing failure modes,
- prognostic of future failure modes and
- final activities.

2.1 Prognostic approaches and tools

In the literature, it can be find different proposals for defining the basic approach of prognostic process. Thus, for example in [6] citing [7] or in [4] identified prognostic approaches based on experience, the model or data. Review article [5] also defines three categories of access statistics, model and approach based on the application of artificial intelligence.

Proposed approaches has obvious match and overlap and use different names for, in principle, the same approaches so that the classification proposed in [8] is the most appropriate classification approach to prognostic of future conditions of a technical system:

- prognostic based on the model,
- prognostic based on the measurement results and
- combined approach.

One of modern engineering and mathematical tools that are widely used for prognostic are the different types of artificial neural networks, independently or in combination with using elements of fuzzy logic which are used primarily for prognostic based on the model.

Prognostic based on the measurement results includes the use of various mathematical tools for monitoring and predicting, such as for example, Kalman filter and its simplified version known as alpha-beta-gamma filter (α-β-γ tracking filter).

3. EXPERIMENTAL POSSIBILITY ANALYSIS OF CARRYING OUT THE PROGNOSTIC PROCEDURE

The objective was to simulate tribological processes in the laboratory conditions on the model of tribomechanical system with hydraulic oil. Collected data were used for analysis of possibilities of applying methods and tools for prognostic of condition and evaluate their effectiveness in conditions that simulate the real processes in hydraulic systems. In this sense, extrapolation was performed with polynomial curves of contamination of hydraulic oil at different operating regimes.

3.1 Extrapolation prognostic

Extrapolation curves of oil contamination, in particular case, means the following. Setting a suitable polynomial, based on the known values measured until specific period, we will be able to extrapolate the next value level of contamination. In addition, by placing a tangent to a certain number of points defined by a polynomial we can determine the variation in the rate of trend change, or whether the process is increasing, decreasing or constant. The obtained value of coefficient tangent direction at a point (K) has such a double diagnostic significance and value. Its positive value indicates an increasing trend, the negative decreasing trend while value close to zero indicates trend of constant value.

On the other hand, the coefficient of the tangent line in the final point of extrapolation polynomial multiplied by a time interval in which measurement is performed (cycles, hours, weeks, months) give the expected increase value of the parameter values of contamination in the future.

The next part is an example of the implementation extrapolation process of certain real measurement results of oil contamination in tribological experiments. The curves that are measured continuously (one measurement every 20 seconds) there are many points, and some tests were performed with a reduction in the number of points through which the polynomial is set (every fifth, tenth, twentieth point is taken).

The initial number of points to set the polynomial was three (it is practically possible to set polynomial with two points but the result usually has significant error). After each new measured point, there is redefinition of the polynomial, which practically runs through all points in history of system condition.

Principle of polynomial extrapolation is shown in figure 3.

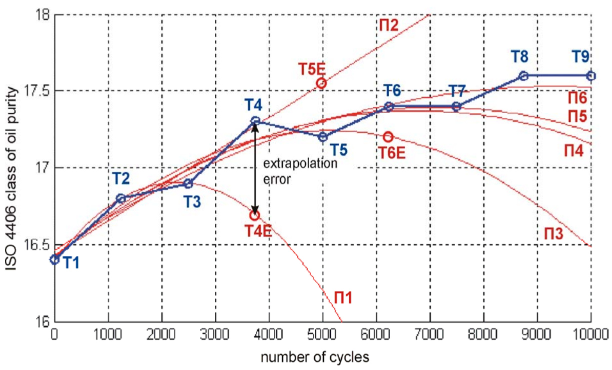

Figure 3. Extrapolation procedure

The first polynomial, P1 runs through the first three points (T1-T3). Based on the values of the polynomial parameters, we can calculate extrapolated value of the next point (T4E). When we measure the real value of that point (T4), it can be calculated extrapolation error in that point.

The procedure continues by running the new polynomial P2 through the points T1 - T4, determine new extrapolated values (T5E) and the new error estimation, and so on.

Example of polynomial extrapolation process for real data obtained by tribological experiment with monitoring of changes in oil contamination level is given on figure 4.

Error of extrapolation process is also calculated and given in separate diagram. It is obvious that for tribological process of continually increased contamination maximal error is less than 0.2 of ISO 4406 contamination code class, which should be examined as fully acceptable.

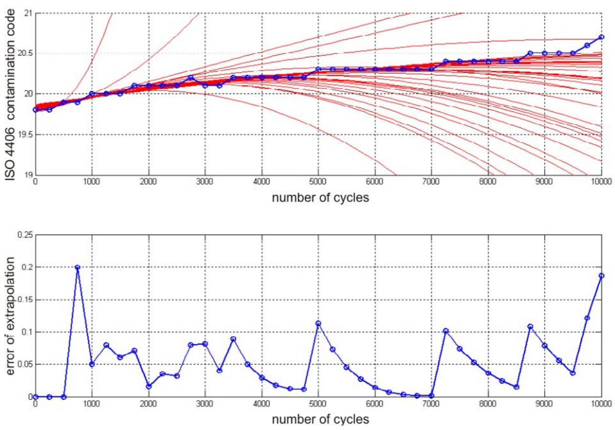

Figure 4. Example of extrapolation procedure

It is obvious that the accuracy of the extrapolation procedure depends on several factors. There are significant differences in the intensity of impact of these factors on extrapolation process as following:

- existence of sudden value jumps and sudden changes in trends,
- value deviations in measured signal,
- integration of the real trend with used extrapolation polynomial profile and
- the number of points through which the extrapolation is done.

4. CONCLUSION

Application of prognostic procedures for tribology processes in hydraulic systems in a term of proactive approach of maintenance has multiple benefits. In addition to the mentioned extension of the exploitation of technical systems, the use of prognostic could lead to reduction of possible level of production failures (breakdowns) and total maintenance cost.

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