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ON-LINE CONDITION MONITORING SYSTEMS FOR HYDRAULIC MACHINES

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Abstract. *Increasing investment costs demand for longer maintenance interval, higher system reliability, less downtime and breakdowns, and the desire to shorten mean-time between failures,…, is forcing machine manufacturers to incorporate condition-monitoring systems within their machine designs. This involves machines that operate around-the-clock, under difficult operating conditions away from professional maintenance staff, and is particularly important for machines with built-in hydraulic drive systems, requiring constant monitoring of equipment status, as well as hydraulic fluid*
This paper presents a short-overview of those modern on-line condition monitoring methods suitable for monitoring single hydraulic components, entire hydraulic drives, and the used hydraulic fluid. In the case of hydraulic fluid monitoring, special attention is paid to knowledge of fluids' physical and chemical properties and their changing mechanisms, particularly the fluid-ageing processes.

Key words: *Hydraulics Systems, Condition Monitoring, Fluid Monitoring*

1. INTRODUCTION

The increasing investment costs of machines, the demand for longer maintenance intervals and higher system reliability with less downtime and breakdowns, and the desire to shorten the mean-time between failures, is forcing the manufacturers of machines to incorporate condition-monitoring systems within their machine designs. This especially involves machines that operate around-the-clock, under difficult operating conditions and away from professional maintenance staff, and is very important for machines with built-in hydraulic drive systems, where constant monitoring of equipment status, as well as the hydraulic fluid, is required – Fig. 1.

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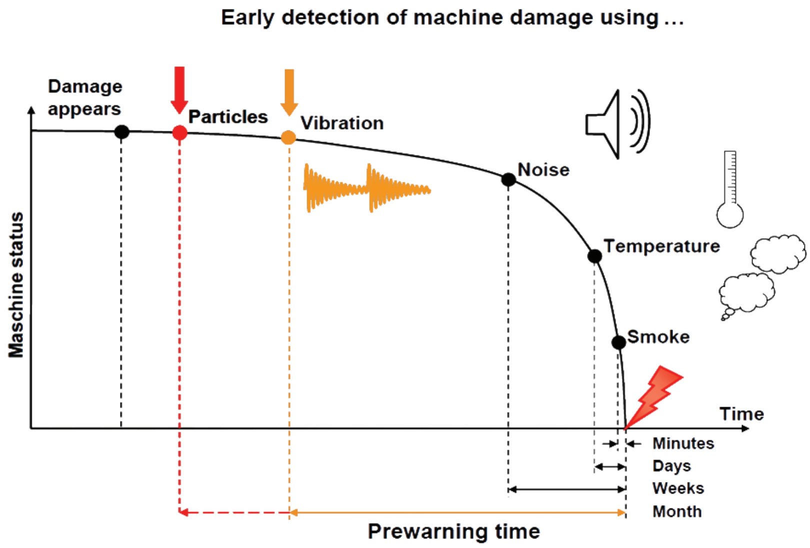

Fig. 1 Pre-warning times for different CM methods [1]

2. Monitoring of Components

Condition monitoring of hydraulic equipment, resp. components, can be arranged in two different groups: into simple measures for component monitoring - simple approach and into measures based on the advanced methods of signal acquisition and conditioning.

2.1 Simple approach for basic components

One of the simplest cases is represented by the continuous monitoring of filter elements within a hydraulic system. It can provide valuable clues to the performance of the filter and the condition of the system.

The warning of filter-bypass is typically afforded by visual or electrical clogging-indicators. These devices indicate when a pressure-drop (delta *p*) across the element is approaching the opening pressure of the bypass valve (where fitted). In the case of a return-filter, for example, if the bypass valve opens at a delta *p* of 3 bar, the clogging indicator will typically switch at 2 bar.

This method has been used for a long time and belongs to a signal-based approach. The example is displayed in Fig. 2. It shows a typical filter used in all hydraulic systems. As the filter gathers the dirt particles and drains them out of the fluid, they collect in the filter element and over time the pressure-drop across the filter increases. Within this time domain approach, a threshold needs to be set for the pressure-drop across the filter and once it is exceeded a failure signal can be generated for exchanging the filter element during the next machine maintenance.

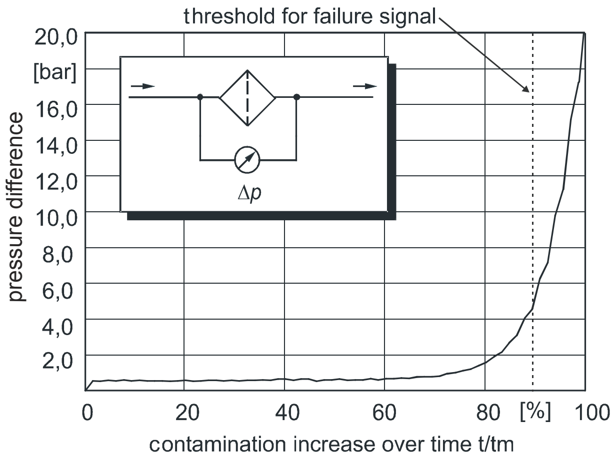

Fig. 2 Signal-based condition monitoring

Advanced filter-condition monitoring represents the replacement standard for clogging-indicators using differential pressure gauges or transducers, which enables continuous, condition-monitoring of the filter element. This permits the trending of fluid cleanliness against filter-element pressure-drop, which may be used for optimizing oil-sample and filter-change intervals. For example, the optimal change for a return-filter in a particular system could be higher or lower than the clogging indicator switching pressure of 2 bar.

It is a well-known fact that the pressure-drop across the filter is also oil-temperature dependent – at low temperatures the oil viscosity increases and, consequently, the pressure-drop. This can lead to a false signal and a missed warning. In order to avoid this, the use of an additional temperature sensor is reasonable.

Continuous monitoring of filter-pressure drop can also provide early warnings of component failures and element ruptures. For example, if delta p across a pressure filter suddenly increases from 1 to 3 bar (all other things equal), this could be an indication of a component's upstream imminent failure. Similarly, a sudden decrease in delta p could indicate a rupture within the element - something that a standard clogging-indicator will not warn of.

In both these mentioned cases, filter monitoring with additional sensors and the implementation of simple logic become more complex.

2.2 Advanced approach for complex systems

A more complex approach to condition-monitoring should be used in the cases of more-complex systems, for example hydraulic linear-drive. One possibility is represented by model-based condition diagnosis.

A model of the considered physical system should be built in order to achieve failure detection using this method. When using a detailed-model of the system, we are able to track any-back changes in the system's performance, down to a single parameter that can be directly interpreted by its physics. As an example, the structure of an electro-hydraulic linear-drive in the form of series-connected block models, which can be diagnosed individually or combined with the use of a model-based failure monitoring system, is shown in Fig. 3 (for more details see [3] and [4]).

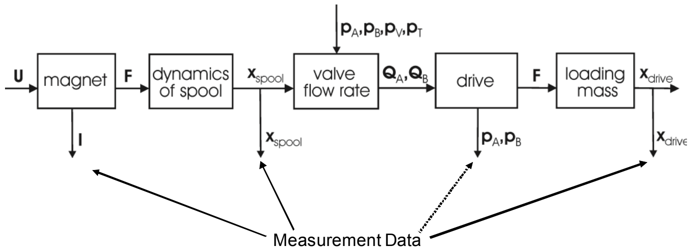

Fig. 3 Model-based approach of a hydraulic linear-drive [3]

The condition of a magnetic actuator and the spool dynamics of a digitally-controlled valve can be monitored using available signals such as voltage, current, and a displacement of the valve spool.

We can therefore use different possibilities for the failure diagnostics on a proportional solenoid. When using e.g. a model with distributed parameters [5], we can reconstruct the armature or spool position by the use of current and voltage signals using signal calculation. Due to the high computing power necessary, this needs to be calculated offline, at intervals of about five seconds.

An advantageous structure for the use of these diagnostic functions, is shown in Fig. 4. The measuring data needed for the control are made available on the used microcontroller. Decentralized diagnostic functions have access to the internal signals and are capable of exchanging additional information via field bus used [4].

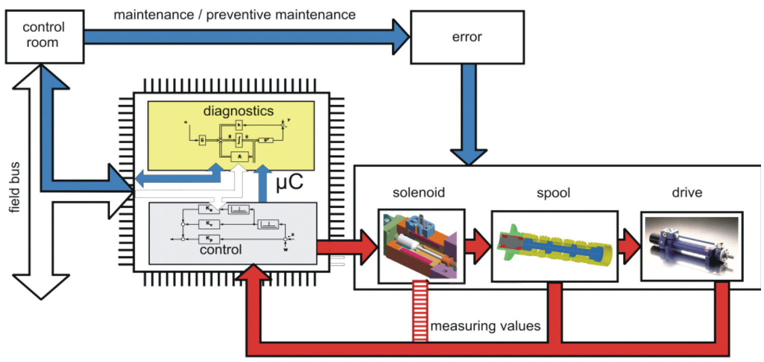

Fig. 4 Integration of control and condition-monitoring functions [4]

External inquiries about a component's condition are possible, whilst alternatively recognized safety risks can be signalled by the component itself. Depending on the used sensors and the component's size, different parts of the electro-hydraulic drive can be modelled and used for calculation of leakages or friction at the cylinder, as well as wear around the valve metering edges.

Condition Monitoring of Fluid

Whilst temperature, flow, pressure, displacement, and vibration sensors all have their part to play within the condition-monitoring of a simple component or complex drive, for early detection of changes in fluid and lubricant condition, other methods and sensor types should be used (see e.g. [6], [7], [8]).

Hydraulic-fluid contains a lot of information about itself and also about the lubricated machine parts and the contamination level. Quite a few years ago, oil analysis in laboratories established itself as the best-practice for verifying whether hydraulic systems are in good working-order. Laboratory analysis became a common feature of such systems, initially as robust field measurement devices in temporarily-installed measurement devices, and later in permanently-installed sensors for continuous oil-monitoring.

Over the years, different methods of hydraulic fluid condition-monitoring have been used: from a simple temperature or fluid colour-monitoring, to viscosity, moisture and particles contamination level measurement, through to more complex methods, e.g. measurement of qualitative and quantitative changes of oil-gas phase-composition during oil ageing [9].

Before looking for suitable sensors for the detection of changes within the fluid, any influences on the fluid deterioration process must be known – Fig. 5 [2], [3].

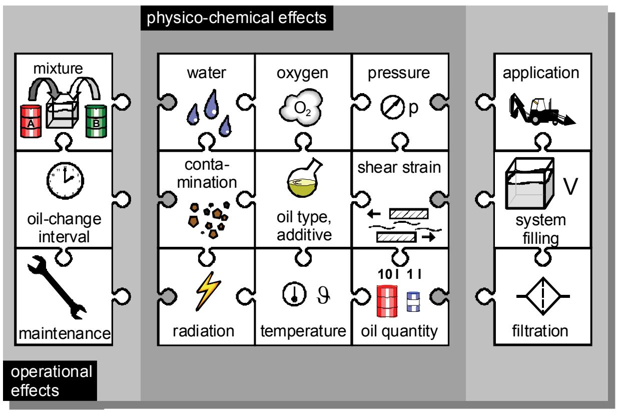

Fig. 5 Influences on the oil-deterioration process [2]

In contrast to discrete oil analysis by external laboratory or on-site methods, on-line condition monitoring (OCM) of the fluid allows continuous monitoring and condition-based machine maintenance, which can also detect unexpected machine failures. Such failures could be oil contamination by water, mixing with other fluids, usage of the wrong oil, etc.

Today, a variety of on-line sensors are available, which are important parts of laboratory analysis due to their sufficient precision. On-line sensors provide trend-analysis, and the laboratory procedure provides the detailed-information required to analyze the trend. Service and maintenance measures are implemented based on the measurement results.

The most important physical and chemical changes in hydraulic oil can be detected using robust and cost-effective on-line sensors, working on different principles as shown in Fig. 6.

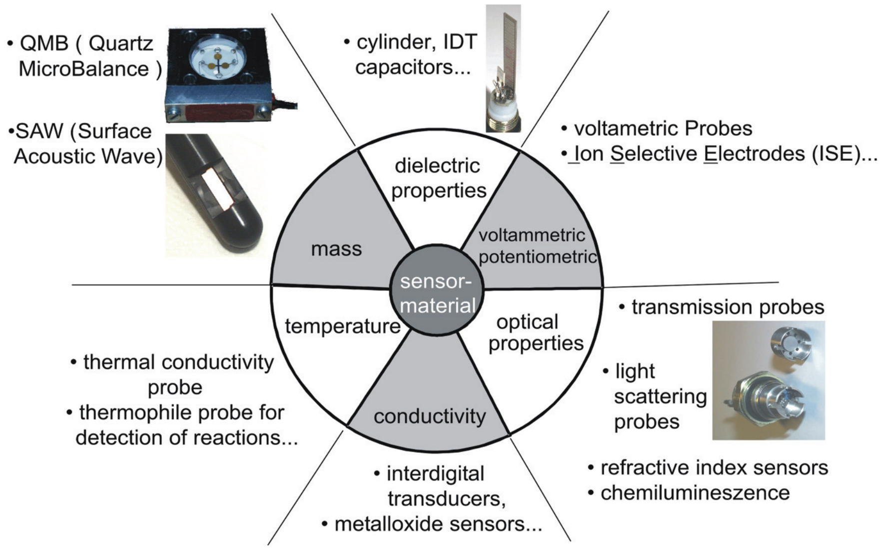

Fig. 6 Sensor principles [2]

In order to have the all more important information about fluid-condition for on-line condition-monitoring built into a machine, the following physic-chemical values should at least be measured:

- *Temperature* as one of the basic and most important physical quantities, which requires continuous monitoring.
- *Fluid cleanliness level*, or changing wear-rate, or wear patterns with on-line particle sensors (particle counters) or wear sensors helping you to make informed maintenance planning decision.
- *Viscosity* as a very important physical property of mineral hydraulic oils, which affects the lubrication-film and thus the friction and wear.
- *Relative humidity* - water is in practice one of the greatest threats to hydraulic and lubricating oils.
- *Relative permittivity* as a measure of fluid-polarity, which depends of the basic oil-type and additive packages. Polarity of the fluid is a quality factor through which oil-changes, oil-mixtures and refreshing can be detected.

Whilst temperature sensors play a basic role within a condition-monitoring sensor package, early detection of changes in oil and lubricant conditions, consistent monitoring of worn-metal debris, and insight into the actual conditions of vital machinery and equipment, need other sensor types. Many manufacturers have developed a range of innovative and practical on-line sensors for oil-condition detection and monitoring.

Fig. 7 shows some of the sensor on the market appropriate for OCM installed into an industrial fix mounted or portable OCM device.

Fig. 7 Different OCM sensors and units

The basis of latest research project is the development of a conventional on-line oil condition-monitoring (OCM) system. This system is based on several on-line sensors – see Fig. 7, connected to a local data acquisition system. Data collected from several monitored systems, are sent to the central-database and processing system, which was developed using LabView. Fig. 8 shows the user-interface panel of developed OCM system, together with real measurements results from industrial application of OCM.

Although the oil-condition data can be accessed at any time from anywhere, and although the measured parameters show some satisfactory trends regarding oil degradation over time, the application itself is universal, robust, user-friendly and a system that can be used by untrained personnel.

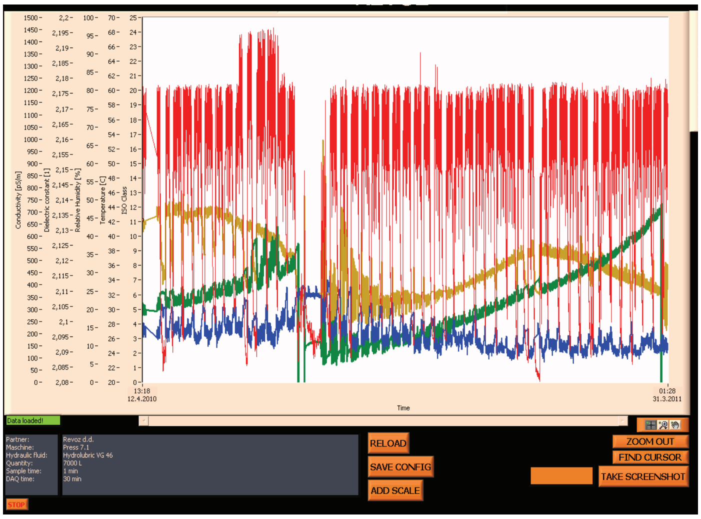

Fig. 8 Industrial application of developed on-line oil condition-monitoring system

Even though only a few parameters are shown in Fig. 8, we can clearly see that it is difficult to read and evaluate oil (and machine) condition from displayed charts.

These factors highlight the main weakness of conventional OCM systems:

- alarms can be triggered only within exact predefined limits,
- an expert is needed to extract full information from the measurements,
- there is no plain information on the hydraulic system's status, and the necessary actions to be taken.

In contrast to conventional OCM, a modern OCM system incorporates an automatic diagnosis-system or so-called expert system. Such an automatic diagnosis system allows for a more-detailed look at the measurements, looking for specific damage pattern, and considering operational conditions.

Ultimately, the maintenance manager is disinterested in diagrams or frequency plots. What is required here is a clear report on the hydraulic system's status combined with recommendation for action.

In addition, OCM also enables a better documentation of oil-changes, machine maintenance, and helps to minimize the total cost of ownership by extending maintenance periods and reducing the downtime of the machine.

4. Conclusion

This paper focused on benefits and importance of using condition-monitoring systems within modern production machines. By explaining two different approaches in the field of hydraulic-drives it provides a short insight into the use of different possibilities for on-line condition-monitoring methods. Special sensors are required and different sensor principles are discussed, for the monitoring of the fluid.

Real-time monitoring of the root cause of a single component, whole machine or lubricant failure, will allow you to take immediate action at the first indication of change. The use of appropriate on-line sensors and monitoring methods [10] definitely helps you to increase productivity, reduce costs, and improve profitability.

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SISTEMI ZA ON-LAJN NADGLEDANJE SISTEMA ZA HIDRAULIČNE MAŠINE

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Sve veći troškovi investiranja zahtevaju duže intervale održavanja, veću pouzdanost sistema, manje vremena za nefunkcionalnost i kvarove kao i potrebu da se skrati srednje vreme između otkaza. Sve to primorava proizvođače da u svoje projekte mašina uključe sisteme za nadzor sistema. Oni obuhvataju mašine koje rade non-stop, pod teškim radnim uslovima i daleko od profesionalnih službi održavanje, a od posebne su važnosti za mašine sa ugrađenim hidrauličnim pogonom koje zahtevaju stalno nadgledanje statusa opreme kao i hidrauličnog fluida.

Ovaj rad predstavlja kratak pregled metoda za savremeni on-lajn nadzor koje su pogodne za nadgledanje pojedinačnih hidrauličnih komponenti, čitave hidraulične pogone i korišćene hidraulične fluide. U slučaju nadzora hidrauličnih fluida, posebna pažnja se ukazuje poznavanju fizičkih i hemijskih svojstava fluida i njihovih promenljivih mehanizama, posebno procesa starenja fluida.

Ključne reči: *hidraulični sistemi, nadgledanje stanja, nadgledanje fluida*