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IMPLEMENTING CONDITION MONITORING SENSORS FOR ON-LINE LUBRICANT MONITORING

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ABSTRACT
Due to specific features, the on-line monitoring of lubricants is much more complex than the monitoring of single physical parameters, such as pressure or temperature. Several years of industrial experience has revealed, that there are several key factors that should be considered and taken into account while designing and implementing on-line oil condition monitoring system, in order to achieve adequate quality of results. Thus, the paper focuses on precautions and actions which should be considered while implementing on-line condition monitoring system for on-line lubricant monitoring in hydraulic systems.
Keywords: on-line condition monitoring, hydraulic oil, sensors

1. INTRODUCTION
Increasing availability of on-line sensors for oil condition monitoring in recent years has led to development and implementation of cost-effective on-line oil condition monitoring systems, which have many advantages over conventional monitoring methods and chemical analyses.

Table 1. Advantages and Disadvantages of different oil monitoring and analysis methods [1]

Method	Advantages	Disadvantages
External laboratory	• high precision devices produce trustable values according to national and international standards • detailed picture of the oil ageing process • data are evaluated by experienced engineers	• time between sampling and finishing the lab report • the detailed picture based on the combination of tests is a snapshot of the sampling moment • the evaluation engineer has no direct contact to the equipment
On-line monitoring	• a permanent measurement "24 hours, 7 days" can reliable detect random, time-discrete events • real-time detection possible • signals can be integrated into a internal or external warning system or into a maintenance solution • data can be directly processed using statistic and other mathematical methods	• sensor output often not correlates „1:1" with the well-known lab results • calibration sometimes complicated and often valid only for a special fluid type • experience for evaluation necessary or has to be included into the device • isolated interpretation of single values can lead to misunderstandings • a limited number of single tests cannot deliver a detailed picture of the complex oil ageing process • location of the sensor important

Thanks to constant monitoring of lubricants in real-time, the system can detect even sudden deteriorations of lubricants' conditions and trigger alarm notification, before catastrophic consequences might occur. Thus, fitting a modern on-line condition monitoring system provides the user with the highest level of operational reliability and allows him/her to reduce machines' down-times and extend lubricant maintenance intervals.

As already mentioned, the greatest advantage of on-line oil condition monitoring systems over conventional laboratory analyses, is their continuous measuring and reliable detection of sudden and unforeseeable events, when the fault can be detected, so to speak, in real-time. Another advantage is the trend recording, considering the data from on-line sensors are usually acquired by automated systems that can store the history of the measurement results.

On the other hand, on-line monitoring of oil has its own limitations. The most significant of them is the limited number of sensors and parameters that can be monitored. Also the parameters, measured by on-line sensors, tend to differ from the parameters, that are determined by laboratory analysis. Thus, a direct comparison between them is impossible. Last but not least, calibration of the sensors is complicated and often valid for only one fluid type.

2. DETERMINE THE MOST APPROPRIATE SENSORS FOR YOUR SYSTEM

Most common parameters, measured by today's on-line monitoring systems for lubricants, are: temperature, relative humidity, viscosity, dielectric constant, electrical conductivity and lubricant cleanliness class.

Above parameters and their measurement with on-line sensors have already been presented in detail in various literature [2-4]. The sensors can be divided into two main groups: sensors that detect the physical-chemical properties of the lubricant and sensors that measure the cleanliness class of the lubricant – particle counters.

While selecting the most appropriate set of sensors for a given system, the user should take into account several factors to determine the optimal choice: the sensor accuracy, repeatability, availability, cost, and last but not least, the product support.

3. DETERMINE THE BEST LOCATION FOR THE SENSOR SYSTEM

After selecting the optimal set of sensors, a special attention should be paid to the installation and locations of the sensors, as the sensors' locations alone (the locations where the lubricants are measured) can have significant influences on the measurements' results.

3.1. Mounting sensor system in a hydraulic tank

When it comes to the mounting locations of the sensors, the biggest difference between sensors of physical-chemical properties of oil and particle counters is that the particle counters need a certain oil flow through the sensor element that usually stands between 30 and 300 ml/min. Therefore, particle counters cannot be used when sensor system is mounted in the tank because the sensors are only immersed in the oil. In such cases it is recommended that the sensors are installed near the pump intake lines. The oil flow in this region of the tank is usually the calmest and more stable with the least amount of contaminants (e.g. air, soiled-contaminants), that might distort the measurements' results [5].

If cases when the system includes particle counter, it is necessary to obtain oil flow through the sensor system, for which there are three main options, as presented hereafter.

3.2. Mounting sensor system on main return line

Mounting the sensor system on the main hydraulic return line seems more adequate, as the oil is being measured before the filter element. This oil has just passed the whole hydraulic system and contains the most contaminants and, thus, information about the condition of the hydraulic system. This method of mounting usually takes the advantage of pressure difference on the filter element (2 – 5 bar), which is used to power the fluid flow through the sensor system. If a particle counter is being used, this small pressure difference just nearly satisfies the flow needs of a counter. Moreover, this flow is low-pressurised and is also variable, as it depends on the fluid's viscosity and temperature. As our tests have revealed, that the accuracies of on-line particle counters are much better at higher flows and pressures, we do not recommend the installations of a particle counter in such way.

3.3. Mounting sensor system on main pressurised line

When mounting a sensor system on the main hydraulic pressurised line, an additional flow valve is needed, which regulates the oil flow rate through the sensor system, regardless of oil pressure, viscosity, and temperature. The particle counter is usually installed at the front of the valve, so that oil flowing through the counter is under high pressure, which also compresses any air bubbles (if present) and thus improves the accuracy and stability of the oil cleanliness class measurement. Since the sensors for physical-chemical properties of oil must not be exposed to high pressures, they are placed after the valve, where only low pressure is present (on return line to the tank).

3.4. Mounting sensor system on bypass line

By using an additional small pump, which powers the fluid through the sensor system, a bypass hydraulic system can be designed for on-line oil condition monitoring. Although such a design is the more expensive one, it provides the best and most constant flow conditions for on-line sensors, which is especially important when an on-line particle counter is being used.

Suction and return line locations within the hydraulic tank must be placed carefully when designing a condition monitoring bypass system. Pumping and measuring oil from "dead-zones" of a hydraulic tank (where fluid does not circulate) could lead to substantial errors during condition monitoring [5].

4. CALIBRATE EACH SENSOR WITH EACH SPECIFIC (BATCH OF) OIL

In order to obtain high quality results with on-line oil condition monitoring system, knowing well the flow conditions in the system is insufficient. It is also crucial to understand the operating principles of the on-line sensors and to additionally calibrate them to each specific oil, or even each specific batch of oil.

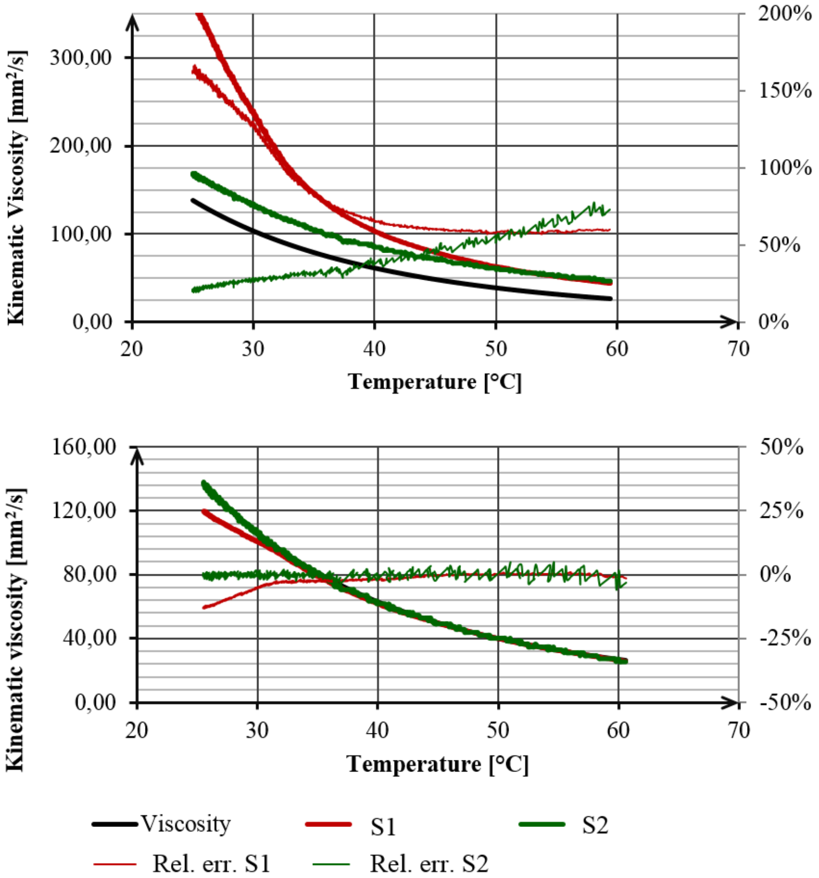

Figure 1. On-line viscosity measurements vs. actual viscosity
above: raw sensors readings; below: after the implementation of calibration curve.

Here we will present an example on on-line viscosity measurement, since the viscosity of oil is one of its more important properties that must be constantly monitored. The accuracies of two on-line viscosity sensors were tested on mineral hydraulic oil ISO VG 46 within a temperature range from 30 to 80 °C, as shown on

Figure 1 (above), where the black line represents the "actual viscosity" of the oil (determined in a chemical laboratory), while the bold red and green lines represent the viscosity measurements' results from two on-line sensors.

The results show a strong deviation of on-line measured viscosity compared to the actual kinematic viscosity. The measuring errors of the on-line viscosity sensors are also presented in the form of relative errors (thinner lines), which reached up to 70 % for both sensors S1 and S2. The presented inaccuracies are definitely too large and monitoring with such sensors would only be a waste of time and money. We assume that such deviations occur because the sensors are factory calibrated only by a certain type of fluid. Nevertheless, the accuracy can be greatly improved if a particular sensor is additionally calibrated to a specific type of oil, or even better, a batch of oil.

In comparison to chart above in Figure 1, the chart below shows the on-line viscosity measurement results after the sensors had been additionally calibrated. It can be clearly seen from the figure, that calibration of a specific sensor to a specific oil batch significantly improves the accuracies of on-line viscosity measurements.

In addition to the implementation of a dedicated calibration curve, valid only for a specific oil and sensor combination, the viscosity trend can only be monitored if the kinematic viscosity at the operating temperature (which is measured) is calculated to the viscosity at 40 °C. Thus, knowing the viscosity-temperature behaviour of our oil is essential to be able to develop special software, which will trend the viscosity change over a longer period of time, despite the temperature fluctuations within the hydraulic system.

5. DATA ACQUISITION AND USER-INTERFACE

In addition to these installation procedures and additional measures for improving the qualities of the measurements, it is also essential to establish an adequate system to record and display the results, which, from our point of view, should have the following features:

- allow implementation of special functions, e.g. calibration curves, temperature compensation,…
- display of multiple parameters on a single time-chart, since the user should observe several quantities at the same time, e.g. temperature and relative humidity,
- trigger and send an alarm when limits are exceeded;
- user-friendly interface that can be access almost from everywhere (PCs, laptops, mobiles, tablets,…) without any additional software needed.

6. CONCLUSION

The use of on-line oil condition sensors together with appropriate knowledge of physicochemical changes in oil allows user to have constant overview of the oil quality and its properties. This information can sometimes be crucial to prevent damage and ensure reliable operation of the system. Presented on-line monitoring systems for lubricants offer us the highest level of protection for our systems since the lubricant and the system are monitored constantly – 24 hours a day.

7. REFERENCES

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