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An Advanced Multi-Parameter Condition Monitoring System for Lubricants and Hydraulic Fluids

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Summary

A compact measurement unit for fluid monitoring based on simultaneous measurement of viscosity and density is introduced. It will be shown that measuring fluid parameters over varying fluid temperature provides additional monitoring parameters and enhances data consistency. Suitable temperature models are demonstrated. Measurement results are discussed, which show the potential of this approach and the applicability of the measurement system in an industrial environment.

Keywords: viscosity, density, tuning fork, oil sensor

Introduction

In order to reduce maintenance costs as well as the risk of unplanned downtimes, industry gradually adopts online condition monitoring (OCM) methods combined with predictive or proactive maintenance approaches. Enabled by the increasing level of automation, plenty of data can be made available to maintenance personnel and condition monitoring algorithms, and sophisticated evaluation methods can be implemented to assist in planning of maintenance actions. With the implementation of such data based decision methods, the reliability and precision of the collected data obviously has significant impact on the effectiveness of the maintenance actions triggered. Furthermore, the sooner a problem can be identified, the easier and cheaper the appropriate maintenance action will be. So in many cases, the benefit of a sensor increases over proportionately with its accuracy and long term stability.

In this contribution, we present an innovative method to increase data reliability, as implemented in a novel fully automated online condition monitoring system for hydraulic fluids and lubricating oils. The device continuously monitors the viscosity, mass density, and several other relevant parameters of the fluid. With the integrated active temperature control, measurement data can be acquired at any desired reference temperature and thus are independent of the operating conditions of the machine. By cyclic variation of the temperature, additional information is provided and used for validating the consistency of the data.

Fig. 1. Condition monitoring system for industrial use.

Monitoring System

Fig. 1 shows the compact OCM system. The temperature controlled measurement cell within the system, houses the vibrating quartz tuning fork sensor (QTF), a Pt100 temperature sensor and a capacitive relative humidity sensor as shown in Fig. 2. From the fluid induced resonance changes of the QTF, the viscosity and density of the fluid are determined [1,2]. As viscosity shows significant temperature dependence, it needs to be measured at well-defined temperatures. Therefore, a precise thermoelectric temperature controller is implemented which can be used to cycle temperature and to determine additional characteristic fluid parameters. These comprise the temperature coefficient of the density and various viscosity-temperature indices such as the VTC, the VI or the m-value [3]. Although not discussed in this publication, the system also provides the electrical fluid parameters [4] and the relative humidity, which, if measured over temperature, yields a true multi-parameter characterization of the fluid under test.

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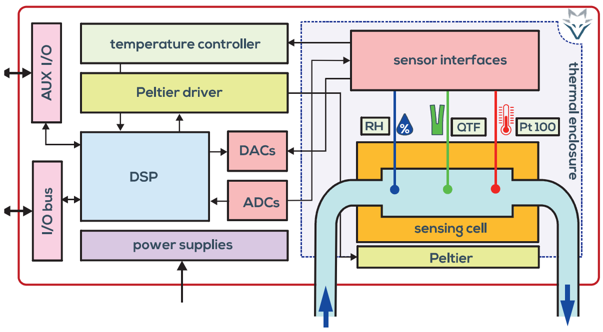

Fig. 2. Components of the OCM system.

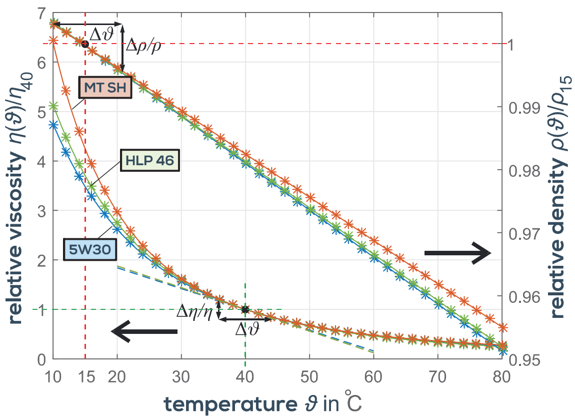

Fig. 3. Measured viscosities and densities (*) and the models in (1) and (3) using the fitting parameters in Tab. 1.

Results

A common model for describing temperature dependence, is the Vogel-Cameron model (VCM) [3] which we use in an adapted form (1) such that the model parameter η_{40} represents the viscosity at the usual reference temperature for viscosity of ϑ_0=40 °C. Parameters A and B are the slope of the normalized viscosity curve (see Fig. 3), and the original temperature offset variable of the VCM, respectively.

$$\eta(\vartheta) = \eta_{40} e^{A\frac{(\vartheta-40°C)(40°C+B)}{B+\vartheta}} \quad (1)$$

$$\Delta\eta/\eta\big|_{\vartheta=40°C} = A\Delta\vartheta\big|_{\vartheta=40°C} \quad (2)$$

$$\rho(\vartheta) = \rho_{15}\cdot\left(1+C\cdot(\vartheta-15°C)\right) \quad (3)$$

The viscosity vs. temperature curves for two oils (5W30 and HLP 46) and the heat transfer fluid Marlotherm SH (MT SH) are shown in Fig. 3. The curves differ apparently, but the slope parameter A is very similar for all fluids (see Tab.1). However, the B parameter, characteristically around 110 °C for oils, is only 63 °C for MT SH. Standardized viscosity-temperature parameters such as VTC or VI-Index [2] are based on kinematic viscosity $v=\eta/\rho$, and therefore the density (ρ) measurements provided by the instrument can be used to calculate these values, as well. The density changes in Fig. 3 are linear over temperature and therefore the model in (3) can be applied. The temperature coefficient C is therefore independent of the reference temperature, (usually 15 °C for density) and given in Tab. 1. The average fitting errors between model and data are approx. 0.2% for viscosity and 0.01% for density, which underscores the applicability of the models.

Fluid	η_{40} mPas	ρ_{15} g/cm³	-A %/K	B K	-C 10^{-3}/K
5W30	56.67	0.85	4.20	117.16	0.728
HLP46	36.12	0.86	4.38	112.18	0.718
MT SH	16.98	1.05	4.39	63.15	0.671

Tab.1. Fitting parameters for the three fluids.

The parameters of the model were defined such, that they represent physical quantities and are therefore easier to relate to certain oil alterations. Due to the demonstrated low fitting errors, it can be assumed that abnormal sensor function can be detected, if fitting accuracy is impaired, or sudden changes of the parameters occur.

Conclusions

A novel measurement system for simultaneous measuring of viscosity and density over temperature was introduced. The suitability of temperature models which require only a minimum of parameters was verified.

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References

[1] A.O. Niedermayer, T. Voglhuber-Brunnmaier, M. Heinisch, B. Jakoby, Accurate Determination of Viscosity and Mass Density of Fluids using a Piezoelectric Tuning Fork Resonant Sensor, Proceedings SENSOR 66-71. (2015), doi: 10.5162/sensor2015/A2.4

[2] T. Voglhuber-Brunnmaier, A.O. Niedermayer, F. Feichtinger, B. Jakoby, (2019). Fluid sensing using quartz tuning forks—Measurement technology and applications. *Sensors*, *19*(10), 2336.

[3] Mang, T., & Dresel, W. (Eds.). (2007). *Lubricants and lubrication*. John Wiley & Sons.

[4] Voglhuber-Brunnmaier, T., Niedermayer, A. O., Feichtinger, F., Reichel, E. K., & Jakoby, B. A multi-parameter physical fluid sensor system for industrial and automotive applications. *tm-Technisches Messen*.