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Investigation of the suitability of MEMS-FPI-based NIR spectral detectors for the analysis of cooling lubricants

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Summary: This paper presents a new approach to monitoring and analyzing cooling lubricants. For this purpose, a compact MEMS-FPI-based NIR sensor is used, which can be integrated online into a process and should enable conclusions to be drawn about the condition and various parameters of the cooling lubricant. Experimental investigations of different cooling lubricants of the NIR sensor are presented. The properties of the cooling lubricants differed not only in terms of type but also in terms of concentration and pH value. In addition, the analysis methods used are presented and evaluated in the context of parameter detection of cooling lubricants.

Keywords: NIR spectroscopy, MEMS sensors, cooling lubricant analysis, process technology, chemometrics

Introduction

In many metalworking production processes, cooling lubricants are a decisive factor that is essential for a high level of performance during machining. In addition to the main tasks of cooling and lubrication, they also ensure the continuous removal of metal chips and abrasion as well as corrosion protection, that protects the workpiece as well as tools and machines.

The components and composition of cooling lubricants vary depending on the type and area of application: In addition to a base oil (often mineral oil) and water in the case of water-miscible coolants, various additives are integral components to prevent corrosion and the formation of fungi, bacteria and foam, among other things.

In addition to a growing interest in sustainable management, increasing occupational health and safety requirements as well as a significant cost factor are decisive factors for an increasing interest in improving the service life and quality of cooling lubricants. In small individual systems, monitoring and maintenance is usually carried out by trained personnel at regular intervals.

In this article, we present a new approach to analyzing cooling lubricants. A compact NIR process spectrometer based on MEMS-FPI (Fabry-Pérot interferometer) sensor technology is used here, the aim of which is to analyze inline cooling lubricant parameters. The publication focuses on the analysis results obtained to determine various cooling lubricant parameters (including type, concentration, pH value) using chemometric and machine learning methods.

Experimental Setup

In order to be able to analyze the properties of cooling lubricants, various cooling lubricant samples were measured and examined using NIR spectroscopy. The focus here was on water-miscible cooling lubricants, as these are the most commonly used, accounting for over 90 %. The NIR spectral data was recorded using a MEMS-FPI spectral sensor, which covers a wide wavelength range by integrating several complementary narrowband detectors [1]. The application of the measurement principle of (diffuse) reflection according to Figure 1 also enables the measurement of cloudy and opaque cooling lubricants.

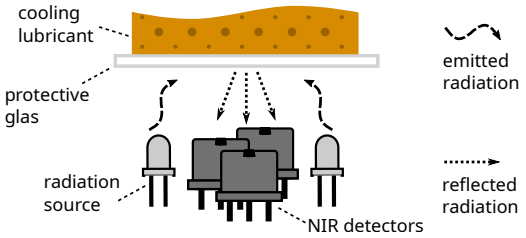

Fig. 1: Experimental setup for NIR spectroscopic investigation of cooling lubricants.

A total of around 500 samples were measured and different parameters of the cooling lubricant were systematically varied. In addition to different types of cooling lubricant, the concentrations and their pH values were also measured; crucial properties that allow conclusions to be drawn about the performance and condition of the cooling lubricant. The parameters of interest were recorded by corresponding reference measuring devices.

Analysis Methods and Results

The measured NIR spectra were pre-processed in a first step. In addition to smoothing using a Savitzky-Golay filter, a correction and normalization were carried out. A principal component analysis (PCA) was then applied to increase the information content of the measurement data

and to reduce redundant data to the relevant information content. A Support vector machine (SVM) was used to classify the different types of cooling lubricant. This was based on findings from [2]. Figure 2 shows the classification results plotted over the principal components. The left graph shows the explained variance with increasing number of principal components. The right graph shows the average accuracy of the classification of the cooling lubricant type.

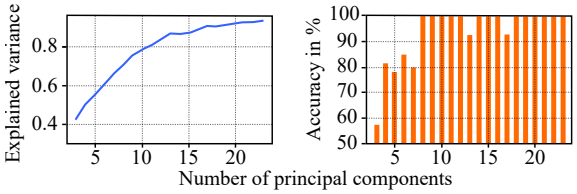

Fig. 2: Determining the type of cooling lubricant by using an SVM with different principal components.

The results were cross-validated and are independent of the concentration of the cooling lubricant used. A reliable statement about the type of cooling lubricant is already possible with a small number of principal components (almost 10).

In addition to the type of cooling lubricant, the concentration of the cooling lubricant was also analyzed and determined. For this purpose, corresponding samples were measured that differed in terms of this parameter. The applied linear regression methods were developed separately for the different types of cooling lubricant. To assess the quality of the regression, the coefficient of determination R^2 was used, which standardizes the difference between the prediction and the true value. Figure 3 shows the course of the coefficient of determination plotted against the number of main components used for two different cooling lubricants.

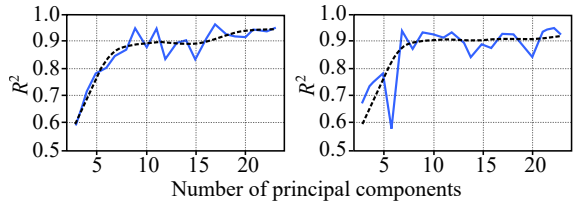

Fig. 3: Determination of the concentration of two cooling lubricants using linear regression with different number of principal components.

As was to be expected, the accuracy of the regression model increases as the number of main components used rises. However, the gain in quality per additional feature decreases sharply from around 8 features and the risk of overfitting increases. It should be noted that the results shown in Figure 3 are predictions in a large variation range of the concentration. In the typical application range of about 5 - 12 %, the predictions could be improved to a value of approx. R^2 = 0.95.

Finally, the pH value of the cooling lubricants was to be determined, which is a frequently considered parameter for assessing the condition of the cooling lubricant. Measurements were carried out at a constant concentration of 5 % in a pH value range of approximately 4 to 10 and then analyzed. The best results were achieved with a partical least square regression (PLSR). Figure 4 shows the measured over predicted test values of the optimized prediction model. The algorithm used achieves an R^2 of 0.92 with a root mean square error (RMSE) of 0.28.

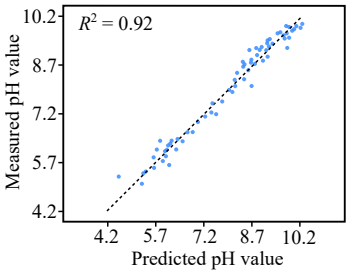

Fig. 4: Regression of the ph value of a cooling lubricant at a constant concentration used PLSR.

Conclusion

In this work, the analysis of cooling lubricants using MEMS-FPI-based NIR sensors was presented. For this purpose, cooling lubricant samples were systematically measured by NIR spectroscopy and different parameters such as type, concentration and pH value were varied. The spectra were then pre-processed and analyzed. The results obtained were used to prove that the MEMS-FPI NIR sensors used are suitable for determining the parameters of cooling lubricants in conjunction with appropriate analysis methods.

The knowledge gained here serves as a basis for determining other relevant parameters such as nitrite content or tramp oil and to develop a multifunctional, integrable cooling lubricant analysis sensor.

Acknowledgment

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