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POSSIBILITIES OF PROCESSING THE TRIBODIAGNOSTIC DATA

Marie Sejkorová[1]

Summary: As it is difficult to monitor and evaluate the state of operated oil effectively based on individual determinations of many of its tribodiagnostic parameters (TDP), a possibility of processing the procedure of selected methods of multidimensional statistical analysis – principal component analysis (PCA) on the matrix of tribodiagnostic data of worn-out OA-M6 ADS II engine oil and discriminant analysis (DA) – was tried.

Key words: tribotechnicals diagnostics, tribodiagnostic data, principal component analysis, discriminant analysis. chemometrics.

INTRODUCTION

One of the most efficient methods of monitoring the technical state of each component are non-dismantling tribotechnical diagnostics (TTD) which, among others, deals with evaluating the changes of selected qualitative parameters of the lubricating medium that occur as the oil is ageing during its operation.

The TTD methods allow to achieve an extensive data set by continuous monitoring of the status of lubricating oils. For processing the multidimensional data in technical practice, knowledge of natural sciences, mathematical statistics and computer science combined with powerful computer support is used (1). The science discipline that applies the mathematic-statistical methods to the results of chemical measuring for the purpose of extracting as much relevant information as possible from the chemical data is called chemometrics.

There are three different chemometric approaches (2):

1. Basic exploratory data analysis used to evaluate objects or variables. The most widely used method is the principal component analysis (PCA).
2. Classification of objects into one of two or more groups based on the similarity of their variables. Multivariation classification methods include e.g. discriminant analysis (DA), analysis of clusters (CLU), classification of k-nearest neighbor (CNN) and so on.
3. Multivariation calibration models, i.e. mathematical models that allow predicting $\boldsymbol{y}$ values based on the knowledge of $\boldsymbol{x}$ values. Commonly used methods of multiple regression include partial least squares method (PLS), principal component regression (PCR) and classical least squares method (CLS).

[1] Ing. Marie Sejkorová, Ph.D., University of Pardubice, Jan Perner Transport Faculty, Department of Transport Means and Diagnostics, Studentská 95, 532 10 Pardubice, Czech Republic, Tel.: +4206036696, E-mail: marie.sejkorova@upce.cz

The methods of multidimensional statistical analysis (factor analysis, discriminant and classification analysis, regression analysis) were used (3) e.g. to propose an algorithm to determine an appropriate moment for changing the engine oil based on the evaluation of the degree of its degradation. Authors (3) proposed an algorithm that can be used as an effective tool for predictive strategy of maintenance of the vehicle fleet. Discriminant analysis was also used for modeling the degradation processes taking place in mechanical systems (4, 5) and for constructing the prediction model for classifying worn-out engine oils (6).

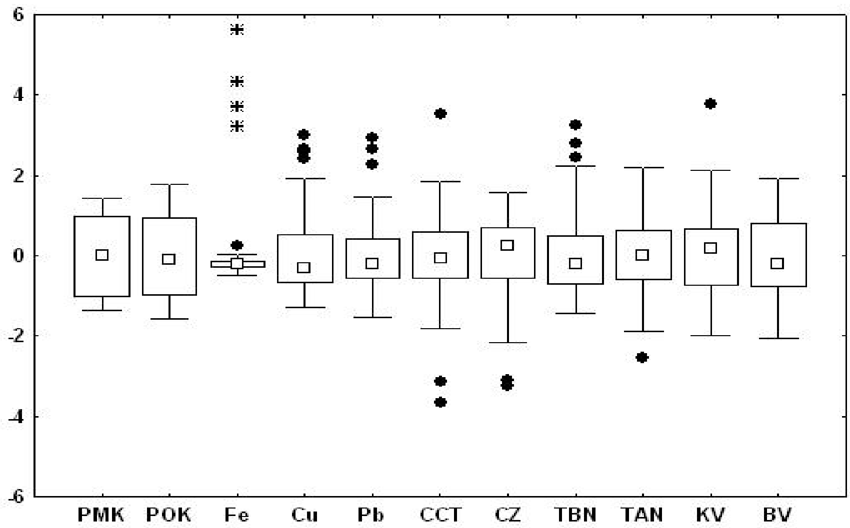
1. USE OF MULTIDIMENSIONAL STATISTICAL METHODS FOR PROCESSING THE TRIBODIAGNOSTIC DATA

As the continuous monitoring of tribodiagnostic data allows for obtaining a data matrix that is often rendered as not well-arranged enough for practical use, they were processed and verified procedures using methods of multivariate statistical analysis on a matrix of concrete data and were interpreted the results that can be achieved by using these procedures.

Overall evaluations of possibilities of using these proposed and experimentally proven procedures of applying the mathematic-statistical methods in tribotechnical diagnostics as well as discussions of results are listed in the text below.

1.1 Application of the Principal Component Analysis on the Matrix of Tribodiagnostic Data

By using the mathematic-statistical multidimensional methods, relations and connections among monitored tribodiagnostic parameters of worn-out engine oils and among the OA-M6 ADS II oils samples taken from Tatra 815 trucks with T3-93 series engines. Details are presented in the publication (7).



Source: Author

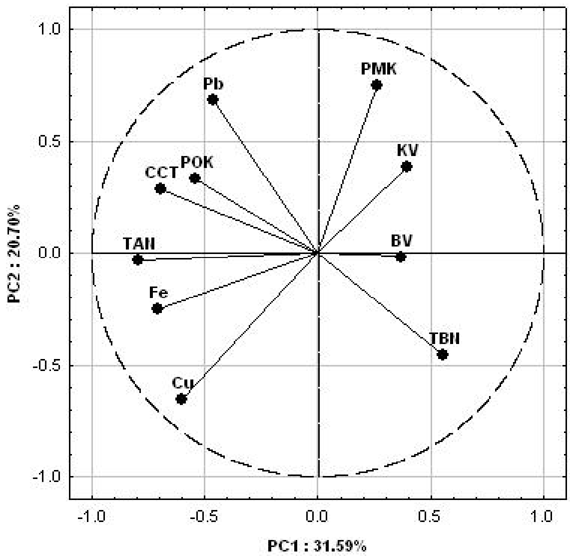
Fig. 1 - Box-and-whiskers plot of standardized data

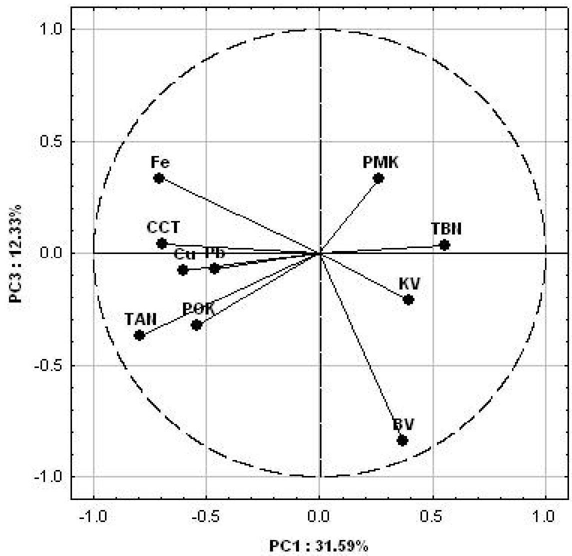
Legend: *PMK* – total mileage of the vehicle [km], *POK* – mileage of the oil fill [km], *Fe* – iron content [mg.dm^{-3}], *Cu* – copper content [mg.dm^{-3}], *Pb* – lead content [mg.dm^{-3}], *CCT* – Conradson carbon residue [hm. %], *CZ* – total pollution [d], *TBN* – total base number [mg KOH/g of oil], *TAN* – total acid number [mg KOH/g of oil], *KV* – kinematic viscosity [mm^2.s^{-1}], *BV* – flash-point [°C].

Basic methods of exploratory analysis (e.g. the box-and-whiskers plot method) (1, 8, 9) were found useful for finding distant values of parameters of the oil fill samples in the monitored file (Fig. 1). These oils were evaluated as those with boundary qualitative parameters.

The PCA method was used for transforming the original ten tribodiagnostic parameters to three latent variables – principal components. These new variables describe 64.14 % of the variability of original attributes, they represent linear combinations of original attributes and they have no mutual correlation.

The explanation of the meaning of the first principal component (from charts of component loads for each pair of principal components (fig. 2a, 2b)) allowed to formulate the conclusion that *PC1* can be named *oil quality*. Predominant parameters that influence the oil quality are total base number (TAN) and total acid number (TBN). Total mileage of the vehicle (the PMK parameter) is not a significant parameter that could be used to determine the remaining quality of the engine oil.





Source: Author

Fig. 2a - Component loads PC1and PC2 Fig. 2b - Component loads PC1 and PC3

Explanation of the second principal component was also found. *PC2* (fig. 2a) *distinguishes* among the oil samples from the *thermooxidation load* point of view and from the *increased concentration of abrasion particles* point of view which indicate abnormal load of the engine and adverse abrasion rates between the contact areas of the aggregate.

The results of the PCA analysis apply to T3-930 series engines operated with the OA-M6 ADS II engine oil. In the area of TTD, correct results can only be achieved by individual analysis of oil fills for a particular engine.

1.2 Application of Discriminant Analysis in TTD

The possibility of applying the classification methods of multidimensional statistical analysis on specific results of analyses of the OA-M6 ADS II engine oil was checked. Details are presented in [7].

The overall group of tested objects (oil samples taken) was divided into two classes based on the knowledge of all values of attributes (tribodiagnostic parameters). Oil in an operable state was marked as suitable oil and oil with boundary values of some attribute was marked as unsuitable oil. The analyzed selection contained 71 oil samples in total; 48 were assigned to the class of suitable ones and 23 to the class of unsuitable ones.

Each attribute was examined separately for each object using the diagnostics of exploratory analysis.

Using the step-by-step method of discriminant analysis, the value of the discriminant function was calculated for the class of engine oils that were known to have suitable qualitative parameters (equation 1), and for the class of engine oils (equation 2) where the values of monitored qualitative parameters fell outside the range that ensures an operable state of the engine with given oil fill.

$$Z_{suitable} = 2.120x_{Cu} + 6.775x_{TAN} + 19.463x_{CCT} - 0.423x_{Pb} + 70.460x_{KV} + 0.001x_{POK} + 0.413x_{TBN} - 448.841 \qquad (1)$$

$$Z_{unsuitable} = 4.088x_{Cu} + 17.549x_{TAN} + 46.278x_{CCT} - 0.871x_{Pb} + 64.513x_{KV} + 0x_{POK} + 1.260x_{TBN} - 477.281 \qquad (2)$$

Tribodiagnostic attributes with the highest contribution to the discrimination of monitored engine oils into two qualitative classes include the following parameters: kinematic viscosity, total pollution and total acid number of oils.

The efficiency of the discrimination performed was verified by performing re-substitution, i.e. by applying the discrimination sorting to the selection file.

The prediction ability of the proposed model is related to the number of objects classified into correct classes. Due to the fact that the analyzed selection of engine oil samples was not extensive enough, the discrimination functions were made from the whole selection, and the whole selection was consequently used for classification. All classified oils were assigned to classes correctly.

CONCLUSION

Due to the fact that it is difficult to monitor and evaluate the state of operated oil based on individual determinations of many of its different parameters in case of an extensive vehicle fleet effectively, some of the methods of exploratory analysis can be applied to data matrices. In the work (7) was tried a possibility of processing the procedure of selected methods of multidimensional statistical analysis – *principal component analysis* on the matrix of tribodiagnostic data of worn-out OA-M6 ADS II engine oil and *discriminant analysis*.

These multidimensional methods of statistical analysis allow for ex-post extraction of information not only about oil fills but about the transport vehicles (or other machinery) themselves that they had been operated in, from the experimental data. This information helps the tribodiagnostician to achieve a complex view on processes that take place in monitored objects.

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