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# CLASSIFICATION OF WEAR PARTICLES BASED ON QUALITATIVE MORPHOLOGICAL FEATURES

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## ABSTRACT

Wear debris morphology is closely related to the wear mode and mechanism occurred. Image recognition of wear particles is, therefore, a powerful tool in wear monitoring. An algorithm of classification of wear particles is proposed based on qualitative morphological features. The standard classes are presented as a set of vectors of coded ratings. Descriptions of the standards are based on the knowledge-base of experts. A distance between the particle and the standard classes in the multidimensional space of features showed rating of the similarity. The classification of particles is determined by identifying the closet standard. The coding of the semantic features of the morphological feature of wear particles was demonstrated to be useful for classification with statistical methods. The results showed that the presented method was satisfactory in solving practical problems.

## 1. INTRODUCTION

The conditions of machine operation are related to the process of wear particles generation and finally to their morphology. Thus, classification of wear particles in different morphological classes provides a valuable information on the condition of a machinery. Initially, the morphology of wear particles was examined visually by an expert. Nowadays, advances in computers and image recognition make automatic evaluation of the wear particle morphology possible.

In this paper, it is proposed a method to classify wear particles based on the analysis of the space of coded semantic descriptors. The original set of the descriptors is structured as a list with fixed serial numbers of elements.

Description of a particle is represented by a vector of 0 and 1 depending upon the applicability of this or that descriptor for describing the morphology of the particle.

The elements of the vectors are interpreted as coordinates of a certain point in the multidimensional space of features, the decision to which class the particle belongs is accomplished by searching for a validated representative of the class nearest to the given point. The coordinates of the location of standard class representatives are determined by processing the data obtained after interviewing a group of experts. Final decision is made using the database of expert rules intended to settle conflicts caused by the inter-section of characterizing descriptions of various types of particles

## 2. DESCRIPTION OF WEAR PARTICLES

Analysis of the publications and the poll of experts have allowed to draw a list of basic morphological features useful for identification of a particle type. Each feature is characterized by a number of qualitative descriptors specifying the morphological features of particles. Table 1 represents the list of identified features and their descriptors providing the possibility to describe the properties of particles as a list of their qualitative features. We consider some vector and determine an explicit relationship between Table 1 and representative classification of wear particles.

The features of the standard representatives were determined by polling experts. Expert assisted in weighting the descriptors of the standard descriptions. The rating was assigned to descriptors corresponding to the degree of their significance. The significance coefficient of the descriptors in each class was decided by an expert. As a result, each standard representative would be described by its own vector of features in which elements acquire values within the range from 0 to 1. Descriptors values of the same feature can be presented as:

$$\sum_{j=1}^{m} F_{ij} = 1.0, i = 1-9 \qquad (1)$$

where i= wear class, m= No. of descriptor with same feature

**Table 1 The list of features and descriptors**

| Outline shape | | | | Edge Detail | | | | Surface Texture | | | | Texture features | | | Colour | | | | | | | Color spectrum | | | Size (um) | | | | | | Thickness/ dimension | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Regular | Irregular | Circular | Elongated | Smooth | Rough | Straight | Serrated | Smooth | Rough | Cracked | Serrated | Holes | Pitted | Striations | Brown | Black | Yellow | Blue | Red | Silver | Varies | Bright | Dull | Transpare | 1-5 | 6-10 | 11-25 | 26-50 | 51-100 | >100 | 1:1 | 1:2 - 1:5 | 1:6 - 1:10 | 1:11- 1:40 |

## 3. CLASSIFICATION OF WEAR PARTICLES

The classification of wear particles is accomplished by a two-stage procedure. Statistical recognition has been used based on the estimation of the similarity between the examined particle and the standard representatives of the class by applying a measure of distance in the multidimensional space of features. It is known that the wear particles within the same class are varied in morphology strongly, meanwhile, the particles of different types may frequently possess intersecting descriptions. As a result, the features in the space form clusters with indistinct boundaries creating certain problems of classifying particles along them.

The algorithm of classification was based on consecutive comparison of descriptions of a sample with standards and on rating their disagreement. The class closest to the standard determine the class of a particle. The degree of disagreement was determined as a sum of squares of the difference between the relevant descriptors of the sample and the standard:

$$\rho\,(F, S) = \sqrt{\sum_i (F_i - S_i)^2} \qquad i = 1 \ldots N \qquad (2)$$

The concept of the space of features served for geometrical interpretation of the method. According to the concept the features are treated as values of coordinates, the examined object is treated as a certain point in the multidimensional space with the dimensions equal to the dimensions of the feature vector. It is clearly apparent that the maximum similarity between the objects rated with measure corresponds to the search for the standard in the space of features closest to the examined particle. It is noteworthy that precise projection into the center of the class is impossible since the descriptors of examined particles and standards are coded differently, even when their qualitative descriptions fully coincide.

Next, an expert system consisted of several tens of rules has been used to resolve conflict situations in order to reduce errors in classifying the particles using the statistical approach. Each rule was a multiple statement of the type "IF THEN". The rules were formulated on the basis of expert judgments made at the stage of testing the system.

## 4. IMPLEMENTATION OF THE SOFTWARE

The method has been implemented as a software module attached to the database of images. Figure 1 shows the main window of the module. The results of identification are displayed as a list of ranked ratings. The rating is calculated as:

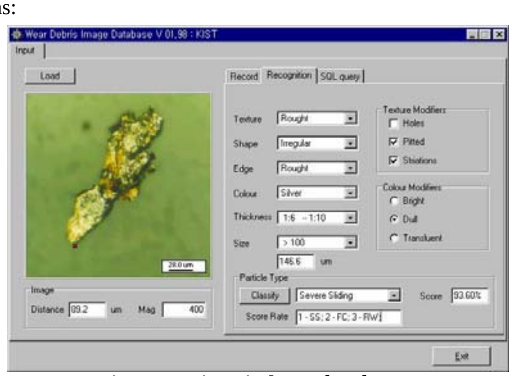


**Fig. 1. Main window of software**

$$G_i = \left(1 - \frac{\rho_i}{\sum_M \rho_M}\right) 100\,\% \qquad (3)$$

The classification has been tested in order to verify the accuracy of the algorithm. The photos of the original particles were preliminarily classified by experts visually and then using the software prepared by the operator observing the images on the display. Table 2 gives the test results. The headings of the lines correspond to the designations of real classes. The sum of the components in the lines equals the number of particles of the relevant class examined in the test. The heading of each column corresponds to the particle type identified according to the discussed method. In other words, the values in cells (*i*, *j*) of the table at *i* *j* equal the number of the particles misclassified.

**Table 2 Results of test**

| | RW | SS | FC | SP | CW | CR | DO | RO | NM |
|---|---|---|---|---|---|---|---|---|---|
| RW | 7 | | | | | | | | |
| SS | | 8 | 1 | | | | | | |
| FC | | 2 | 9 | | | | | | |
| SP | | | | 5 | | | | | |
| CW | | | | | 5 | | | | |
| CR | | | | | | 4 | | 1 | |
| DO | | | | | | | 6 | | |
| RO | | | | | | 1 | | 5 | |
| NM | 2 | | | | | | | | 7 |

RW- rubbing wear; SS- severe sliding; FC: fatigue chunks; SP- sperical; CW- cutting wear; CR- corrosive wear; DO- dark metallic oxides; RO- red oxides; NM- non-metallic

Evaluation of the test results has manifested that the errors in classification are due to two reasons. The first reason is that the morphology of particles within a class is highly variable and that the standard descriptions made by experts reflect just general features within the class. The second reason is that about 30% of errors are due to inaccurate specification of the features by the operator. Still, the general accuracy of 90% corresponds to the standard sufficient for solving majority of practical problems.

In conclusion, the coding of the semantic features of the morphological features of wear particles is demonstrated to be useful for classification with statistical methods. The proposed method is simple to implement and allows us to perform classification by rating. It significantly reduces the amount of inputted data and number of the rules compared with the production methods.


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