FROM DIGITAL IMAGE ANALYSIS TO EXPERT SYSTEM: PROCESS IDENTYFICATION OF MATERIAL STRUCTURES

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Abstract

Digital image analysis in the study of geometric structures of machine parts and engineering materials is a complex issue that the author tries to systematize and generalize, treating it as a process. The article proposes a comprehensive approach independent of the observation scale, material type, and purpose of analysis. Key stages of analysis have been identified, from determining technological needs and the research goal to selecting the scale, devices, and methods of assessing the structures of the tested object based on digital images, which leads to obtaining results. The process approach proposed in the article, identification of key objects, their features, and mutual relations, will allow for creating an expert system that, regardless of the researcher's experience, will enable consulting in selecting the optimal research plan.

Keywords: Image processing, material structure geometry, expert system

1. INTRODUCTION

Quantitative methods of geometric structure analysis of materials have been developed for many years. It became a part of the standard analysis of manufactured elements, their surfaces, and material structure. Geometric structure analysis is a part of quality control analysis, which involves the design of new materials by inspecting the relation between the material structure and its properties. It also plays an important role in searching for the cause of the destruction of components or their excessive wear.

Many studies focused on describing classical stereological methods and their implementation using computer analysis methods for quantitatively describing material structures [1-7]. This paper presents the geometrical analysis as a more generalized form, a process in which the most crucial stages are identified and described. This model would optimize and automate research procedures by implementing an expert approach [8-13]. Such an approach is the first step towards developing an expert system that would support selecting the optimal research path, optimizing the costs of the conducted analyses, and maximizing information on the geometric structure of the tested materials and elements. In this paper, the author will focus on presenting the general scheme of the model and the process of quantitative analysis of digital images of geometric structures of materials.

2. PROPOSED ONTOLOGY AND PROCESS MODEL

Analysis of the geometric structures of materials can be divided into several stages, which are equally important and significantly impact the reliability of the measurements.

Stage I is when the researcher defines the purpose of the analysis. The precise definition of the aim of the research allows for the selection of the optimal scale and method of observation. The typical aim of the analysis of the geometric structures may be:

- quality control of the manufacturing process, both materials and machine elements,

- analyse the influence of manufacturing parameters on the final product,

- assessment of the operating condition of machine parts

- searching for the causes of the element's destruction.

Depending on the defined aim of the analysis, destructive and non-destructive research methods, observation methods, analysis methods, and digital measurements can be selected. An example of the process of testing structures using digital image analysis techniques is presented in **Figure 1**.

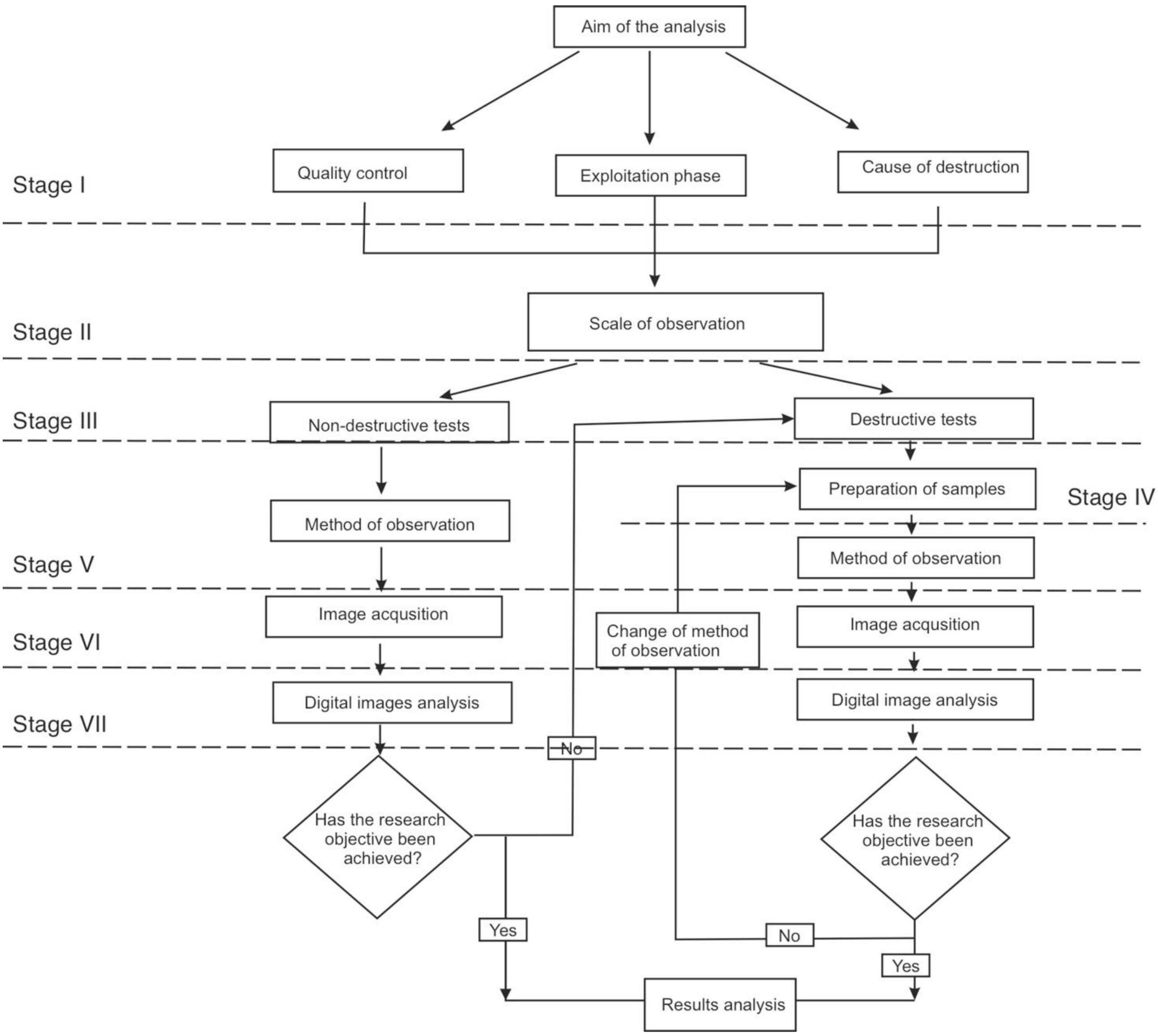

Figure 1 Model of the process identification of the material structures

The second stage selects the observation scale appropriate to the tested element. For ontological classification, the following classification of objects was proposed:

– small – macroscopic scale, which does not require specialist devices for assessing the structure (camera, flaw detectors),

– medium – microscopic scale, enabling the observation of microstructural elements,

– large – nanometric scale – enabling the observation of individual structural elements and their detailed structure,

– very large–scale – the observation of crystal lattices and individual atoms.

In the third stage of the process, the researcher must choose between conducting tests using non-destructive or destructive methods. Depending on the research objective and scale, the choice of non-destructive methods narrows the scope of element imaging techniques and the possibility of detecting possible geometric structure elements and their description. Destructive testing, which the research objective set must carry out, requires taking a sample.

The fourth stage for destructive methods is preparation, i.e., preparing the sample for observation. The basic requirement that research samples must meet is representativeness. The samples must represent the geometric features characteristic of the entire tested product. Precise descriptions of sample preparation procedures for observation are the subject of industry normative acts. The sample preparation method depends on the selected research device and the tested materials [14,15].

Acquisition is the fifth stage of the process, which provides data that is the subject of quantitative and qualitative analysis. The image of the tested element (or sample) presents its digital representation, which is a result of recording the interaction of the imaging source with the tested object [15-17].

The choice of imaging technique depends on the material type and observation scale. The type of material determines the choice of the imaging device due to the physics of the interaction of the source of information about the image with the tested material [18-21].

The values of stereological parameters characterizing the geometric structure presented in the image. The image analysis process must be adapted to each type of analysed image, but can be presented in a generalized form, as presented in **Figure 2**.

The image analysis process includes acquisition, pre-processing, and correcting image defects if their presence is detected. Image defect can be significantly reduced, using appropriate algorithms, such as:

– noise,

– shadow effect correction,

– slight sharpness correction.

After pre-processing, the next step in data processing is detection, i.e., isolating the structures being examined from the image background [1-3]. Detection can be a single-action or multi-action process. Available detection methods allow for selecting the appropriate one for a given type of image. The final effect of these actions is to obtain a binary image, the pixels of which take on values 0 and 1. The image areas representing the elements being examined are represented by pixels with a value of 1. The rest of the information contained in the image has been degraded to value 0. A binary image representing objects is the subject of quantitative analysis, enabling the geometrical characterization of the examined structure based on the values of stereological parameters. Basic stereological parameters are local and global [4-6]. Local parameters are averaged values of metric (measurement) features of the studied object (e.g., particle, grain) in the analysed space, i.e., average volume, cross-sectional area, perimeter, chord, etc. In the case of structure elements with high heterogeneity in size, shape, or size distribution, local parameters may give a result that is biased by too much averaging. Therefore, it is also necessary to analyse their value distribution and divide it into appropriate classes.

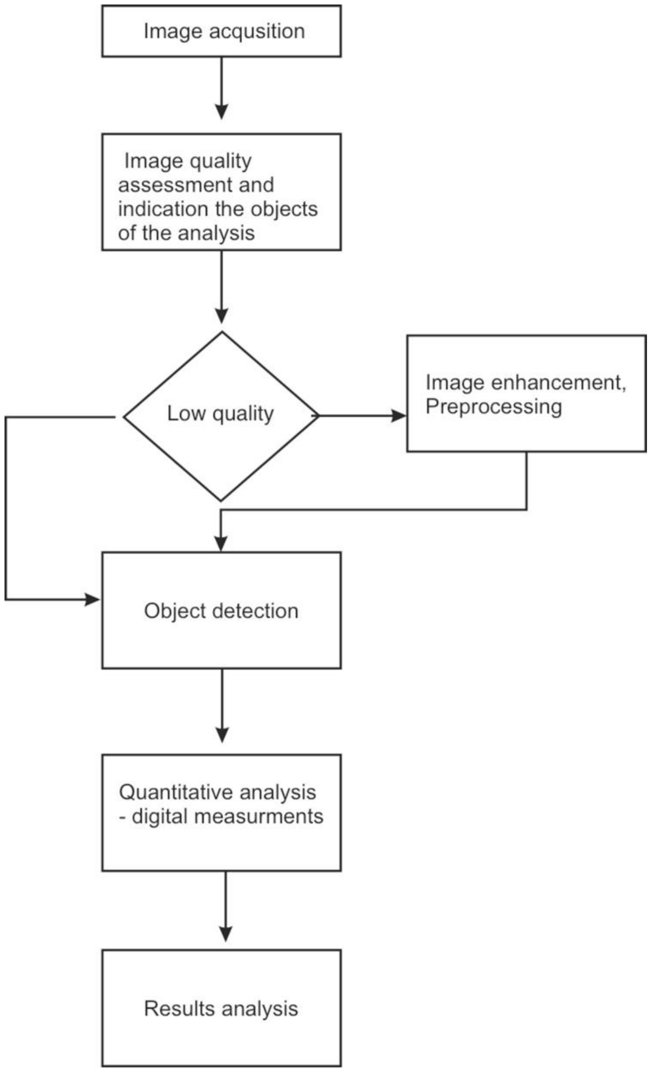

Figure 2 Model of digital image analysis process

Global parameters determine the relationship between selected features of the studied structure and the entire analysed space. Formal derivations and methods for determining all the mentioned stereological parameters can be found in the monographs by Underwood and Saltykov [4-6].

The characteristics of the analysed objects may concern the following features:

– quantity,

– size,

– shape,

– arrangement.

Obtaining quantitative results of chosen parameters gives valuable information that, combined with other physical tests, allows achieving the intended research goal [21-23].

3. EXAMPLE OF USE

On the example of geometric measurement of fatigue changes (pitting) of the inner raceway of a rolling bearing in order to quantitatively analyse the geometric features of the fatigue damage areas of the bearing raceway surface layer (so-called pitting). The measurements of geometric features of the surface layer were one of the elements of the analysis of the causes of damage to the element during its operation (**Figure 3**).

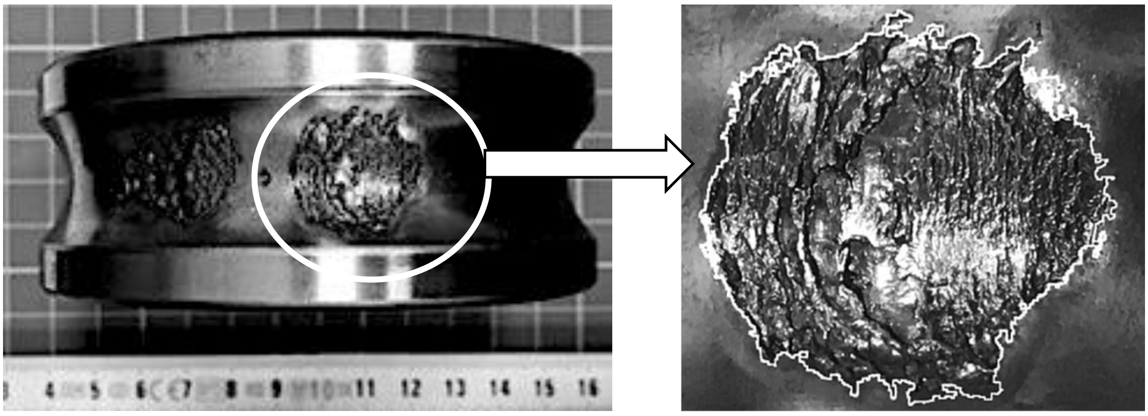

Figure 3 Digital image analysis of fatigue changes of the inner raceway of a rolling bearing

The research was carried out in cooperation with the Institute of Rail Vehicles of the Faculty of Mechanical Engineering of the Cracow University of Technology.

STAGE I. AIM OF THE ANALYSIS – CAUSE OF DESTRUCTION

STAGE II. SCALE OF OBSERVATION - SMALL

STAGE III. NON-DESTRUCTIVE TESTS

STAGE IV. NOT APPLICABLE

STAGE V. ACQUISITION TECHNIQUE – LIGTH MICROSCOPY

STAGE VI. ACQUTION – GREYSCALE, 8 BIT, 1024X800 PX

STAGE VII. DIGITAL IMAGE ANALYSIS – PARAMETERS: AREA, FERET DIAMETERS MAX, MIN, SHAPE FACTOR.

Results of performed measurements presents **Table 1**.

Table 1 Results of quantitative analysis of the fatigue changes of the inner raceway of a rolling bearing

Area [mm^2]	F_{max} [mm]	F_{min} [mm]	Circularity
563.13	29.81	27.85	0.24

4. CONCLUSION

The development of intelligent decision-making systems allows for a significant reduction in the time and cost of research, enabling faster achievement of the assumed production goals. Decision support systems can help young scientists and are an important element of product quality control systems. The issues presented are only a fragment of the entire concept, which considers the vast diversity of the analysis process, which is influenced by many factors.

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