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COMPARATIVE EVALUATION OF CLEANING METHODS FOR AVIATION MINIATURE ROLLING BEARINGS

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Abstract: The results of the granulometric and chemical composition of the removed contaminant particles from ball bearings by the non-separable pulse-magnetic turbulent and ultrasonic methods are presented. The removed contaminants from aircraft ball bearings of two standard sizes 24×12×6 mm and 28×12×7 mm, were studied using a laser scanning microscope and a scanning electron microscope REM-106I. The analysis of the microparticles from the rolling path of the ball bearings showed contaminants such as non-metallic particles, steel chips and dust, copper alloy chips, organic fibres, and lubricant residues. The particle size analysis showed that particles of less than 1 micron to 50 microns were removed from the rolling path. Comparative experiments have shown that the magnetic turbulence method allows for more efficient removal of contaminant particles much larger than 1–2 microns. The ultrasonic method showed the highest efficiency on the smallest contaminants.

Keywords: .

1. INTRODUCTION

One of the ways to improve the reliability and durability of precision parts of machines and mechanisms is to increase the efficiency of removing microcontaminants from the working surfaces of critical friction units. This is especially true for high-precision mechanical systems in aviation and space technology, where miniature bearings and precision parts of complex shapes are widely used, and their failure can lead to a disaster with human casualties.

The issue of industrial cleanliness of ball bearings is addressed through the use of special methods and cleaning tools for parts, assemblies, units, and complete systems during their production and operation, along with a properly organized system of quality and cleanliness control [1].

Currently, in addition to traditional methods of cleaning parts, such as cleaning with alkaline aqueous solvents [2], various solutions and compositions that allow cleaning its parts and ball bearings without disassembling the mechanism before the scheduled lubricant change, new technologies are being developed for cleaning surfaces from burrs using mechanical, hydraulic, and ultrasonic methods [3].

The most common and effective methods today are based on the use of ultrasonic waves [4], which cause cavitation in a liquid [5]. However, even these highly effective methods can face difficulties in achieving sufficient removal of submicron contaminants from ball bearings. The reason for this is the unidirectional nature of the fields and forces that activate and disrupt the contaminants, along with the static nature of the cleaning object and its design features. These factors contribute to the formation of shading zones on the working surfaces by structural elements. As a result, effectively and efficiently cleaning the working surfaces of a ball bearing without detailed disassembly is challenging, and in the case of non-separable bearings, it is impossible.

To date, the problem of removing micro- and submicro-ferromagnetic contaminant particles from the rolling path of ball bearings with an outer diameter of more than 30 mm can be solved by the developed pulsed magnetic turbulent (PMT) method [6], which is based on the ideas of excitation and removal of ferromagnetic particles from surfaces by acting on them with pulsed electromagnetic fields.

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In order to determine the advantages of the most effective methods today - ultrasonic (ultrasonic) and pulse-turbulent – laboratory studies of such performance indicators as particle size distribution, fractional and physical and chemical composition of the removed contaminant particles were conducted.

2. EXPERIMENTAL

For laboratory studies of the cleaning efficiency on the created laboratory sample of the combined field, aircraft ball bearings of two sizes 24×12×6 mm and 28×12×7 mm, which had not been previously cleaned, were used. Aviation kerosene TS-1, previously purified by fine filters, was used as a cleaning medium.

The external standard conditions for the laboratory tests were: temperature 23–25°C, atmospheric pressure 760±3 mmHg, and relative humidity 40–60%.

Cleaning was conducted on the pre-operational preparation stand for gas turbine engine bearings ОПШ-01 (Figure 1) and a standard ultrasonic digital bath (USB) from Kaisi K-105 (China) with a reservoir volume of 500 ml and a maximum power of 50 W, as well as an ultrasonic generator (Poland) with a submerged transducer of maximum power 100 W (Figure 2). Any suitable technological laboratory container with the appropriate cleaning solution can serve as the bath.

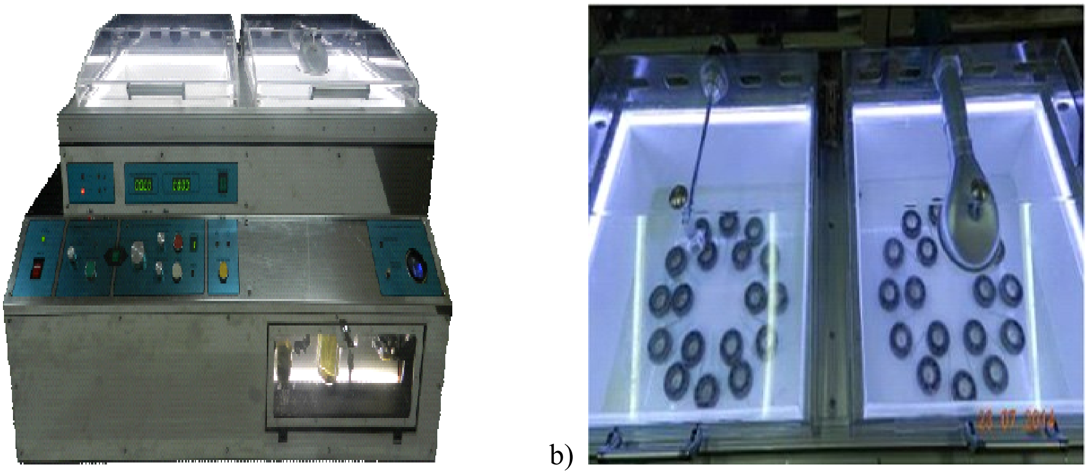
a)


Figure 1. The turbine engine bearing pre-operational preparation stand: a) external appearance of the stand; b) cleaning and drying chamber for assembled ball bearings

Considering the sizes and the inner ring seat diameter of the test ball bearings, special holders were made to allow their positioning on the working surfaces of the tanks of the aforementioned devices in more effective zones for the generation of acoustic flows and cavitation (Figure 2).

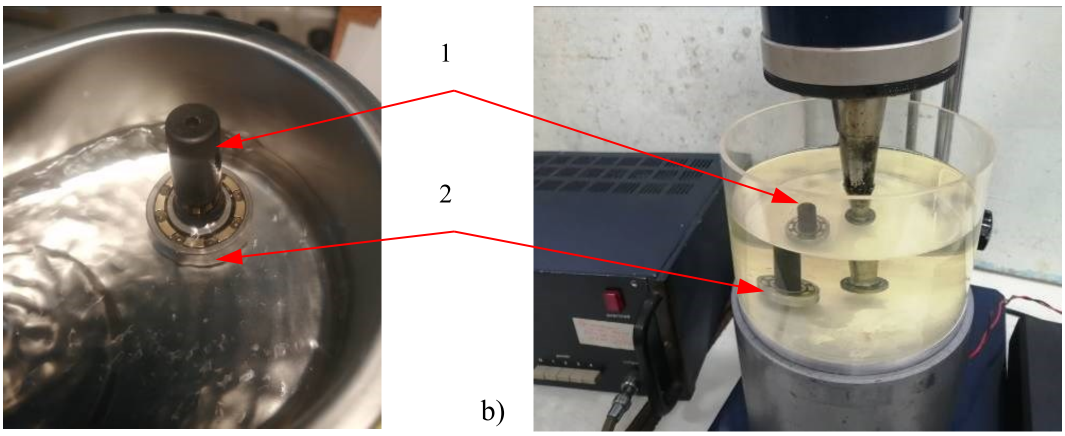
a)


Figure 2. The external appearance of the tanks of the laboratory devices and the method of positioning the test bearings during their cleaning: a) Ultrasonic bath from the «Kaisi» company; b) «Ultrasonic generator» device; 1 – holder; 2 – test aircraft ball bearing

After cleaning two batches of aircraft bearings, 24×12×6 mm (series №5-1000901T2) and 28×12×7 mm (series №75-70001016T2), in the cleaning fluid TS-1, a significant number of particles of various sizes and types accumulated in the areas of maximum magnetic field stress (ОПШ-01 stand) and at the bottom of the cleaning chamber (ultrasonic cleaning devices) (Figure 3). The micro-particles removed through the filtration of the cleaning fluid (TS-1) via a fine filtration element were subject to further analysis.

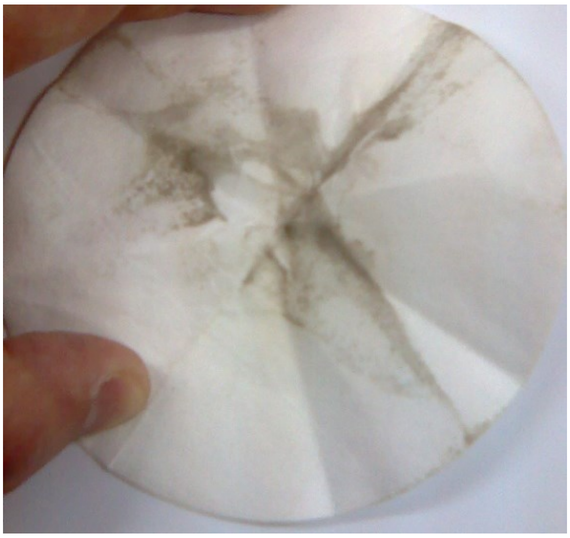


Figure 3. Appearance of the filter element after filtering the cleaning fluid

The contaminants removed from the aircraft rolling bearings were examined to determine their average size, granulometric, phase, and chemical composition using a laser scanning microscope and a REM-106I scanning electron microscope (Figure 4).

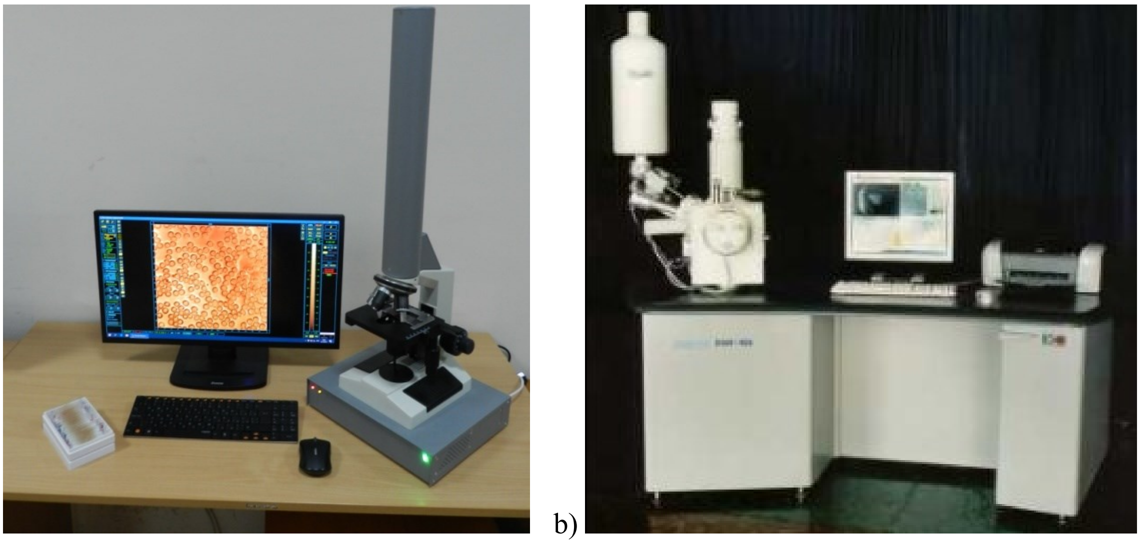
a)  b)

Figure 4. Exterior of laboratory instruments: a) laser scanning microscope; б) electron microscope REM-106I

To determine the linear dimensions of contaminant particles using the REM-106I scanning electron microscope, a double-sided conductive carbon tape for scanning electron microscopy, manufactured by «Nisshin Emco., Ltd.» was used. The removed contaminant particles from the bearings, which were extracted from the cleaning liquid, were placed on the tape, and the quantity of contaminant particles was assessed by size groups over a specified area.

The analysis of the granulometric composition of contaminants was carried out using the method of grain size distribution by chord size. For this purpose, a series of intersecting lines with a length corresponding to the scale bar were drawn on the obtained images of contaminant particles with the same magnification (Figure 5).

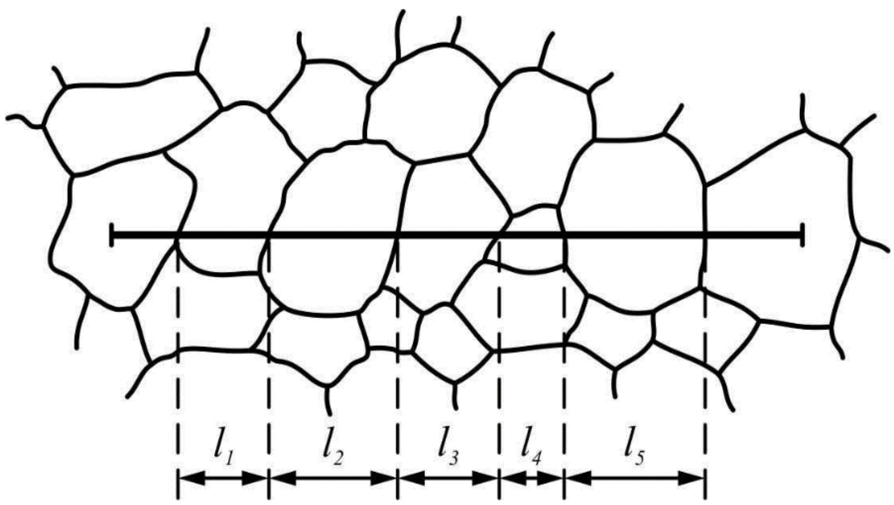


Figure 5. The method of measuring chords formed by the intersection of secant lines with the boundaries of contaminant particles

Afterward, the lengths of the chords l, formed by the intersection of the secant lines with the boundaries of the contaminant particles, were measured. The chords are divided into size groups with a step calculated by the formula:

$$H = l_{max}/K, \tag{1}$$

where K is the number of size groups.

The number of chords in each size group P_i and the chord density $P_{Li} = P/l$ are determined. The number of grains per unit volume N_{Vi} belonging to the i-th size group is calculated.

3. RESULTS

The contaminants removed from the bearings were sorted by the cleaning method (magnetic-turbulent or ultrasonic) and analysed using the REM-106I electron microscope. Examples of the removed contaminants at magnifications of 100x, 200x, and 1000x are shown in Figures 6–7.

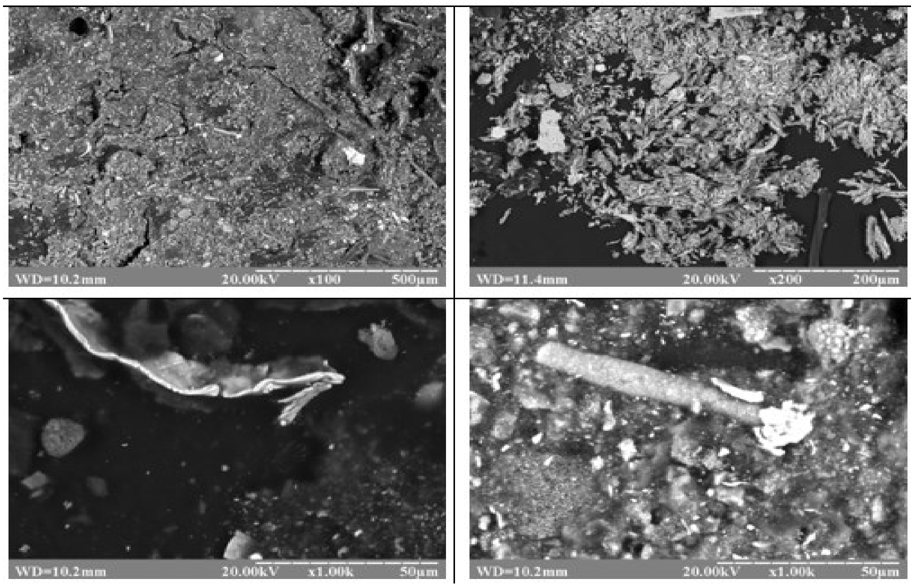


Figure 6. General view of the contaminants removed from the bearings using the magnetic-turbulent method at different magnifications

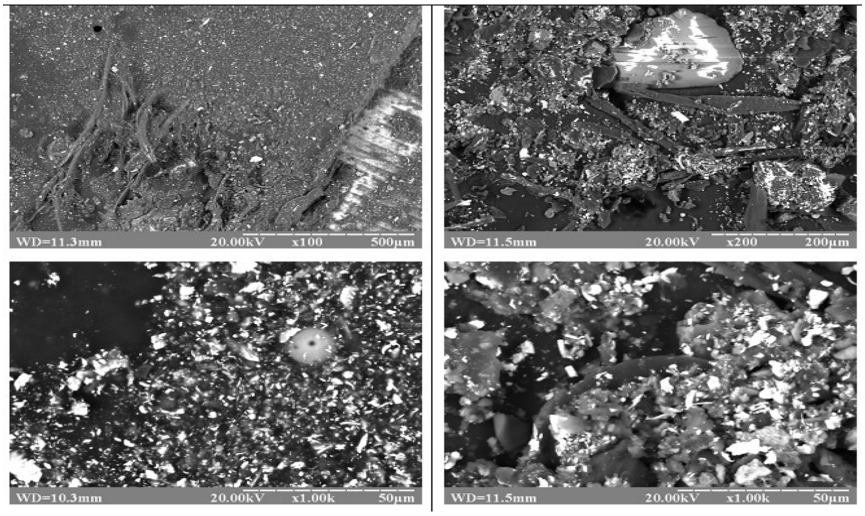


Figure 7. General view of the contaminants removed from the bearings using the ultrasonic method at different magnifications

The study of the chemical composition revealed the elemental makeup of the contaminants and allowed for the identification of contamination sources: inorganic particles, ferromagnetic particles, the presence of copper, and others (Figure 8).

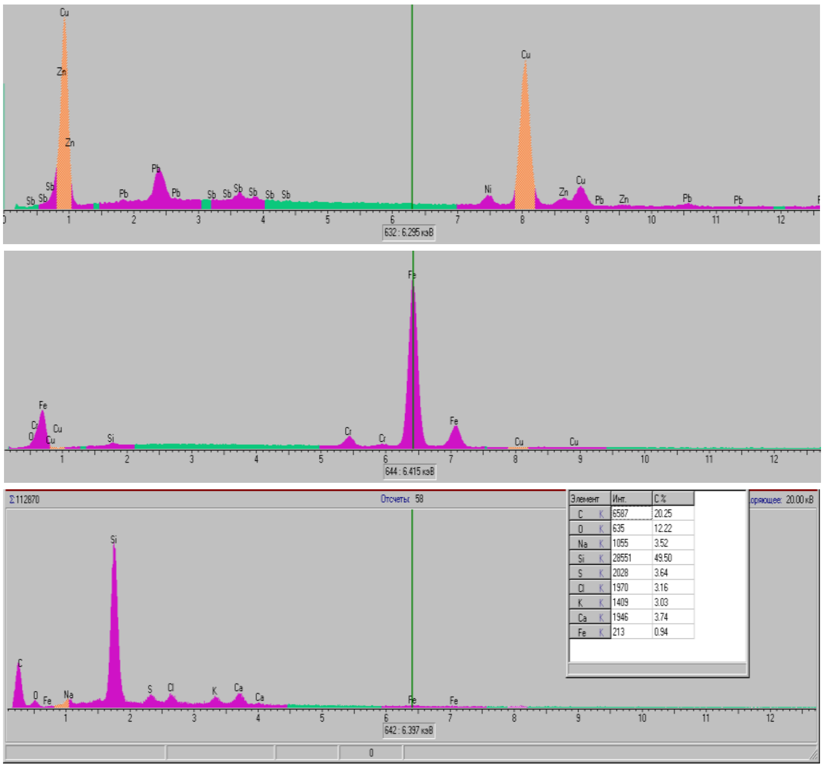


Figure 8. Spectra of the chemical composition of contaminants: a) copper alloy; b) steel chips; c) non-metallic contaminants.

4. DISCUSSION

The analytical processing of the obtained results allowed for determining the granulometric composition of the removed contaminant particles. The study of the sizes and chemical composition of microparticles removed during the non-contact cleaning process of non-separable ball bearings on the test stand showed that microparticles sized 30–50 µm accounted for 8%, 10–30 µm for 12%, 1–10 µm for 50%, and the remaining 30% were particles smaller than 1 µm. The granulometric composition study revealed that the majority of contaminants consisted of various metallic ferromagnetic fragments in the form of scales, micro-shavings, etc.

A comparative assessment of ball bearing cleaning methods showed that the magnetic-turbulent method allows for more effective removal of contaminant particles larger than 1–2 μm. In contrast, the ultrasonic method demonstrated the highest efficiency in removing contaminants smaller than 1 μm.

A significant number of metal fragments observed during the magnetic-turbulent cleaning method had a relatively large length, which can be explained by the specific magnetic interaction of such particles. Among this group were ferromagnetic contaminant particles, whose composition matches that of the materials from which the structural elements are made, namely steel ШХ15, used for the rolling elements and raceways. However, the chemical composition of the contaminant particles also revealed the presence of copper, zinc, and other diamagnetic materials. The presence of these contaminants is directly related to the use of bronze and brass in the bearing cages.

Thus, the use of pulsed magnetic fields in the cleaning process allows for the effective removal of ferromagnetic contaminants of micro- and submicron sizes, which are retained on the surface of parts, including at domain boundaries. Since the cleaning takes place in a medium of polar or non-polar liquid, where the flow in the working zone is turbulent, this process also facilitates the removal of diamagnetic contaminant particles. During cleaning, the outer bearing ring rotates without direct contact, while the impact of the pulsed magnetic field and the turbulent flow of the liquid contribute to the detachment and removal of contaminants into the flow of the cleaning fluid.

Non-ferromagnetic particles are primarily represented by abrasive materials, particularly silicon carbide and silicon oxide (Si – up to 49.5%, C – up to 20.25%, O – up to 12.2%). A significant portion of the non-metallic contaminants consists of fragments of polymerized components of lubricants, which, during the operation of ball bearings, form boundary lubrication layers on friction surfaces [7]. These components polymerize, oxidize, or remain as residues of preservation oil.

5. CONCLUSIONS

The analysis of microparticles removed from the rolling path of ball bearings, conducted using the REM-106I electron microscope, revealed the following types of contaminants: non-metallic particles (abrasive, sand, etc.), steel chips and dust, copper alloy chips, organic fibres, and lubricant residues. The physical and chemical composition of the contaminant particles removed by both the magnetic-turbulent and ultrasonic cleaning methods from the rolling paths of miniature ball bearings is practically identical. However, their size and quantity, particularly of larger particles, differ significantly.

A comparison of the results from the laboratory studies showed that the magnetic-turbulent method is more effective at removing contaminant particles significantly larger than 1–2 microns. In contrast, the ultrasonic method demonstrated the highest efficiency in removing the smallest contaminants.

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