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Non-contact monitoring of rotating machine elements

By

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Abstract:

The main objective of this paper is to help in solving the most important research and engineering problem - precision of non-contact inspection of mechanical condition of mechanisms and machine elements either in steady-state or in dynamic mode.
Due to safety and economical reasons the interest to diagnostic and monitoring systems is growing rapidly in industry in all complex industrial production lines and power plants. Key components of power plants are rotating machinery like mills, blowers, water pumps and turbines. Diagnostic systems help to prevent severe failures.
The designed complex provides acquisition of objective information concerning mechanical conditions of important mechanisms and machine elements at technological process stage and during lifetime period in the operating mode, which cannot be done by the majority of traditional measuring systems.
With the help of the designed diagnostic complex and special mathematical processing methods, the unique experimental data concerning the change of commutator profile of high-speed electric machines during the lifetime period, shape and value of bearing vibrations were collected.

Keywords:

Non-contact, eddy current, measuring, testing, monitoring, surface quality, sensor, vibration, rotating machine elements, electric machine, commutator, contact ring, shaft, bearing vibration, shape, cross section

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1. Introduction:

Today the diagnostics of rotating machinery and other mechanisms is an actual topic [1-10]. Besides safety and economical reasons, there are quality control requirements. The greatest attention at machine-building enterprises is paid to quality control of working surfaces of commutators and contact rings of electric machines. The quality control is conducted on different production stages. However, the experience shows that the existing quality control is not efficient enough since it is functioning only in steady-state mode with the help of micrometer heads or industrial indicators and does not take into consideration the whole range of centrifugal, vibratory and temperature loads, influencing the commutator in working electric machine. That is why nowadays machine-building enterprises, producers of commutator electric machines and some consumers face the need for quality control of commutators, contact rings and shaft surfaces during development, production, lifetime usage and repair stages, both in steady-state and in dynamic mode.

The majority of existing diagnostic systems are based on vibrational diagnostic methods [1, 2, 4] and they cannot provide information about cross section of rotating part or its surface quality. In order to fulfill these requirements, a diagnostic system 'MICROCON' was designed at Tomsk Polytechnic University (TPU) [10]. This complex is used for non-contact precision control of cross sections of shafts in machines and mechanisms, commutators and profiles of contact rings of electric machines in static and dynamic modes, measurement of linear micro-movements and vibrations of machine elements.

2. Diagnostic System:

The work of developed non-contact measuring system 'MICROCON' is based on a principle of high-frequency electromagnetic flexing of a controllable surface (Eddy current testing) and determines a row of its advantages in comparison with other types of measuring systems, for instance laser measuring systems. 'MICROCON' has high protection from external influences (presence of dust, vapor, oil fog and other pollutions of a controlled zone), there is no 'patch of light' effects, it has rather low cost (at equal precision characteristics), and also, an opportunity of simultaneous acquisition of information on several parameters of a controllable object. Special processing methods allow determination of object micro-movements, specific electric resistances, as well as surface temperature (if temperature via specific electric resistance is known) using eddy current testing method. Non-contact measurement of specific electric resistance is especially important for thin-film structures control because it simplifies the measurement process considerably and reduces time expenses.

Diagnostic system 'MICROCON' has a modular architecture (Figure 1), and consists of several units:
– Module of sensors;
– Analog to digital converter (ADC) unit;
– Main Board;
– Step motor drive of eddy current sensor (SM);
– Electric motor control unit (to measure commutator profile at different rotational speeds);
– Personal Computer (PC).

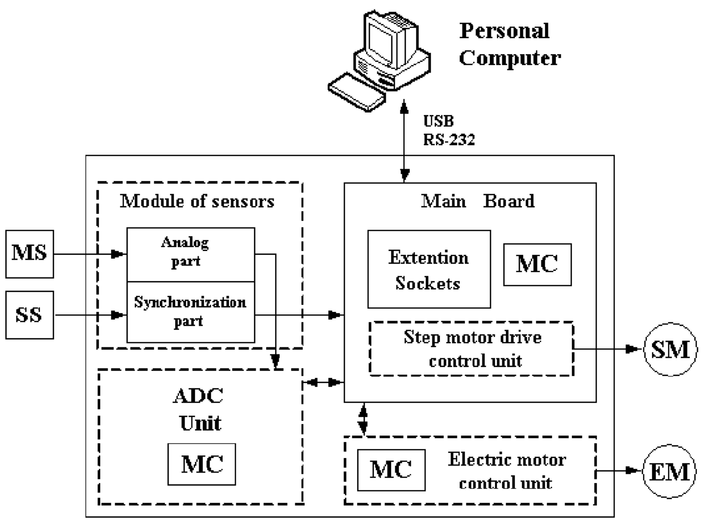

Figure (1): *Diagnostic system 'MICROCON'*

All units of a diagnostic system can function as a whole and every unit is able to operate autonomously. The Main Board has its own CPU and coordinates the work of all units. It also has extension slots for other additional units. If we install several ADC units, the measuring system becomes multi-channel. PC is intended for hardware management, acquisition of measurement results and their mathematical processing. Data exchange between PC and 'MICROCON' is possible via RS-232 or USB interface.
The important advantage of a measuring complex is the possibility of continuous monitoring.

Basic technical specifications of 'MICROCON':
– Sensor type — Eddy Current
– Gap between a measuring sensor and an object to be measured — 0-0.8 mm
– Measurement resolution (depends on many parameters, such as distance to a measured object, precision of sensor positioning system and some other parameters. That is why the resolution should be calculated for each

particular case and can be different from the given value)	0.0001 mm
– Maximum linear speed of a surface to be measured	100 m/s
– Sampling rate	1 MHz
– Minimum tangential dimension of a commutator plate	1.5 mm

Designed measuring complex has better technical characteristics compare to other systems existing on the market due to original design of eddy current sensor, patented method of master correction of measurement results [11] and special mathematical processing methods of measurement data. Eddy current sensor of measuring system has a narrow sensitivity diagram which allows differentiate profile levels of commutator plates with tangential dimension of 1.5 mm or wider.

Great advantage of this complex is specially developed method of master correction of measurement results [11]. The main idea of the proposed method of master correction is moving of sensor on fixed distance relative to controllable surface during measurements and further measurement results correction according to special algorithm. This method allows to avoid various measurement errors, caused by ambience conditions, work modes of a sliding contact, specific electric resistance of a controlled object surface layer, temperature of an object, inaccuracy of the sensor installation and etc. Therefore, developed diagnostic system 'MICROCON' has a big advantage in measuring accuracy compare to other measuring systems. For instance, we measure a commutator profile with a 100 micrometers gap between sensor and the commutator, then we move sensor on 500 micrometers with positioning error of 1 micrometer and measure again, the systematic error of measurement will be 0.2%. That means following: if we measure vibration of commutator with amplitude 50 micrometers, the systematic error is 0.1 micrometer; if we measure the height difference between neighbor commutator plates which has a value of 5 micrometers, the systematic error is 0.01 micrometer. The given example shows, that vibrations of a commutator is tens micrometers, height difference between neighbor commutator plates is several micrometers [10], therefore, without master correction method a wrong conclusion concerning commutator profile could be done.

Moreover, the measurement error can rise up in dynamic mode, when gap between sensor and the same point on controlled object can vary on tens micrometers from one revolution to another due to wear of bearings and other reasons. In this conditions there is impossible an exact correction of results of measurements with method described above. Separation and structuring data into controllable surface profile and vibrations caused by rotation is also impossible. This problem could be solved by new measurement method, invented in TPU [12]. The main idea of this method is correction of measurement results by using average values in series of measurement cycles; also, the distance of the sensor displacement is calculated taking into account sensor positioning error and acceptable measurement error (required precision of measurement). By using patented method, it is possible to separate the whole array of initial measured data into a real controllable surface profile and vibrations caused by rotation of measured object. Calculation of acceleration values during rotation is also possible. Knowing of average acceleration value is necessary for estimation of work stability of a sliding contact brush-commutator, and also for forecasting of lifetime of a brush-commutator unit with help of special developed software.

3. Collected Experimental Data:

Unique data about changing of commutator profile of high-speed electric machine during lifetime period, shape and value of bearing vibrations were collected with help of this measuring complex during research cooperation with LG Electronics Inc.
The purpose of this experimental research was gathering experimental data concerning changing of commutator profile of high-speed electric machine while lifetime period, information about anchor vibrations (caused by bearing vibrations), as well as their influence upon mechanical condition of the brush-commutator unit during lifetime period. Collected data should become a basis for mathematical modeling of dynamic processes in sliding contact and also for feather recommendations development concerning lifetime increasing of brush-commutator unit.
Object of the research – commutator electric motor produced by LG Electronics, model VCE280E02, 35000 rpm, 1800 Wt, application area: vacuum cleaners. During experiment tested electric motor was loaded by a standard centrifugal fan with special calculated cross-section of incoming hole in order to provide necessary load and therefore necessary current consumption. Duration of lifetime test achieved 709 hours. Every 35-45 hours brush wear was measured with help of micrometer and special manufactured tools. Commutator profile in dynamic mode at standard rpm also was measured with help of non-contact measuring system ‘MICROCON’ [10].
Brushes HG25 are used in tested electric motor. Received data shows that wear of each brush during 709 hours achieved critical value of 28.8 mm (1900 mm3). Wear of the commutator for the same time period, measured with help of ‘MICROCON’ (without stopping and disassembling the motor), was 0.74 mm (532 mm3). Collected data shows that commutator has approximately 3 times longer lifetime compare to brush lifetime (considering, that constructive wear limit for commutators is 2-3 mm). Therefore, lifetime increasing of brush-commutator unit in similar models of electric motors is possible by decreasing of brush wear, which depends on friction wear and electric erosion components. Electric erosion – the biggest component of brush and commutator wear, it depends on sparkling level, which depends on commutator profile and anchor vibrations, caused by wear of bearings. As was mentioned above, created in TPU methods allow to select information, required for engineers, involved in design of commutator electric machines, out of whole data array, gathered by non-contact

measuring system.
Separation of measured data array and further analysis shows that commutator geometry is essentially changing during lifetime period. In particular, intensive commutator profile changing starts after 350 work hours – approximately after half-lifetime period. Out of collected data follows that height difference between two neighbor commutator plates raised up in 7.8 times during lifetime period; average value of height differences for all commutator plates increased in 13.5 times. It should be mentioned, that during first 220 work hours of testing, maximum values of height difference between two neighbor commutator plates decreased on 30%, average value of height differences for all commutator plates also decreased, but slightly. All that parameters show, that this is a wear-in period. After wear-in period commutator geometry is getting worse – degrading.
It is known out of technical literature, that after decomposition of vibration signal of rotating body into Furie series, first harmonic characterizes eccentricity, second harmonic characterizes ellipticity, third harmonic characterizes trihedral and etc. Received data show that after work-in period amplitudes of all harmonics rising up. During lifetime period eccentricity increased in 21.2 times, ellipticity increased in 5.6 times, trihedral increased in 7.7 times. All this data demonstrates us again degradation of commutator geometry during lifetime of electric machine.
According to developed in TPU method, accelerations, caused by commutator profile and acting on brush were determined. Received data also shows clear work-in region, after which acceleration amplitude increases while working of electric motor. That again shows deterioration of commutator geometry caused by uneven wear and, probably, strength reduction caused by mechanical and thermal loads. Average acceleration caused by commutator geometry increased in 6.5 times during lifetime.
With help of patented method information about anchor vibrations (mostly caused by bearings vibrations due to not precise enough manufacturing and mechanical wear) was selected. During lifetime testing maximum of anchor vibrations increased in 5.9 times, average value of anchor vibrations increased in 6.6 times.
It is necessary to mention that during lifetime cycle, vibration influences on electric brushes, caused by anchor vibrations (caused by bearings), on average in 1.6 times higher than vibration influences on brushes, caused by commutator profile.
Average resulting acceleration behavior, caused by commutator geometry and anchor vibrations is shown on Figure 2.
If we know dynamic of brush wear and its density, we can determine dynamic of brush mass change. By using strength coefficient of brush pressing spring (in our case $k = 48$ N/m), we can find acceleration, produced by the spring at any time of lifetime.
As it is shown on the figure 2, average resulting acceleration due to commutator geometry and anchor vibrations increased in 6.5 times during lifetime and at 600 hours its value achieved the limit for normal functioning of brush-commutator unit. At this

point and after there is a probability of loosing electric contact in brush-commutator sliding contact (hanging a brush) from time to time, bad commutation (sparkling) and therefore rapidly wear increasing of brush-commutator unit.

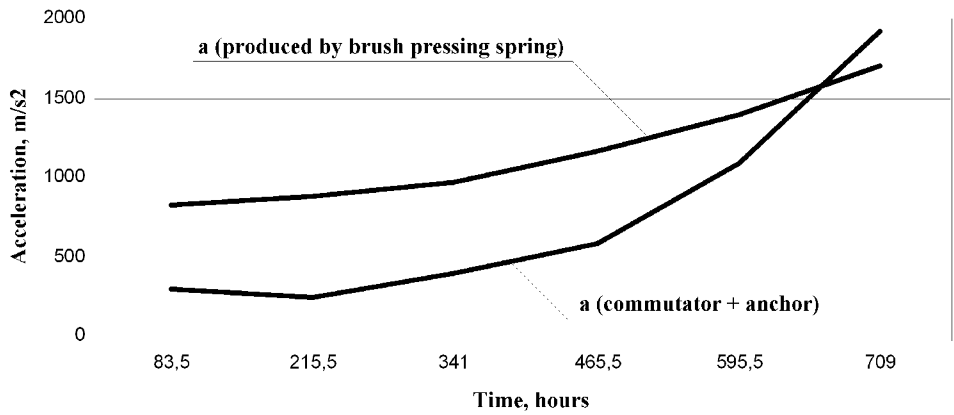

Figure (2): *Acceleration produced by brush pressing spring and average resulting acceleration caused by commutator geometry and anchor vibrations during lifetime of tested electric motor*

For feather lifetime increasing of electric motor it is necessary to provide reliable electric contact in brush-commutator unit at the final stage of lifetime. It could be done either by correction of acceleration curve, produced by brush pressing spring (it is necessary to provide higher acceleration value), or by correction of average resulting acceleration curve, caused by commutator geometry and anchor vibrations (it is necessary to make the curve more smooth).

Acceleration curve behavior, produced by brush pressing spring, depends on spring properties, design of brush-pressing unit itself, type of electric brush and brush wearing speed. Influence of mentioned above factors on brush resource has to be analyzed and recommendations concerning lifetime increasing should be worked out. It is also important to improve such well-known directions like increase of collector strength and bearings quality.

4. Conclusions:

Due to technical advantages various modifications of the measuring complex are in use in several Russian companies. Some foreign companies such as SPARKY, ABB, LG Electronics Inc., etc are highly interested in this development. Further development of 'MICROCON' is possible in terms of hardware and software improvement in order to provide new consumer properties. Firstly, the sensor positioning system should be improved to achieve better measurement resolution. It is planned to improve the

software by expanding its functional properties and adding wavelet analysis.
High technical features of the designed complex using new measurement methods allow satisfying the growing requirements of industry in precise and reliable inspection systems integrated in production process.

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