Determination of automobile alternator faults using harmonic analysis of external magnetic field

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Abstract. Evaluation of the external magnetic field parameters allows determining the technical condition of the automobile alternator with minimum labour intensity and sufficient informativity. However, measurement of the external magnetic field magnitude with Hall sensor doesn't allow expressly recognizing an occurring fault. It has been established that the spectral decomposition of external magnetic field oscillogram significantly increases informativity of this diagnostic parameter. Indicating harmonics, which extreme value allows identifying the technical condition of the automobile alternator, are distinguished. The article materials can be used for further development and implementation of the automobile alternator diagnostics based on the parameters of the external magnetic field.

1 Introduction

The classification of the up-to-date diagnostics methods for the automobile alternators is given in Figure 1. The classification is based on the following features: measured parameters (structural, operating and associated processes); measurement principle (subjective and instrumentation); determination method (requiring removal from the automobile and disassemble or not); diagnostic devices (external, integrated and on-board) [1, 2, 3].

Direct methods (componentwise diagnostics, flaw detection) have such advantages as accuracy, obviousness, reliability, the possibility to use sufficiently simple measurement procedure and tools. The structural parameters directly associated with the alternator serviceability can be detected only by the direct methods. Such parameters can include the following: electrical resistances of stator and rotor windings, interturn and groundwall insulation, semiconductor diodes; diameter and contact ring runout; brush height; bearing play, etc. The disadvantages of the direct methods shall include the necessity to the alternator from the automobile, as well as partial or complete disassembly of the alternator and high labour intensity. One more disadvantage of the direct diagnostics methods consists in that upon operation completion alternator bench tests are required, as only check of the output parameter conformity to the technical standards allows installing the alternator back on the automobile.

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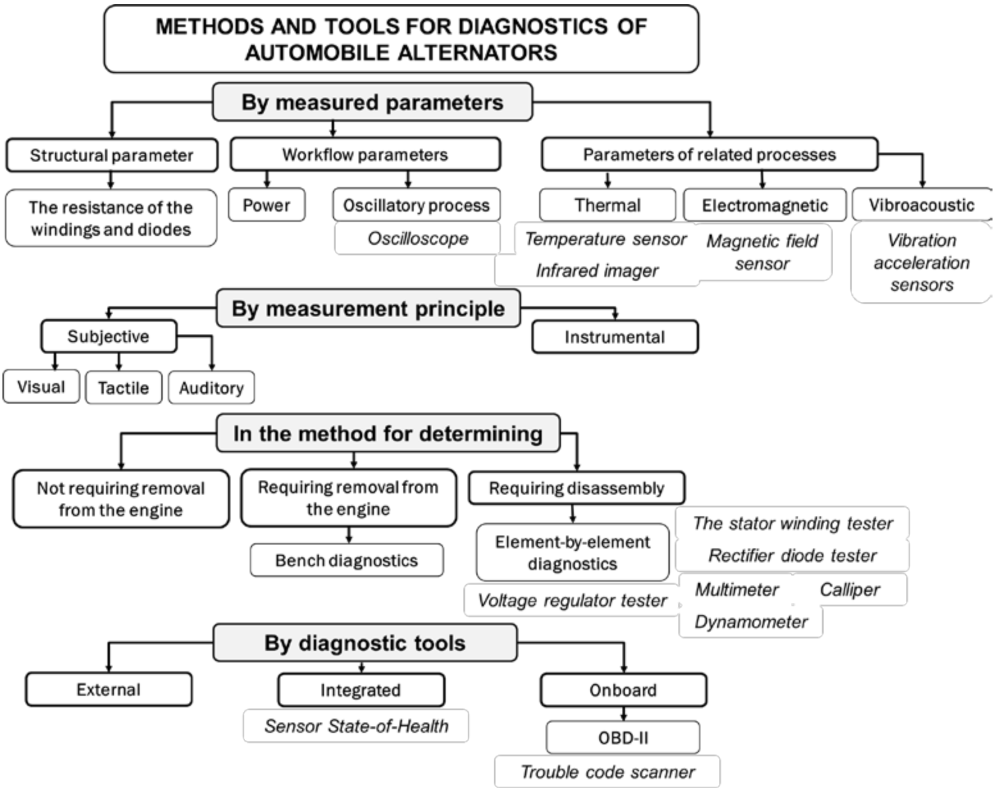


Fig. 1. Classification of Diagnostics Method for Automobile Alternators

The subjective methods are based on the determination of the automobile technical condition by the dynamic process output parameters. However, obtaining, analysis of information, as well as decision making concerning technical condition shall be performed with the operator sense organs that has sufficiently high error.

The objective methods allow not disassembling the alternator, monitoring with less labour intensity, and promptly receiving the measurement results. The disadvantages of the indirect methods include complexity of diagnostic equipment, significant cost of the proper equipment and monitoring, and the necessity of high-skilled personnel.

One of the objective methods for electrical machine technical condition monitoring is parameter analysis of the electromagnetic field generated during operation [4, 5, 6, 7, 8, 9]. Since the automobile alternator frame is made of aluminium alloys not screening the generated magnetic field, then its serviceability can be monitored based on the parameter analysis of the external (in relation to the automobile) magnetic field. The advantages of such methods can include high efficiency and informativity, however, their use on the automobile alternators is not sufficiently studied [10, 11, 12, 13, 14].

2 Analysis of Publications on the Research Issue

In article [15] the problem in diagnostics of the rotor bar breaking in electric machine by the external magnetic field parameter is studied. While analyzing the spectrum of the magnetic field generated by the asynchronous motor, occurrence of sf component, which exists only in axial component of the magnetic field, can be observed. Parameter sf can be ignored in the properly functioning electrical machine. Summarizing the above it can be said that this method is efficient to detect breaking in squirrel cage bars and provides reliable data concerning technical condition of the asynchronous motor. The disadvantages of sf and 3sf diagnostic parameters can include their small value, as well as the necessity of highly-accuracy equipment being capable to identify these low-frequency and low value parameters.

Work [16] considers the problem of short-circuit stator winding detection based on the harmonic analysis of the magnetic field. The considered method for detection of faults allows detecting turn short circuit by increase of the certain harmonics in the spectrogram.

Work [17] is concerned with the problem of rotor eccentricity detection by means of the external magnetic field. The described method allows detecting only dynamic eccentricity or dynamic eccentricity at combined eccentricity with minimum effect of static eccentricity.

Authors [18] have suggested the method for winding turn short-circuit detection based on the magnetic field analysis. For analysis of magnetic fluxes time-and-frequency signal spectrum is required from the sensor responding to the magnetic flux, which is installed within end face area of the alternator and with subsequent processing and extraction of the distortion value due to turn short-circuit from this signal. The authors of this article have used continuous wavelet transform to obtain the time-and-frequency signal spectrum. For this diagnostic method, the magnetic field sensors installation is required strictly in the certain places on the alternator surface, deviation in the installation will cause the reliability of the obtained results. The installation is not mobile and cannot be used for diagnostics of non-stationary alternators, for example, automobile ones.

In work [19] the spectrograms of serviceable motor and motor with faults have been analyzed, according to the research results it can be observed that value of the first harmonic much more than harmonics of other order, it concerns the serviceable asynchronous motor. Thus, the authors have distinguished such diagnostic parameters as the intensity of the external magnetic field and spectral analysis of oscillograms. These parameters allow determining the asynchronous motor technical condition with the sufficient accuracy. The article disadvantage consists in that these diagnostic parameters are adapted only for the asynchronous motor diagnostics, researches for the alternators were not performed.

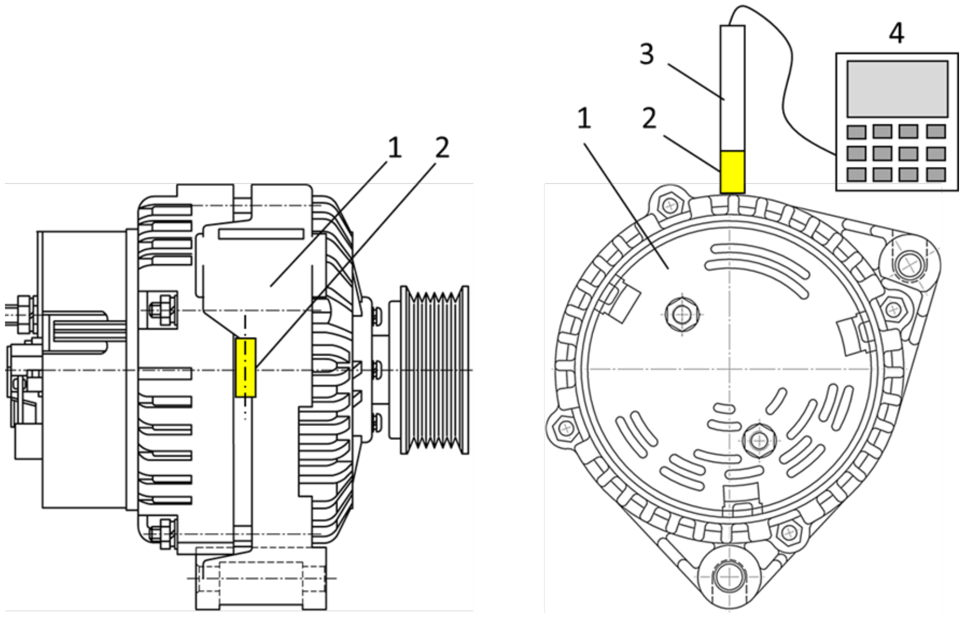
The author of article [20] has assembled the pilot unit, in which the magnetic field sensor is located in close proximity to the asynchronous motor, then the signal is directed from it to the personal computer and processed by fast Fourier transform method. The reference spectrogram has been obtained for fault-free motor, it is apparent that it consists of the first-order harmonics (50 Hz), and the other ones have low amplitude, and they can be ignored. It is obvious that the first harmonic is not single, harmonics of the second and higher order are added to it, moreover, the amplitude of the first harmonic is reduced that can be evidence of the fault. The advantages of this method can include the possibility to evaluate the technical condition and remaining life of the asynchronous motor based on the developed diagnostic method. The disadvantages can include insufficient number of the considered specific faults that doesn't provide complete idea about the technical condition of the alternator, moreover, during spectrogram construction insufficient frequency range (650 Hz) was chosen, and for the complete idea the required range is equal to 1000 Hz. Moreover, all spectrograms include zero-order harmonic, but the author does not mention this harmonic in its article and doesn't consider it as the diagnostic parameter.

Thus, a major part of the considered works requires positioning of several magnetic field sensors in relation to the electric machine at the certain distance, while arrangement of the automobile alternator in hood space significantly restricts such a possibility.

3 Experiment Procedure

The Hall sensor was used for experimental researches of the external magnetic field of the automobile alternator. The Hall sensor transforms the magnetic field intensity into output voltage; thus, we will use a relative value representing the magnetic field magnitude expressed in volts as the external magnetic field parameter. The Hall sensor used in the automobile diagnostic represents textolite ruler, at the end of which the Hall element is located, equipped with BNC connector for connection with the oscillograph [21].

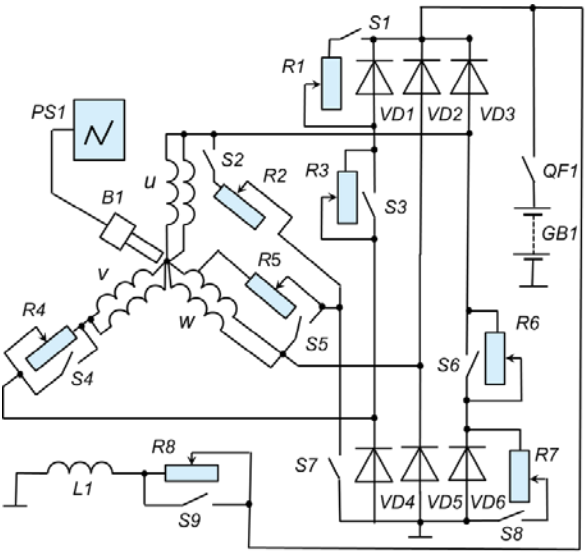
The Hall sensor is oriented in relation to the automobile alternator so that it directly contacts with external surface at the top of the joint between front and rear cover, moreover, the sensor axis is perpendicular to the alternator axis (Figure 2).



1 – Automobile Alternator, 2 – Magnetic Field Sensor (Hall Sensor), 3 – Textolite Base of the Hall Sensor, 4 – Portable Oscillograph

Fig. 2. Orientation Method for Magnetic Field Sensor (Hall Sensor) in Relation to External Surface of the Automobile Alternator

The experiment was performed on special bench [22] allowing changing the rotor speed and alternator current intensity within the wide ranges, as well as simulating its specific electrical faults (Figure 3).



B1 – Hall Sensor,
GB1 –Battery,
L1 – field winding,
QF1 – Automatic Circuit Breaker,
PS1 – Oscilloscope,
R1 – short circuit positive diode,
R2 – Phase-to-phase fault, R3 – open circuit of the positive diode,
R4 – open stator phase,
R5 – Interturn Short-Circuit,
R6 – short circuit negative diode,
R7 – open circuit of the negative diode,
R8 – open field winding, S1-S9 – Switches

Fig. 3. Experiment Electric Diagram.

The experiment was performed in the following order: the magnetic field sensor (Hall sensor) is connected to the portable oscillograph; the magnetic field sensor is oriented in relation to the external surface of the automobile alternator as shown in Figure 2; the portable oscillograph is switched on and the oscillogram of external magnetic field changing is recorded; the relative value (magnitude) of the external magnetic field is recorded.

4 Results if External Magnetic Field Parameter Analysis

Change of the external magnetic field magnitude through time for the serviceable alternator despite distortion generally reminds symmetrical sine curve [23] (Figure 4). According to the fault modelling results it has been established that at different points of the alternator surface the external magnetic field magnitude can be both increased and decreased in relation to the serviceable alternator values, moreover, decrease and increase of the magnetic field magnitude can indicate different faults that means uncertainty of this parameter.

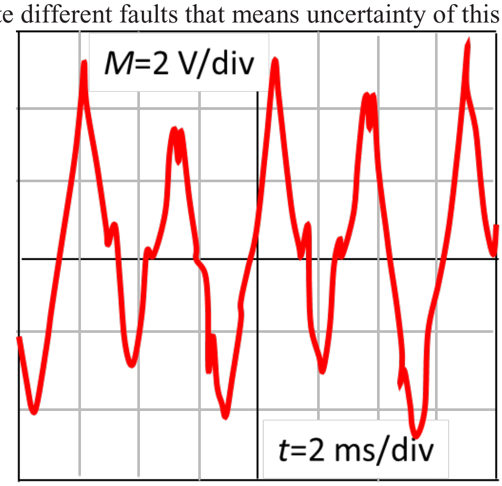


Fig. 4. Oscillogram of External Magnetic Field Change Obtained with Hall Sensor

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Thus, to increase informativity of this diagnostic parameter spectral analysis of the external magnetic field oscillogram was performed with the function of fast Fourier transform integrated into the oscillograph. Figure 5 shows the spectrum of the external magnetic field for the serviceable alternator, and Figure 6 shows change in the spectrum at the specific electric faults.

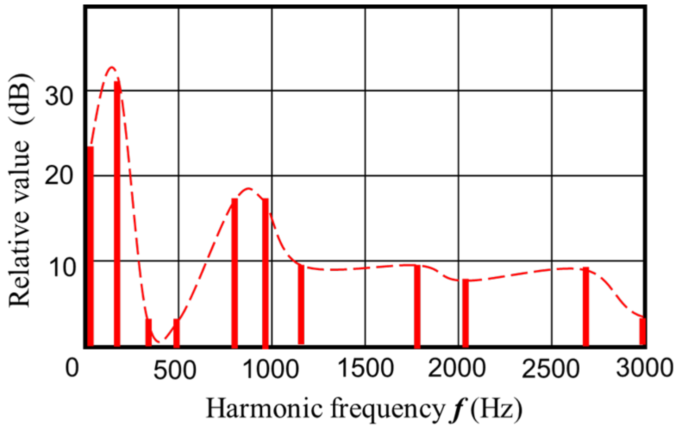
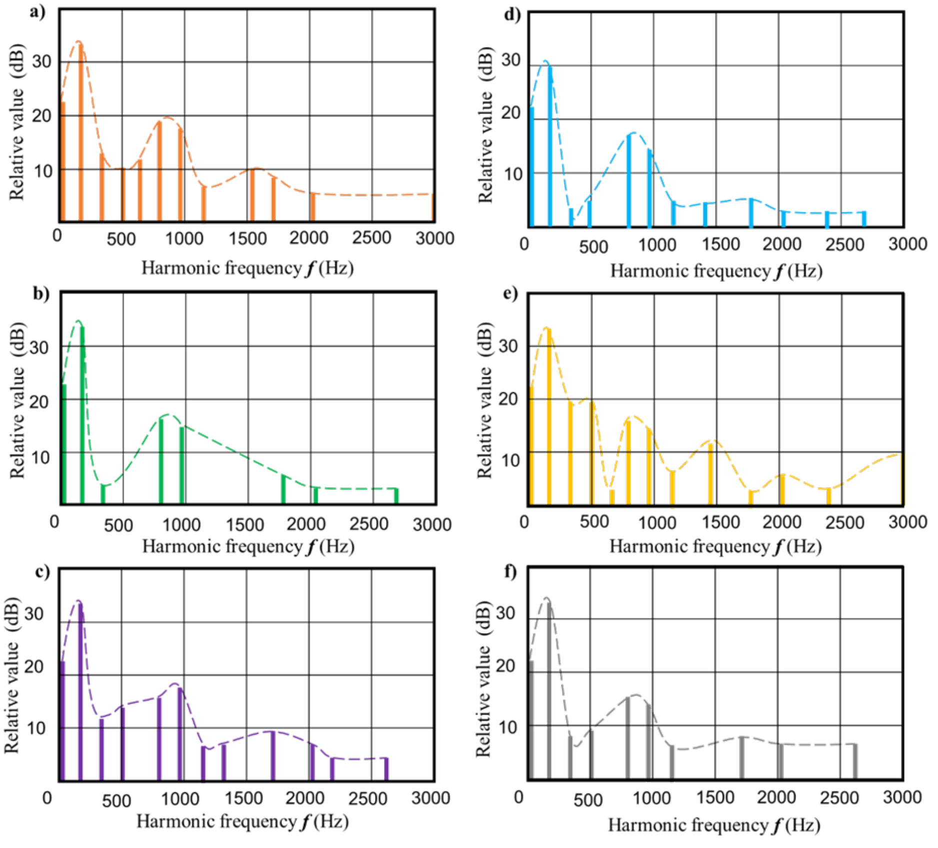


Fig. 5. Spectrum of External Magnetic Field of the Serviceable Automobile Alternator



a) Phase Break, b) Diode Break, c) Interturn Short-Circuit, d) Contact to Frame, e) Diode Fault, f) Phase-to-phase fault

Fig. 6. Spectrum of External Magnetic Field at Alternator Electric Faults

For practical use of the spectral analysis as a automobile alternator diagnostics method the following shall be detected: which harmonic components will be an indicator of a particular fault.

For this purpose, value of harmonic components in relation to the constant component shall be calculated. The calculation results are given in Table 1.

Table 1. Spectral Analysis of the Alternator External Magnetic Field

Harmonic Frequency	Serviceable	Phase Break	Diode Break	Interturn Short-Circuit	Contact to Frame	Diode Fault	Phase-to-phase fault
0	1	1	1	1	1	1	1
166	1.32	**1.304**	1.478	1.478	1.478	1.478	1.478
333	0.12	0.174	0.174	**0.870**	0.522	0.348	0.565
500	0.12	0.261	**0**	**0.870**	0.609	0.391	0.435
666	0	0	0	0.130	0	0	**0.522**
833	0.72	0.739	0.696	0.696	0.696	0.696	**0.782**
1000	0.72	0.609	0.609	0.609	**0.782**	0.609	0.739
1166	0.4	0.217	0	0.304	0.304	**0.435**	0.304
1333	0	0.217	0	**0.522**	0.304	0	0.435
1500	**0.4**	0.261	0.261	0.130	0.391	0.391	0.348
1833	0.32	0.130	0.130	0.261	0.304	0.304	0.217
2000	**0.4**	0.130	0.130	0	0.174	0.304	0
2333	0.12	0	0	**0.435**	0	0	0.217
Amount	5.64	5.043	4.478	7.304	6.565	5.956	7.043

In Table 1 indicating harmonics having maximum and minimum relative value, which allows detecting a particular specific fault of the automobile alternator, are given in semi-bold. Some technical conditions of the alternator are characterized with two indicating harmonics (for example, serviceable alternator), the other ones are characterized with only one. Moreover, it can be observed that the amount of harmonics for the serviceable alternator external magnetic field and specific faults also differ. Thus, the spectral analysis of the external magnetic field parameters increases informativity of this method when determining the automobile alternator technical condition.

5 Conclusion

Analysis of the automobile alternator diagnostics method has shown that the objective methods of diagnostics, particularly, electromagnetic field parameter analysis methods, have minimum labor intensity.

Review of the publications devoted to the electric machine diagnostics allows making a conclusion that the major part of the works requires positioning of several magnetic field sensors in relation to the electric machine at the certain distance, while arrangement of the automobile alternator in hood space significantly restricts such a possibility.

The external magnetic field magnitude measured with the Hall sensor changes when modelling specific faults of the automobile alternator, however, it does not allow expressly recognize the occurring fault.

For increase of the diagnostic parameter informativity spectral decomposition of the external magnetic field oscillogram is performed. Indicating harmonics, which extreme value allows identifying the technical condition of the automobile alternator, are distinguished.

The article materials can be used for further development and implementation of the automobile alternator diagnostics based on the parameters of the external magnetic field.

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