Diagnostics of Commutator DC Motor Basing on Spectral Analysis of Signals

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Summary: Measurement investigations have been carried out for commutator dc motor with internal asymmetries. Construction of considered motor enables to realize the breaking of one rotor coil and shorting of two groups of rotor coils. Each group contains three rotor coils. The basis of study were signals: current and voltage of field winding, current and voltage of armature winding and velocity of the rotor. The presented in this paper results of spectral analysis of signals create new possibilities for diagnostics of commutator dc motor.

Key words:
commutator dc motor, rotor asymmetries, spectral analysis

1. INTRODUCTION

Study of features of dc motor and presentation of new problems is purpose of this paper. Experimental investigations were carried out for specially designed dc motor. Construction of this motor permits to investigate the internal asymmetries. Authors carried out spectral analysis of field and armature currents, field and armature voltages and rotor velocity in failure conditions of dc motor searching best diagnostic signal.

2. MATHEMATICAL DESCRIPTION OF COMMUTATOR DC MOTOR

The mathematical description of dc motor is derived on the following assumptions:
- the magnetic circuit is linear,
- the air-gap is uniform,
- the unipolar flux is neglected,
- the eddy currents in iron are not taken into account,
- the commutator of the motor is approximated by circuit with variable parameters.

The commutator of dc motor is approximated by resistance circuit. Extremely different values are assigned to parameters of circuits depending on the angular position of the rotor. Mathematical model of dc motor formed in this manner is a set of stiff nonlinear differential equations [5]. This model is competitive in comparison with models presented in literature [1, 4, 6]. The commutator dc motor circuit is described by nonlinear stiff differential equations:

$$\frac{d}{dt}\left(\mathbf{C}^{\mathrm{T}}\mathbf{L}_{\mathrm{b}}\mathbf{C}\ \ \mathbf{i}\right)+\mathbf{C}^{\mathrm{T}}\mathbf{R}_{\mathrm{b}}\mathbf{C}\ \ \mathbf{i}=\mathbf{u} \qquad (1)$$

$$J\frac{d}{dt}\omega+D\omega=T_e-T_l \qquad (2)$$

$$\frac{d}{dt}\varphi=\omega \qquad (3)$$

$$T_e=\frac{1}{2}(\mathbf{i})^{\mathrm{T}}\frac{\partial}{\partial\varphi}(\mathbf{C}^{\mathrm{T}}\mathbf{L}_{\mathrm{b}}\mathbf{C})\ \ \mathbf{i} \qquad (4)$$

In the model equations the following notation was applied:
ω — angular velocity of rotor,
φ — angular position of rotor,
$\mathbf{C}$ — matrix of constraints,
$\mathbf{L}_{\mathrm{b}}$ — matrix of branch inductances,
$\mathbf{R}_{\mathrm{b}}$ — matrix of branch resistances,
$\mathbf{u}$ — vector of mesh source voltages,
$\mathbf{i}$ — vector of mesh currents,
T_e — electromagnetic torque,
T_l — load torque.

The effective implicit integration method is used for solution of model equations.

Measurement investigations were aided with computer simulation [2, 3, 7]. From simulation implied that field and armature currents, field and armature voltages and rotor velocity may contain diagnostic information.

3. MEASUREMENT INVESTIGATIONS

This motor enables to realize the breaking of one loop rotor coil and shorting of two groups of rotor coils. Each group of coils contains three loop rotor coils. DC machine operating as a motor in open and closed regulation system was investigated in following cases: faultless state, shorting of first group of coils, shorting of second group of coils, shorting of two groups of coils, breaking of one coil, shorting of first group of coils and breaking of one coil, shorting of second group of coils and breaking of one coil, shorting of two groups of coils and breaking of one coil. Measurements have been carried out for supplying of field circuit from dc generator. Armature circuit was supplied from dc generator and thyristor converter. The nominal values of dc machine were: P_N = 13 kW, U_N = 75 V, I_N = 200 A, U_{fN} = 220 V, n_N = 700 rpm. It was assumed that each group of three loop rotor coils is shorted through resistance R_{bz} = 44 mΩ. Measurements have been developed by means of 16-bit a/d converter. The dc generator connected with external resistance produced the load torque. The additional resistances were used in short-circuits to avoid damage of rotor winding. Measurement stand and investigated commutator dc motor are presented in Figures 1 and 2.

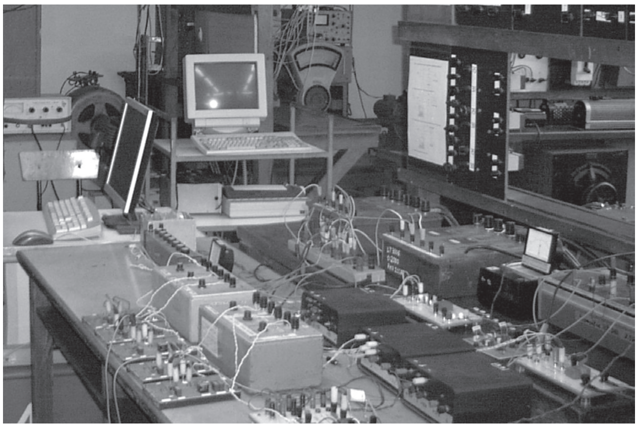

Fig. 1. Measurement stand

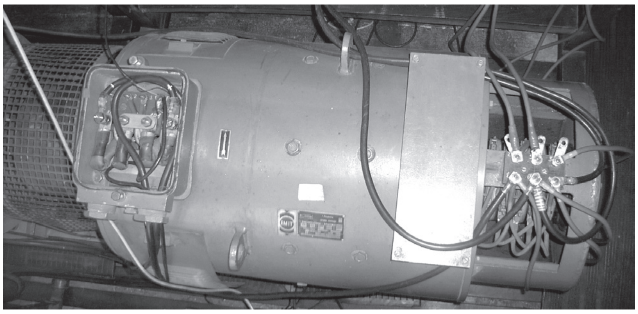

Fig. 2. Investigated dc commutator motor

4. SPECTRAL ANALYSIS

Spectral analysis of signals of commutator dc motor has been carried out for different velocities of rotor using Matlab environment. Amplitudes of harmonics of spectral analysis are presented for open regulation system. Results for dc generator fed armature circuit are showed in Figures 3–6, whereas results for thyristor converter fed armature circuit are presented in Figures 7–10. Frequency of diagnostic harmonic of field current is depending on the rotor velocity and is 4 times greater than rotor revolutions per second (investigated dc motor has 4 field poles). Corresponding amplidudes of diagnostic harmonics of field current are presented in Tables 1–4.

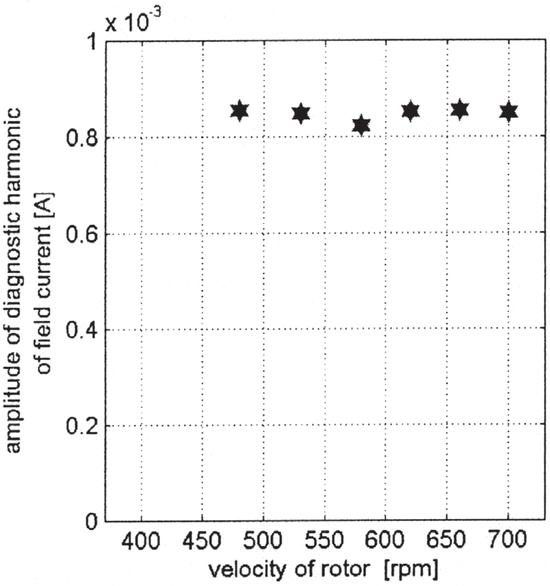

Fig. 3. Diagnostic harmonic of field current in faultless state of dc generator fed armature circuit

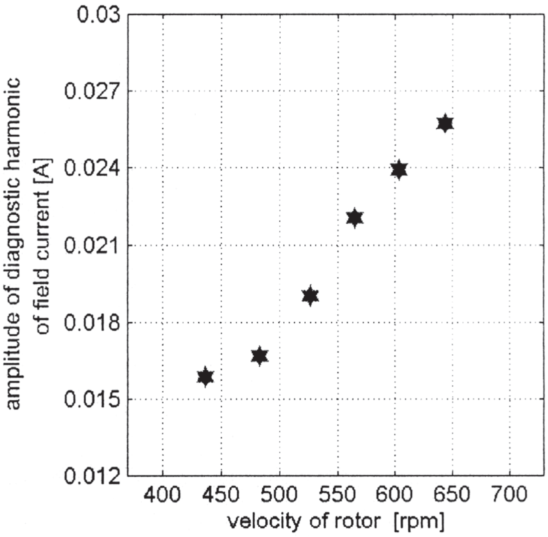

Fig. 4. Diagnostic harmonic of field current in conditions of three coils shorting of dc generator fed armature circuit

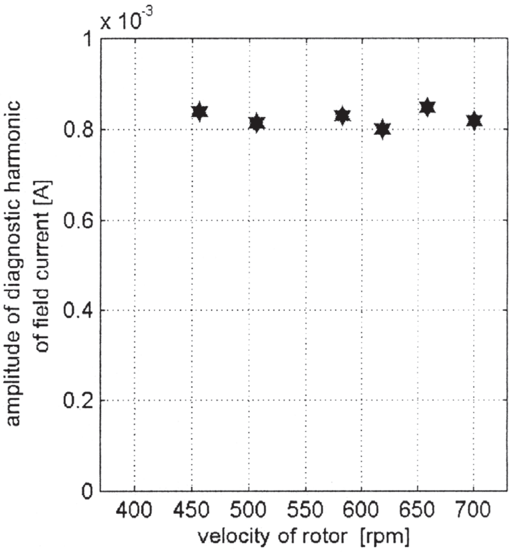

Fig. 5. Diagnostic harmonic of field current in conditions of one coil breaking of dc generator fed armature circuit

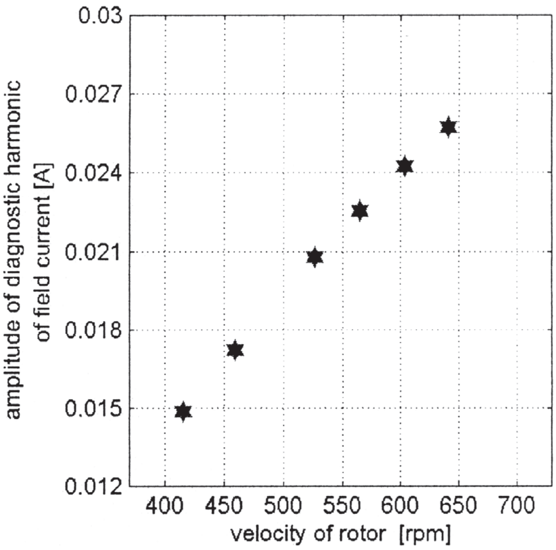

Fig. 6. Diagnostic harmonic of field current in conditions of one coil breaking and three coils shorting of dc generator fed armature circuit

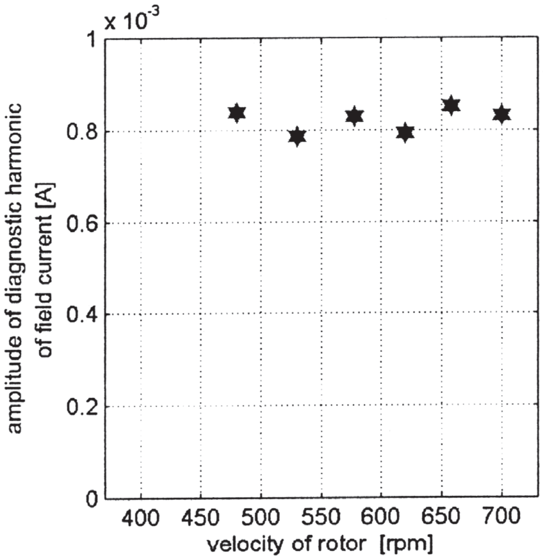

Fig. 7. Diagnostic harmonic of field current in faultless state of thyristor converter fed armature circuit

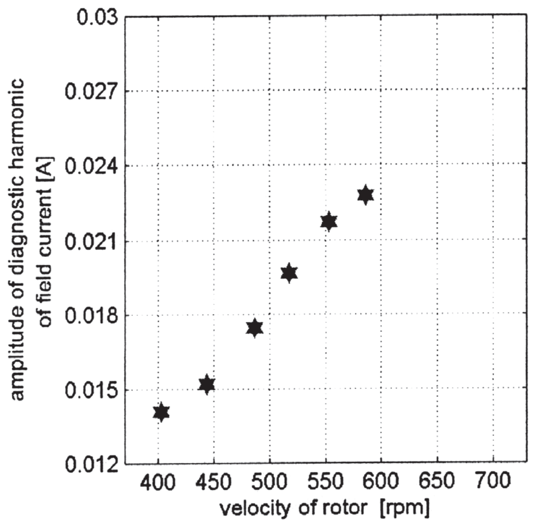

Fig. 8. Diagnostic harmonic of field current in conditions of three coils shorting of thyristor converter fed armature circuit

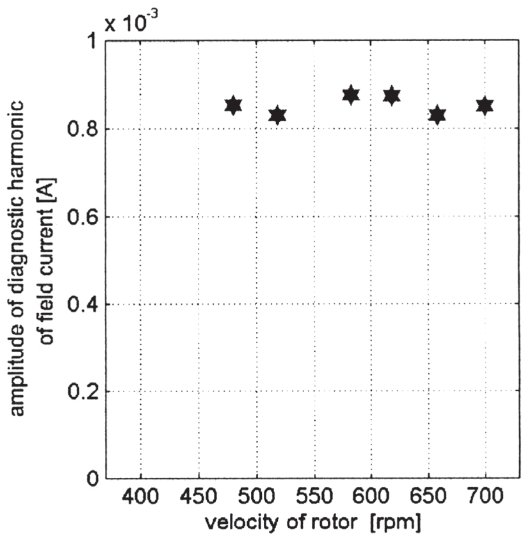

Fig. 9. Diagnostic harmonic of field current in conditions of one coil breaking of thyristor converter fed armature circuit

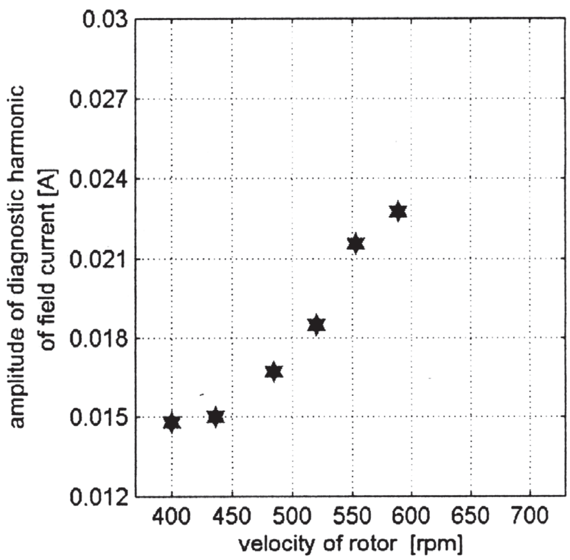

Fig. 10. Diagnostic harmonic of field current in conditions of one coil breaking and three coils shorting of thyristor converter fed armature circuit

Table 1. Amplitudes of diagnostic harmonic of field current in open regulation system for faultless state [A]

Open regulation system			
dc generator fed dc motor		thyristor converter fed dc motor	
velocity of rotor [rpm]	amplitude of harmonic [A]	velocity of rotor [rpm]	amplitude of harmonic [A]
480	0.000854	480.0	0.000838
530	0.000847	530.0	0.000785
580	0.000821	577.7	0.000829
620	0.000851	620.0	0.000792
660	0.000854	657.7	0.000850
700	0.000849	700.0	0.000831

Table 2. Amplitudes of diagnostic harmonic of field current in open regulation system for shorting of three coils [A]

Open regulation system			
dc generator fed dc motor		thyristor converter fed dc motor	
velocity of rotor [rpm]	amplitude of harmonic [A]	velocity of rotor [rpm]	amplitude of harmonic [A]
437	0.0158	403	0.0141
483	0.0167	444	0.0152
527	0.0190	487	0.0175
565	0.0220	517.7	0.0197
603	0.0239	553	0.0217
643	0.0257	586	0.0228

Table 3. Amplitudes of diagnostic harmonic of field current in open regulation system for breaking of one coil [A]

Open regulation system			
dc generator fed dc motor		thyristor converter fed dc motor	
velocity of rotor [rpm]	amplitude of harmonic [A]	velocity of rotor [rpm]	amplitude of harmonic [A]
456.6	0.000838	480.0	0.000851
506.6	0.000814	518.3	0.000827
582.3	0.000828	582.3	0.000875
617.7	0.000798	617.7	0.000871
657.7	0.000847	657.7	0.000829
700.0	0.000818	700.0	0.000849

Table 4. Amplitudes of diagnostic harmonic of field current in open regulation system for breaking of one coil and shorting of three coils [A]

Open regulation system			
dc generator fed dc motor		thyristor converter fed dc motor	
velocity of rotor [rpm]	amplitude of harmonic [A]	velocity of rotor [rpm]	amplitude of harmonic [A]
415.9	0.0149	400.7	0.0148
459.6	0.0172	437.0	0.0150
527.0	0.0208	484.7	0.0167
565.0	0.0225	520.0	0.0185
603.0	0.0243	553.0	0.0216
640.6	0.0257	588.3	0.0228

5. CONCLUSIONS

The shorted and broken rotor coils influence on commutator dc motor signals: field and armature voltages, field and armature currents and rotor velocity. In case of shorting of three rotor coils occur considerable deformations of these signals. In case of breaking of one coil the deformations of mentioned quantities are also visible. Field current is best diagnostic signal. Frequency of diagnostic harmonic of field current is depending on the rotor velocity. Amplitudes of diagnostic harmonic of field current in cases of: shorting of three coils (Fig. 4, 8) and breaking of one coil and shorting of three coils (Fig. 6, 10) are strongly depending on rotor velocity. Similar dependences occur for field and armature voltages, armature current and rotor velocity. Amplitudes of diagnostic harmonic of field current in cases of faultless state (Fig. 3, 7) and breaking of one coil (Fig. 5, 9) are weakly depending on rotor velocity. Similar dependences occur for field and armature voltages, armature current and rotor velocity. Effects of commutation processes can be found in the waveforms of signals. Particularly field and armature voltages as well as field and armature currents of dc motor contain deformations which repeatability is closely connected with the velocity of the rotor. Amplitudes of harmonics of field and armature voltages as well as field and armature currents in emergency states are several times greater than those in faultless state. For supply from dc generator in spectrum of signals (particularly in field voltage spectrum) the 50 Hz harmonic and its multiplicities are visible. Results of spectral analysis indicate that field and armature currents as well as field and armature voltages contain information about the motor state and can be used as diagnostic signals. From investigations implies that in rotor velocity is also included information about motor state according to simulation result. Because of this reason deep assessment of rotor state requires the taking into consideration several measured signals.

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