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HF Parameters of Induction Motor

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ABSTRACT

This article describes the results of experimental studies of HF input and primary parameters. A simulation model in Matlab Simulink^{TM} of multiphase windings as ladder circuit of coils is developed. A method for determining the primary parameters of ladder equivalent circuits is presented.

1. Introduction

Investigation of high frequency (HF) process over- voltage in the windings of electrical machines began in the 30s of XX century [1]. These problems of overvoltage are caused by motor supply with variable speed drives (frequency converter PWM). These inverters provide their periodic rectangular output pulses that generate a spectrum of high frequency harmonics. For these high frequencies, there is another type of equivalent circuit for the study of overvoltages in these motors, which are set by evidence of capacitive coupling [2–6].

2. HF primary and input parameters

We consider one phase of a multiphase winding of induction motor. With the reference frequency (1-5) kHz, PWM inverter based on insulated gate bipolar transistor (IGBT) technology control this motor. In the winding operate high harmonics of voltage with frequency $f_{wp} = 10^3 \ldots 10^6 Hz$. For this frequencies f_{wp} correspond HF parameters of induction motors different from those commonly used in frequency control $f_{reg} = 10^1 ... 10^2 Hz$ because of the appearance at $f_{wp} \gg f_{reg}$ capacitive coupling. For determining the HF pa-

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rameters, phase of motor is replaced by a ladder circuit, including N_c coils is represented in Fig. 1.

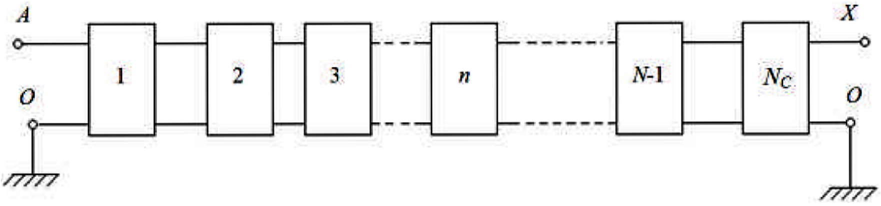

Fig. 1 – Ladder circuit with N_c coils of motor phase.

Number of coils for single layer winding is defining by $N_{CS} = \frac{Q_1}{2m_1 a} = \frac{pq}{a}$, for two layer winding by $N_{CT} = \frac{2pq}{a}$ [7]. In the study of high-frequency processes, coils are replaced by quadripoles [8] with different variants of equivalent circuits. In this paper, it is considered that each coil corresponds to the equivalent circuit as shown in Fig. 2.

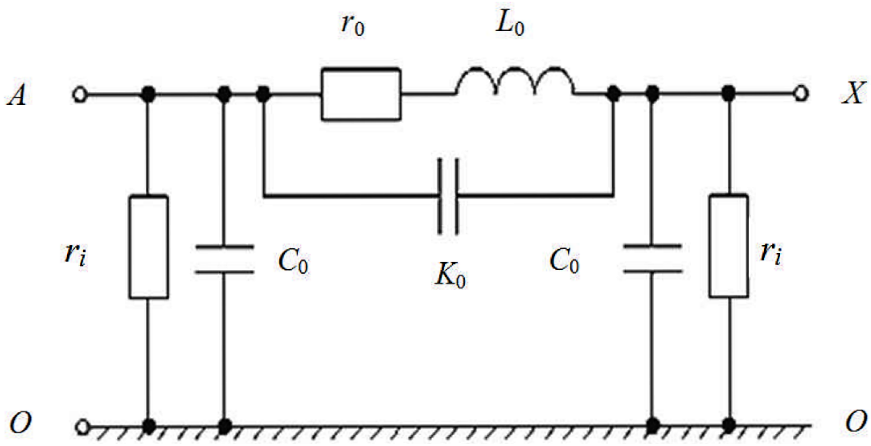

Fig. 2 – Equivalent circuit of coil.

Where r_0– resistance, taking into account the losses in copper, iron and motor screens (Ω); L_0– inductance, which takes into account mutual inductance of machine elements (H); C_0– capacity of the coil conductors with machine frame (F); K_0– longitudinal capacitance, taking into account the capacitive coupling between the coil turns and other coils (F); r_i– resistance, taking into account the power losses in the winding insulation (Ω).

Input parameters for the phase windings are complex functions of the primary parameters [8, 9] and are determined experimentally as shown in Fig. 3.

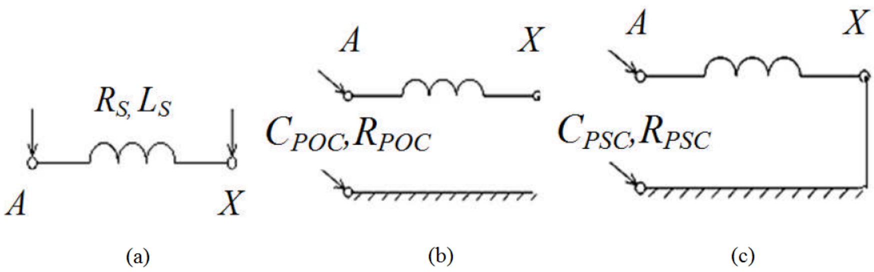

Fig. 3 – Experimental determination of input parameters.

When measuring the input longitudinal equivalent inductances (L_S) and resistances (R_S), LCR meter is connected to the beginning and end of the phase winding Fig.3.a. The equivalent transverse input capacitances (C_P) and resistances (R_P) is measured in open circuit mode (Fig.3.b) and short circuit mode (Fig.3.c).

3. Experimental installation

To investigate the frequency dependence of the input HF parameters are used a flat linear induction motor (FLIM) and serial asynchronous motors with squirrel-cage rotor and phase-wound rotor.

In the FLIM, all stator coils have intermediate voltage terminals on the measuring board (Fig. 4), which create opportunities to identify intercoil and interphase capacitance and inductance.

The winding data of FLIM are : $Q_1 = 36$, $2p = 4$, $m_1 = 3$, $q = 2$. For the measurement of HF parameters is used LCR meter

"QuadTech 7600 Precision LCR Meter Model B" (Fig.5) with measuring ranges of parameters given in the table (tab.1). In the used meter, the source test signal generator is a direct digital synthesis with selectable internal resistance (25 Ω, 400 Ω, 6.4 Ω, 100 kΩ). It allows to obtain a continuous set of frequencies in the range 10 Hz ... 2 MHz with accuracy ±0.25%. Test signal is a continuous sinusoidal oscillation with an RMS value of voltage up to 5V and of current up to 100 mA.

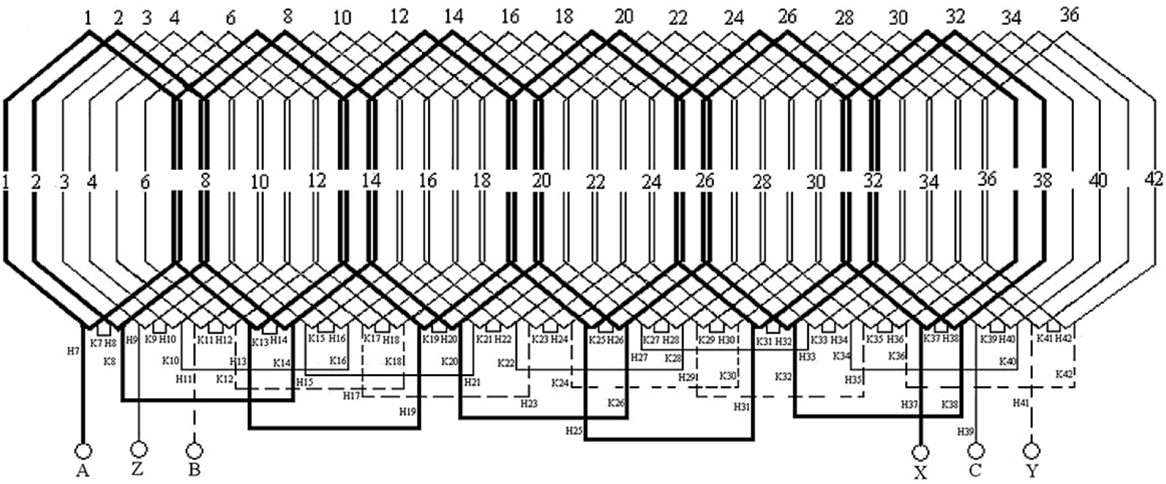

Fig. 4 – Experimental FLIM.

Fig. 5 – QuadTech 7600 Precision LCR Meter Model B.

4. Experimental measurements

The measurement curves of the input HF parameters for different frequencies have the same character of change for all the tested windings of induction motors : curves have resonant peaks and zero points, as well as the range of negative and positive values, caused by the inductance and capacitance interaction. The Fig. 6 - 11 show the curves of tested FLIM. The number of coils NC in phases vary from one to twelve.

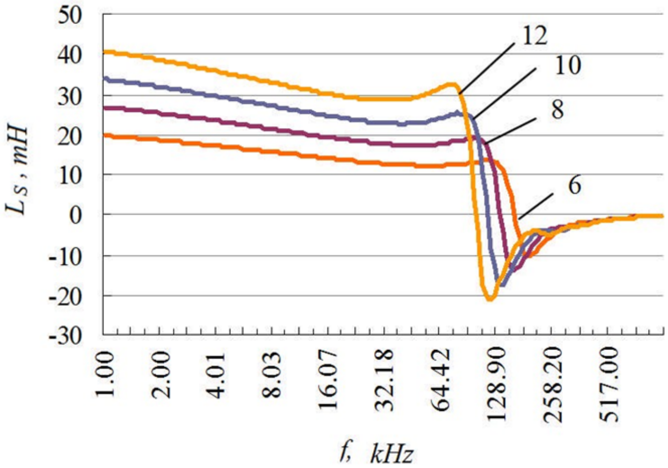

Fig. 6 – Curve of tested FLIM (L_S).

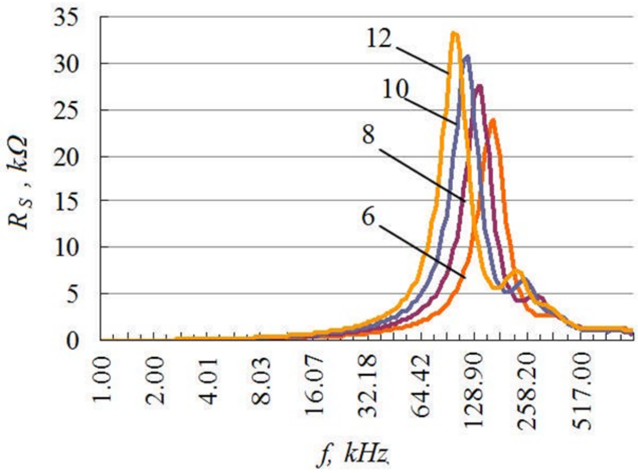

Fig. 7 – Curve of tested FLIM (R_S).

Analysis of the experimental curves shows :

– curves have resonant peaks and the zero points are shifted to higher frequencies by reducing the number of coils in the phase windings ;
– resonant values R_{SMAX} correspond to frequencies at which $L_S = 0$;
– curves C_{POC} have also resonant peaks and nulls determined by interaction of C_0, K_0, r_0, L_0 ;
– experimental curves confirm the necessity to integrate the mutually inductive coupling between slots in the calculation of the resistances of coils. Mutually- inductive

and capacitive couplings give the inequalities $L_{S(NC)} \neq N_C.L_{S1}$; $C_{P(NC)} \neq N_C.C_{P1}$; $R_{P(NC)} \neq N_C.R_{S1}$, included in the determination of primary HF parameters.

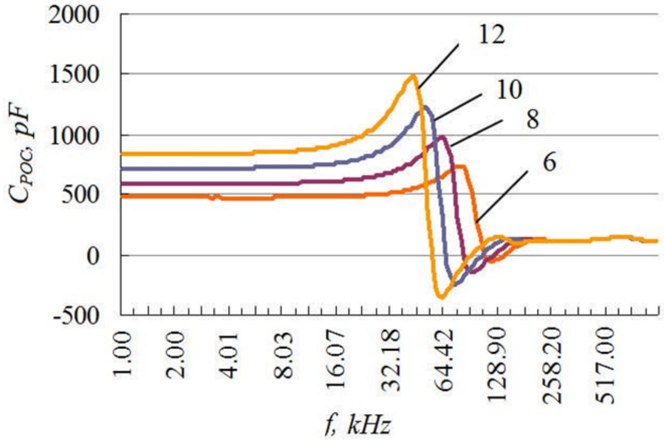

Fig. 8 – Curve of tested FLIM (C_{POC}).

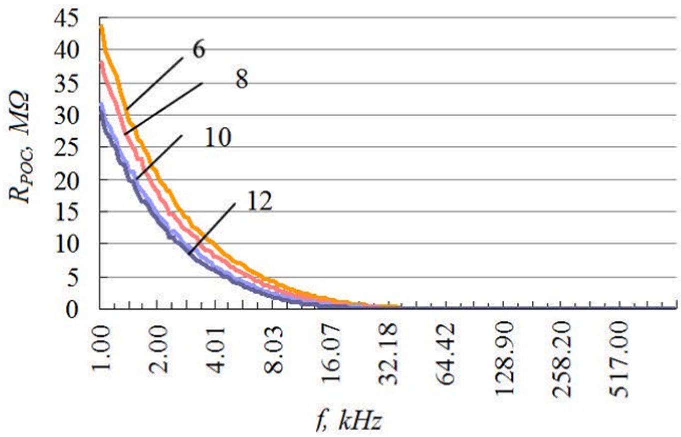

Fig. 9 – Curve of tested FLIM (R_{POC}).

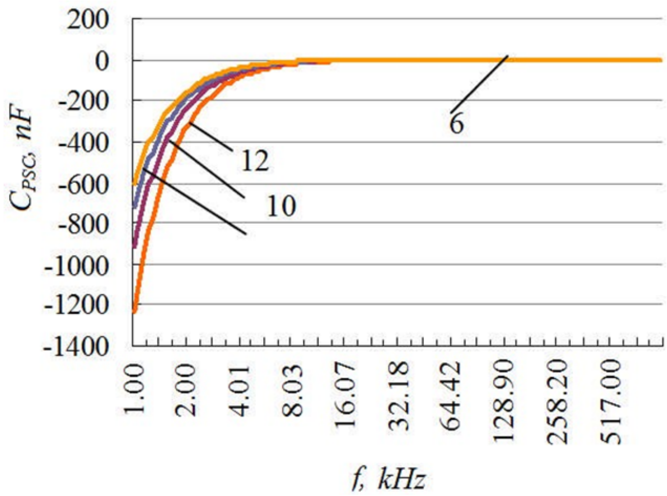

Fig. 10 – Curve of tested FLIM (C_{PSC}).

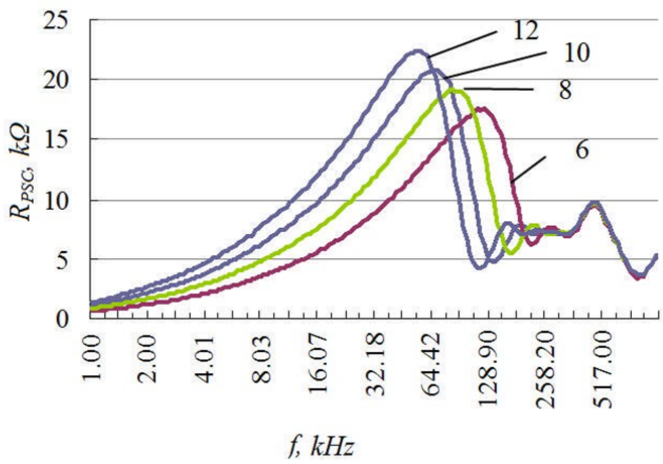

Fig. 11 – Curve of tested FLIM (R_{PSC}).

5. Simulations

Primary HF parameters of the ladder circuit of Fig. 1 are determined by using the simulation package Power System Blockset of Matlab Simulink^{TM}. The simulation scheme related to the definition of longitudinal and transverse input HF parameters is shown in Figs. 12 and 13.

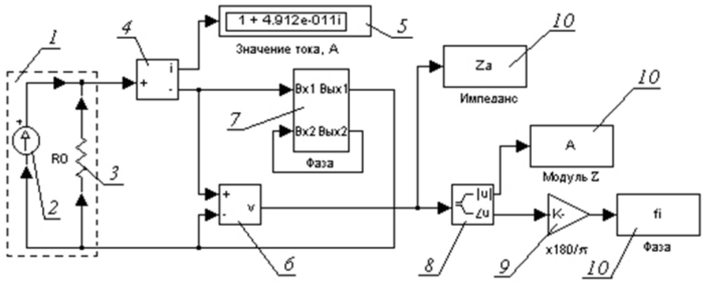

Fig. 12 – Simulation scheme related to the definition of longitudinal.

To determine the parameters of the phase are used models (when connecting the meter of immittance with an isolated neutral (Fig. 12) and with closure phase on the frame (Fig. 13) which include : 1- immittance meter model ; 2- current source ; 3- limiting resistance ; 4- current measurement ; 5- numeric display ; 6- voltage measurement ; 7- phase winding ; 8- magnitude and phase angle of complex signal of impedance ; 9- conversion of radians to degrees ; 10- transfer of calculation results in a system of Matlab for processing ; 11- resistance, administered to simulate an isolated neutral.

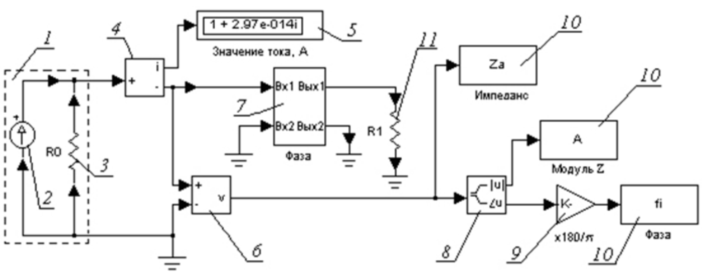

Fig. 13 – Simulation scheme related to the definition of transverse.

In the structural scheme of Figs. 12 and 13 set the values of the primary HF parameters as functions. This functions take into account the dependence of each HF parameters on the frequency, number of coils and parallel branches, windings and the availability of screens. The base frequency f0 is the initial rate of measurements, performed on the experimental electrical machines. Usually f0=1000Hz and the measurement frequency for this value are provided not only for complex instruments, but also for portable LCR meter. Modeling with Matlab is performed in many steps. In the first step, the primary HF parameters are given in the form of approximate dependencies, taking into account the constancy or a decrease (increase) of parameter with the frequency increases. After that, with meter in Figs. 12 and 13 are determined the input HF parameters. The results found of input HF parameters are compared with those found experimentally. If there are differences, the primary HF parameters depending on the frequency are refined in several consecutive iterations until the coincidence of the calculated input HF parameters curves with experimental. Stator winding of FLIM with $N_C = 6 - 12$ correspond to the following values of the primary HF parameters :

$$r_0 = \begin{cases} 4.05 \left(\frac{f}{f_0}\right)^{1.043}, \ f < 160kHz \\ 754, \ f \geq 160kHz \end{cases} \tag{1}$$

$$L_0 = \begin{cases} 3.39 \cdot 10^{-3} \left(\frac{f}{f_0}\right)^{-0.141}, \ f < 160000Hz \\ 1.643 \cdot 10^{-3}, \ f \geq 160000\Gamma u \end{cases} \tag{2}$$

$$r_i = \begin{cases} 36.44 \cdot 10^{7} \left(\frac{f}{f_0}\right)^{-1.3}, \ f < 160kHz \\ 1.5 \cdot 10^{3.75}, \ f \geq 160kHz \end{cases} \tag{3}$$

The values of primary HF parameters at $f = 1kHz$ for N_C coils in a phase are determined by the values of the experimental input HF parameters for the appropriate number of coils.

For variant of FLIM with $N_C = 12$, primary HF parameters at $f = 1kHz$ have the values :

$$L_{0(1000)} = \frac{L_{S(1000)}}{12} = \frac{40.7}{12} 10^{-3} = 3.39 \cdot 10^{-3} H \tag{4}$$

$$r_{0(1000)} = \frac{R_{S(1000)}}{12} = \frac{48.6}{12} = 4.05\Omega \tag{5}$$

$$C_{0(1000)} = \frac{C_{P(1000)}}{12} = \frac{840}{12} 10^{-12} = 70pF \tag{6}$$

$$r_{i(1000)} = 12R_{P(1000)} = 36.44 \cdot 10^{7}\Omega \tag{7}$$

$K_0(1000)$ is determined by matching the experimental and calculated values of the input HF parameters at the resonance points.

For these values of primary HF parameters, the calculated curves of input HF parameters coincide with their experimental analogues of 95. . . 93% (Fig. 14).

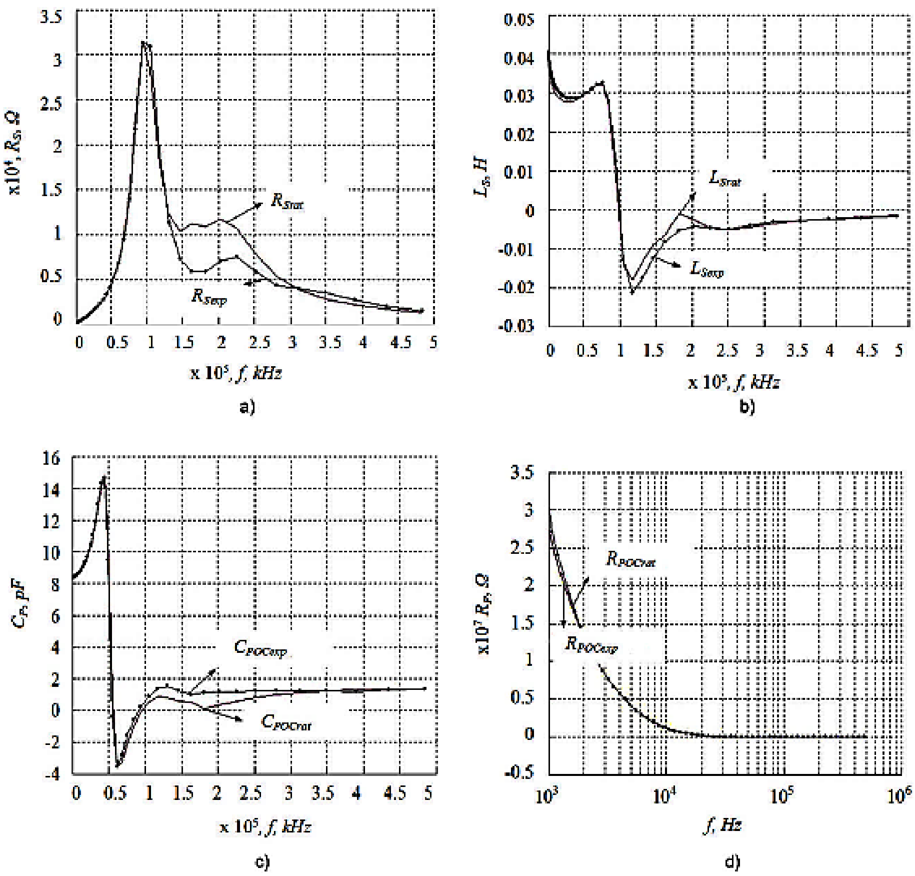

Fig. 14 – Calculated curves of input HF parameters.

6. Conclusion

The experiments show that the HF parameters of a machine change according to the feeding frequency. These parameters have resonance points and null points between 100 and 150 Hz. Curves of the parameters are shifted parallel to the side of the great frequency by reducing the number of coils in the phase.

In determining the primary resistances, the experimental curves confirmed the need to integrate mutually inductive coupling between coils.

The described method for determining the primary HF parameters using MatLab^{TM} software and experimental data on the input HF parameters provides agreement between calculated and experimental data with accuracy (5.... 7%).

Particularities set in the change of HF parameters in function of frequency can be used in defining the parameters of HF AC electrical machines with different powers and achievements.

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