Václav BARTOŠ

TORQUE PULSATION OF THE ASYNCHRONOUS MACHINES CAUSED BY INHARMONIOUS FEEDING

ABSTRACT *Paper presents some solutions for the problems of the torque pulsation of the asynchronous machines caused by inharmonious feeding. Torque pulsation can be solved analytically under simplified conditions at first, but only results of the mathematical model are presented here. The torques under different condition of the feeding modes is solved. The most critical behavior with the rectangular voltage and ripple of them is proved.*

Keywords: *induction motor, torque pulsation*

1. INTRODUCTION

This contribution deals with the torque pulsation of the asynchronous machines caused by inharmonic voltage. The torque pulsation can cause in the squirrel cage braking of the welding connection between rotor bars and rotor ring. The forenamed pulsation can produce strong mechanical stress and excitation in case of the mechanical resonance is extra hazardous.

Prof. Václav BARTOŠ, Ph.D. Ing.
e-mail: bartos@kev.zcu.cz

University of West Bohemia,
Univerzitní 26, 306 14 Plzeň, Czech Republic

The three modes of feed will be studied.

- Asynchronous mode of voltage, usually used for smaller speed of the motor. Voltage spectrum does not create the routine Fourier series. The frequency of the saw voltage is constant and feeding frequency is variable.
- Synchronous mode. The saw voltage is integral multiple of the feeding frequency. This mode is used usually in neighbourhood of the rated speed. Its realization is complicated.
- Square wave of voltage is used for rated and higher speed.

The second and third modes created standard Fourier series containing the 1st, 5th, 7th, 11th, 13th and next harmonic components, Fig. 1. The possible content of voltage components in asynchronous mode is given on Fig. 2. The frequency 801 Hz of saw voltage is supposed here. Detailed frequency spectral must be determined by different way [3].

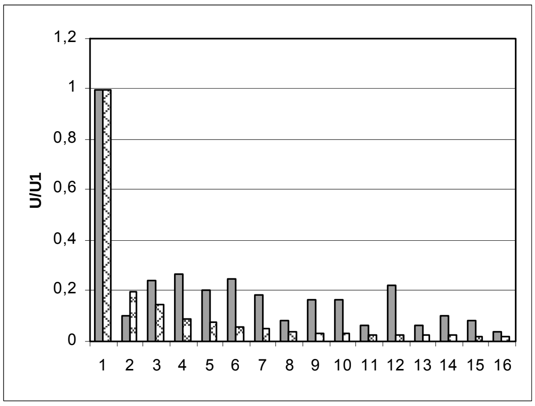

Fig. 1. Voltage spectrum for square wave and for synchronous mode.(Numbers on horizontal axe are not class of harmonics)

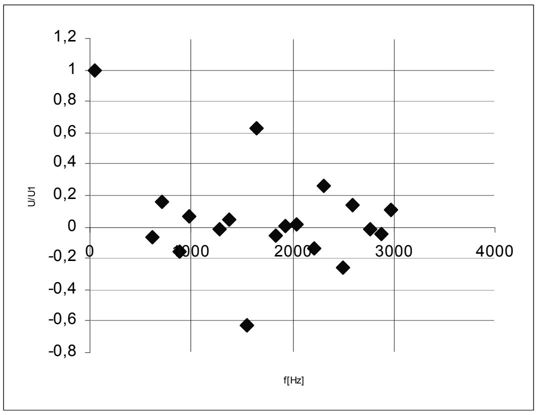

Fig. 2. Voltage spectrum for asynchronous mode and 46 Hz. Minus values indicate back components

The ripple of the voltage caused by imperfect filter circuit for rectified voltage can excited outstanding torque pulsation for case, particularly when feeding frequency and voltage ripple are the same.

The above mentioned modes will be illustrated with help of mathematical model of the asynchronous machine.

2. MATHEMATICAL MODEL

The fundamental equations of the asynchronous machines have following form [2]. For stator is valid

$$
\begin{aligned}
u_a &= \frac{R_s}{L_{\sigma s}}\left(\psi_a - \psi_{\mu a}\right) + \frac{d\psi_a}{dt} + \frac{\sqrt{3}}{3}\omega_k\left(\psi_c - \psi_b\right) \\
u_b &= \frac{R_s}{L_{\sigma s}}\left(\psi_b - \psi_{\mu b}\right) + \frac{d\psi_b}{dt} + \frac{\sqrt{3}}{3}\omega_k\left(\psi_a - \psi_c\right) . \\
u_c &= \frac{R_s}{L_{\sigma s}}\left(\psi_c - \psi_{\mu c}\right) + \frac{d\psi_c}{dt} + \frac{\sqrt{3}}{3}\omega_k\left(\psi_b - \psi_a\right)
\end{aligned}
\tag{2.1}
$$

For rotor we have

$$
\begin{aligned}
0 &= \frac{R_r}{L_{\sigma r}}\left(\psi_A - \psi_{\mu A}\right) + \frac{d\psi_A}{dt} + \frac{\sqrt{3}}{3}\left(\omega_k - \omega\right)\left(\psi_C - \psi_B\right) \\
0 &= \frac{R_r}{L_{\sigma r}}\left(\psi_B - \psi_{\mu B}\right) + \frac{d\psi_B}{dt} + \frac{\sqrt{3}}{3}\left(\omega_k - \omega\right)\left(\psi_A - \psi_C\right) . \\
0 &= \frac{R_r}{L_{\sigma r}}\left(\psi_C - \psi_{\mu C}\right) + \frac{d\psi_C}{dt} + \frac{\sqrt{3}}{3}\left(\omega_k - \omega\right)\left(\psi_B - \psi_A\right)
\end{aligned}
\tag{2.2}
$$

Torque is given following expression

$$
T_i = \frac{p}{\sqrt{3}} \cdot \frac{1}{L_{\sigma s}}\left[\psi_a\left(\psi_{\mu c} - \psi_{\mu b}\right) + \psi_b\left(\psi_{\mu a} - \psi_{\mu c}\right) + \psi_c\left(\psi_{\mu b} - \psi_{\mu a}\right)\right] .
\tag{2.3}
$$

With regard to great moment of inertia we will assume a constant speed. Arrangement of program is following, Fig. 3.

1. Block of voltages, its components are obtained from different computing system [3].
2. Block for skin effect, calculates the change of resistance and inductivity for rotor bars in accordance with actual frequency.
3. Block of the voltage equations (2.1), (2.2) for all assumed voltage components. Here we obtain flux linkages and currents.
4. Block of torques. With help of the expression (2.3) and combination of the different components we obtain constant and pulsation torques.

3. SOME RESULTS

The representative torque components determined via computed system according Fig. 3 will be presented here in graphical or tabular form. Asynchronous mode and 46 Hz (it is half of rated frequency) firstly. Table 1 presents survey of the torque components its magnitudes and frequencies. Components less than 2% are not represented. Figure 4 presents time course of the total torque with the start to load. It was proved that torque pulsation is practically independent on load. Figure 5 is time zoom last figure.

TABLE 1
Tabular summary of the torque components

Frequency [Hz]	**Torque components**	**Magnitude peak to peak [p.u.]**
663	M1_2, M1_3, M2_6 M3_7, M4_8, M5_9, M7_12 M8_13, M9_14, M10_15, M11_16, M13_18, M14_19	0,15
939	M1_4, M1_5, M2_8, M3_9, M4_10, M5_11, M6_13, M7_14, M8_15, M9_16, M10_17, M12_19,	0,144
1326	M1_6, M1_7, M3_12, M4_13, M5_14, M8_18, M9_19	40E-03
1602	M1_8, M1_9, M2_13, M3_4, M3_14, M4_15, M5_16, M6_18, M7_19	1,06
2265	M1_13, M1_14, M2_9, M3_8, M3_19, M4_7	70E-03
2541	M1_15, M1_16, M2_11, M3_10, M5_8	68E-03

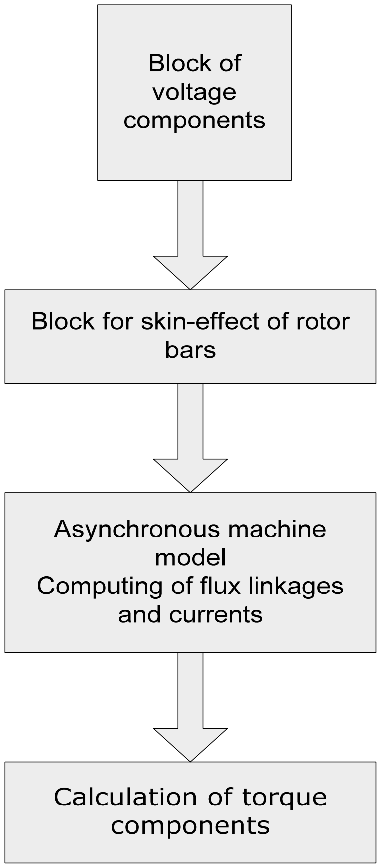

Fig. 3. Block diagram for torque components computing

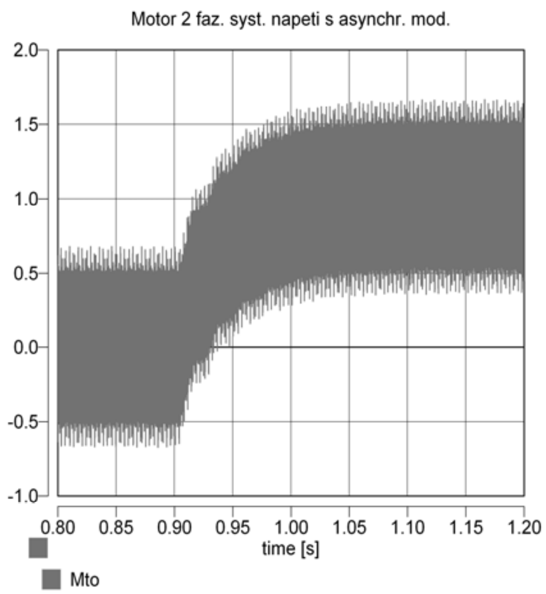

Fig. 4. Time course of the total torque for asynchronous mode and 46 Hz

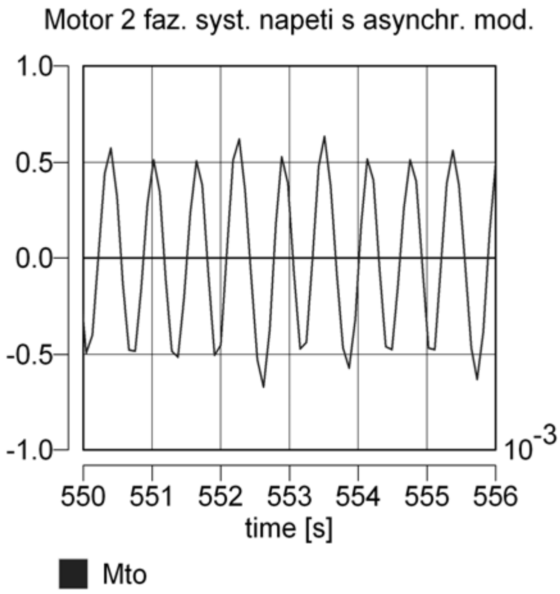

Fig. 5. Time zoom of the foregoing picture

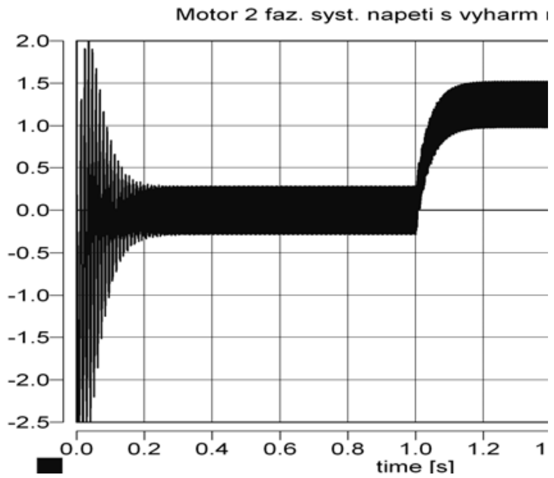

Fig. 6. Square wave mode

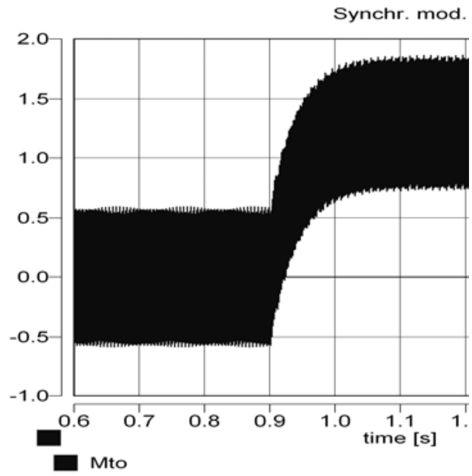

Fig. 7. Synchronous mode

Torque components for synchronous or square wave mode have only order of the harmonic components $\mu = 6,12,18,...$, Fig. 6, 7, for rated frequency (92 Hz).

For overrated frequency is only square wave voltage used. Now we can move on to the following factor caused torque pulsation. It is voltage ripple. Let us assume time course of DC voltage (before inverter) given by next relation

$$U = U_{1N} + 0.01 U_{1N} \sin\left(2\pi f_z t\right) \quad (3.1)$$

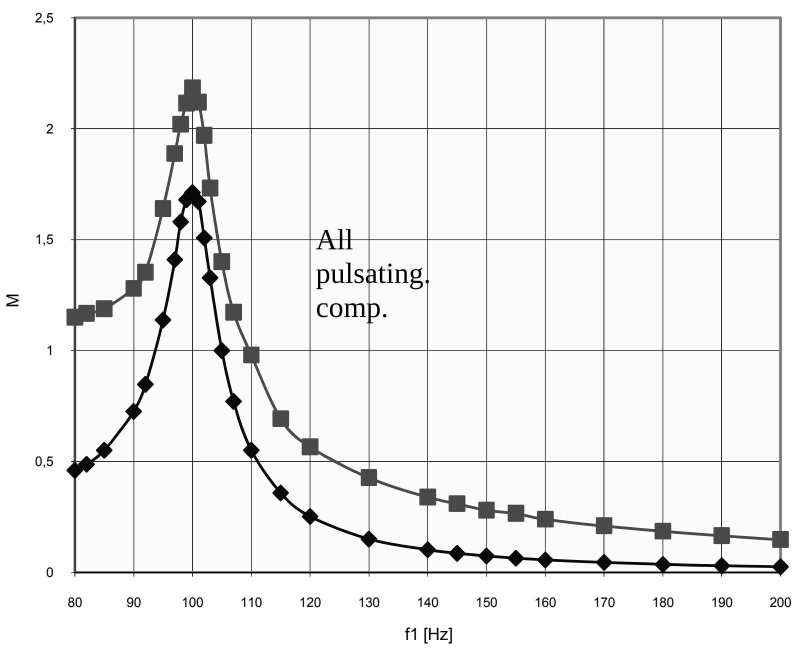

Fig. 8. Torque pulsation frequency course

The ripple frequency is 100 Hz (double of the net frequency) and working frequency of the asynchronous motor will be in range from 80 Hz to 200 Hz. Results is presented in Fig. 8. This shows sharp increase of torque pulsation, which can be hazardous for motor's squirrel cage.

4. CONCLUSION

This contribution is only short digest from comprehensive work devoted to torque pulsations. It is possible to state.

1. It is necessary to take into account the skin-effect for rotor bars. Neglecting of them means markedly lower level of the torque pulsations will be obtained. For investigated motor only about 60% was obtained.
2. The magnitudes of pulsations are practically independent on load, but the greatest pulsations are on no-load conditions, increasing by several percentages only.
3. With help of suitable control in synchronous mode is possible to limit (or full exclude) some components of the pulsations. E.g. 6^{th} component which is usually the most significant.
4. For asynchronous mode modulation, the spectra of torque pulsations don't generate Fourier series. The strongest pulsations arise in neighbourhood of the saw frequency (f_s) or $2f_s$.
5. The significant problem may be ripple voltage in supply system.

Acknowledgement

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PULSACJE MOMENTU OBROTOWEGO MASZYN ASYNCHRONICZNYCH SPOWODOWANE HARMONICZNYMI ZASILANIA

V. BARTOŠ

STRESZCZENIE *Przedstawiono kilka sposobów rozwiązania problemu pulsacji momentu obrotowego asynchronicznych maszyn spowodowanych harmonicznymi zasilania. Problem może być rozwiązany analitycznie przy uproszczeniu modelu – przedstawiono rozwiązanie takiego modelu matematycznego. Podano przykłady obliczeń w różnych stanach i sposobach zasilania. Wykazano, że najmniej korzystne ze względu na pulsacje momentu jest zasilanie napięciem prostokątnym.*