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DOUBLE-CAGE ASYNCHRONOUS MACHINES UNDER TRANSIENTE CONDITIONS

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Abstract: The paper presents analyze double-cage asynchronous machines, i.e. currents, torque and speed under transient conditions. These types of motors have two concentric cage windings in rotor, which can be full separated or connected by their common ring. Their merits are greater starting torque and lesser current. Disadvantage is smaller pull-down torque.
Keywords: Asynchronous motor, double cage, transient phenomena, torque-slip curve.

1 Introduction

These types of motors carry two concentric cages which can be either full separate or connected by their common ring. The outer (starting, marked subscript 2) cage has a high resistance and small reactance,

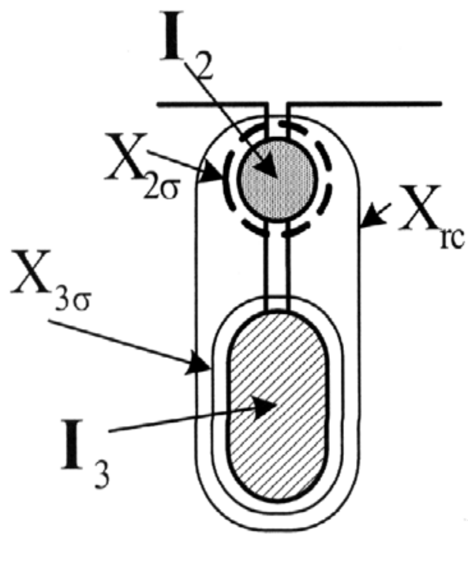

Fig. 1. The dumbbell shape

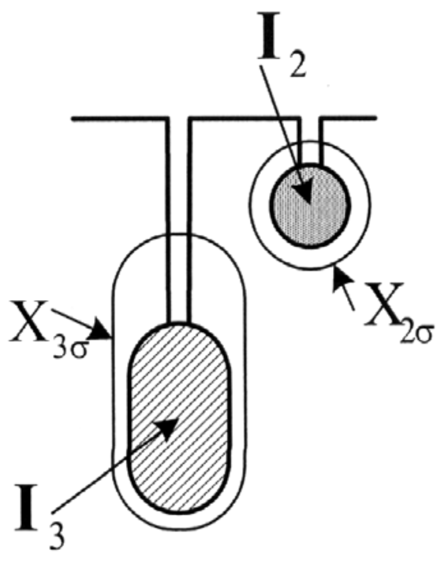

Fig.2. The staggered double cage

while inner one (working, marked subscript 3) has a low resistance and relatively high reactance. The cage bars can be arranged as dumbbell (fig.1), or staggered (fig. 2). Everyone of there two versions has specific qualities.

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The bars of outer and inner cage presented in fig. 1 are connected by mutual flux and outer bars have a very small leakage reactance. In the cage from the fig. 2 the mutual flux may be omitted, but leakage reactance inner cage is higher. The torque-slip curve shape is possible to control by the choice of the suitable cage resistances, the depth of inner cage and by opening or closing slots too. The same is valid for the current curve. The contemporary technology uses the die-cast of the aluminium alloys for cages production. Thanks casting process the upper and inner bars are connected each other by a conducting ply. This circumstance will not be taken into account in theoretical considerations.

Benefits of these types of motors are:

The higher locked-rotor torque

The lower starting current

Failing:

The lower break-down torque, caused by higher leakage reactance of the inner cage.

Somewhat more complicated production.

This contribution is focused on transient phenomena, therefore the system of differential equations will be given in next part. The similar form of equations was presented for motor with simply cage in [2]. Now these equation will be modified for mentioned machine, which represents three-winding system.

2 Double cage machine equations

The basic equations for the double cage machine using space phasors for arbitrary reference frame speed $\boldsymbol{\omega}_{rf}$ have following form. For the stator we have

$$\boldsymbol{u}_1 = R_1 \boldsymbol{i}_1 + \frac{d\boldsymbol{\Psi}_1}{dt} + j\omega_{rf}\boldsymbol{\Psi}_1 \tag{2.1}$$

and for rotor it is

$$\boldsymbol{u}_2 = R_2 \boldsymbol{i}_2 + \frac{d\boldsymbol{\Psi}_2}{dt} + j(\omega_{rf} - \omega)\boldsymbol{\Psi}_2 \tag{2.2}$$

$$\boldsymbol{u}_3 = R_3 \boldsymbol{i}_3 + \frac{d\boldsymbol{\Psi}_3}{dt} + j(\omega_{rf} - \omega)\boldsymbol{\Psi}_3 \tag{2.3}$$

Voltage $\boldsymbol{u}_{1,2,3}$, current $\boldsymbol{i}_{1,2,3}$ and flux linkage $\boldsymbol{\Psi}_{1,2,3}$ are space phasors, defined by relation $\boldsymbol{u} = 2/3\left(u_a + \boldsymbol{a}\,u_b + \boldsymbol{a}^2 u_c\right), \boldsymbol{a} = e^{j2\pi/3}$ etc. The following deductions are valid with the presumption that the zero-sequence components are zero. After several rearrangements we can write subsequent equations in matrix form.

$$[\mathbf{u}_1] = R_1[\mathbf{i}_1] + \frac{d}{dt}[\boldsymbol{\Psi}_1] + \frac{\sqrt{3}}{3}\omega_{rf}[\Delta\boldsymbol{\Psi}_1] \tag{2.4}$$

$$[0] = R_2[i_2] + \frac{d}{dt}[\boldsymbol{\Psi}_2] + \frac{\sqrt{3}}{3}(\omega_{rf} - \omega)[\Delta\boldsymbol{\Psi}_2] \tag{2.5}$$

$$[0]=R_3[i_3]+\frac{d}{dt}[\Psi_3]+\frac{\sqrt{3}}{3}(\omega_{rf}-\omega)[\Delta\Psi_3] \qquad (2.6)$$

and

$$[\Psi]=[L].[i] \qquad (2.7)$$

when it is valid

$$^T[\Psi]=[[\Psi_1][\Psi_2][\Psi_3]] \quad ^T[\Psi_k]=[\Psi_{ka}\ \Psi_{kb}\ \Psi_{kc}] \qquad (2.8)$$

Similar expression is possible to write for current too

$$^T[i]=[[i_1][i_2][i_3]];\ ^T[i_k]=[i_{ka}\ i_{kb}\ i_{kc}] \qquad (2.9)$$

$$[\Delta\Psi_k]=\begin{bmatrix}\Psi_{kc}-\Psi_{kb}\\ \Psi_{ka}-\Psi_{kc}\\ \Psi_{kb}-\Psi_{ka}\end{bmatrix} \qquad (2.10)$$

When the subscript k denotes k = 1 stator, k = 2 upper (starting) cage, k = 3 inner (working) cage and a, b, c represent the machine's phases

The matrix $[\mathbf{u}]$ means the usual three-phase fed system and $[\mathbf{0}]$one represents the short circuit cages. The equation system is completed by the relation of the electromagnetic torque [1]

$$T_i=\left(\frac{p}{\sqrt{3}}\right)[\Psi_{1a}(i_{1b}-i_{1c})+\Psi_{1b}(i_{1c}-i_{1a})+\Psi_{1c}(i_{1a}-i_{1b})] \qquad (2.11)$$

and the motion equation is

$$T_i-T_{ld}=J\frac{d\omega_m}{dt} \qquad (2.12)$$

If the torsion vibrations are included, the equation (2.12) must be replaced by relations given for example in [3].

3 Several results

Only a small part from large group of the possible simulations can be chosen for presentation here, therefore the fundamental switch-on test is given in fig. 3 and 4 switch-on test under no-load speed in fig. 5 The power of the solved motor is 155 kW, 3kV (line-to-line), number of pole-pairs p=2 and rated current 35.8 A.

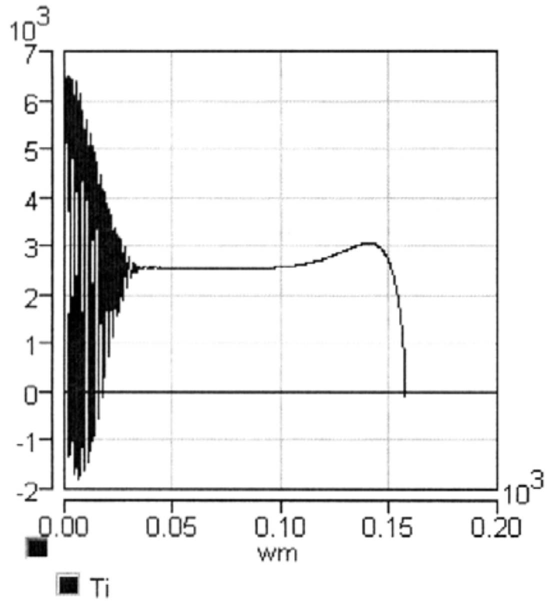

Fig. 3. Torque against speed for switch-on test.

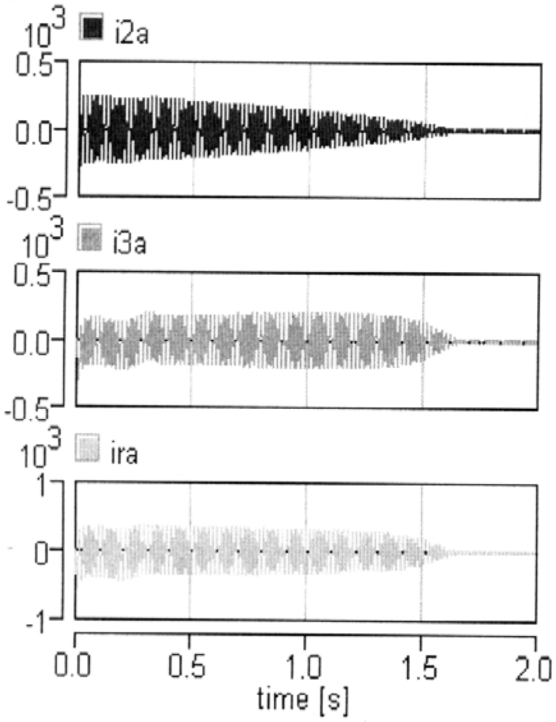

Fig. 4. Currents of rotor under switch-on test

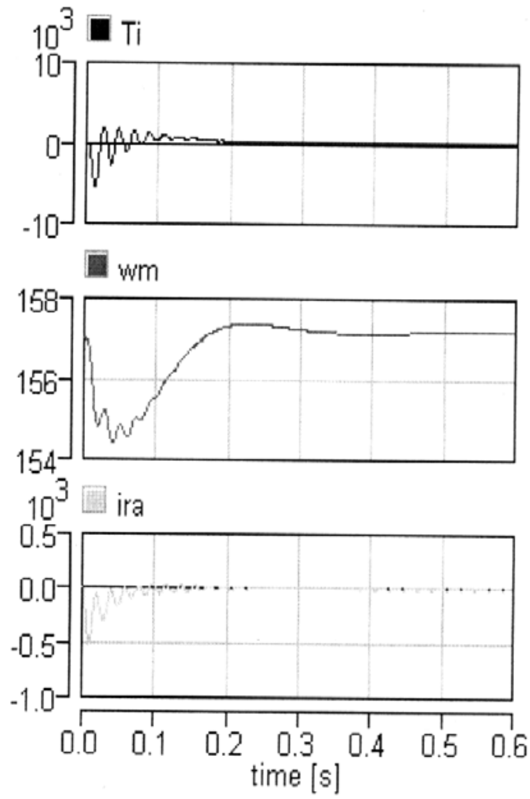

Fig. 5. Quantities for switch-on test from no-load initial speed.

4 Conclusion

The presented equations of the double cage asynchronous machines allow solution various transient phenomena and after small modification of them permit to include unbalanced conditions both in machine parameters and feeding system.

References

[1] Bartoš,V, Kotlanová, A..: *Magnetic saturation in Three-Phase asynchronous Machine Model.* Acta.Techn. CSAV 42, pp. 445-464 (1997)

[2] Bartoš,V.: *Asynchronous Machine in Three-Phase Transformed Reference Frame.* Proc. AMTEE'99, pp B 01-B 04.

[3] Bartoš,V.: *Mathematical Model of the Asynchronous Machine for Nonsymmetrical Modes* . Proc. Int. Conf. MiS 02, , pp 197-201. Krasiczin, Poland, 2002

[4] Bödefeld, Th., Sequens, H.: *Elektrische Maschinen*, Springer-Verlag, Wien, 1971

[5] Kovacs, K, P.:*Transiente Vorgänge in Wechselstrommaschinen* Budapest 1959

[6] Say, M., G.: *Alternating Current Machines*, Longmann Scientific & Technical, New York 1989

[7] Mann, H.: *Dynast, User's Manual* Prague 1998.

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