Laboratory "Modeling and Simulation of Dynamic Systems"
Institute of the Theory of Electrical Engineering, Measurement and Information Systems, WUT

Exercise No 4
Dynamic models of induction motor
Author: S. Osowski

1 The aim of experiments

Learning the performance of the induction machine in transient state in different modes of work. We apply two dynamic models of the induction machine: one based on the coordinate system associated with the synchronous speed of the machine (file **sil_indk.mdl**) and the other based on the coordinate system associated with the immobile stator $\omega_k = 314$ (file **sil_inds.mdl**).

2 The state space model of the machine

The state equations of the machine may be expressed in the following forms:

- at the coordinate system associated with the synchronous speed at $\omega_k = 314$

$$\frac{dx_1}{dt} = -\alpha x_1 + \alpha K_r x_3 + \omega_k x_2 + U_{zas} \tag{1}$$
$$\frac{dx_2}{dt} = -\alpha x_2 + \alpha K_r x_4 - \omega_k x_1 \tag{2}$$
$$\frac{dx_3}{dt} = \beta K_s x_1 - \beta x_3 - (\omega_k - x_5)x_4 \tag{3}$$
$$\frac{dx_4}{dt} = \beta K_s x_2 - \beta x_4 - (\omega_k - x_5)x_3 \tag{4}$$
$$\frac{dx_5}{dt} = \frac{3p^2 K_r}{2\sigma L_s J}(x_2 x_3 - x_1 x_4) - \frac{p}{J} M_z \tag{5}$$

- at the coordinate system associated with the stator

$$\frac{dx_1}{dt} = -\alpha x_1 + \alpha K_r x_3 + U cos 314t \tag{6}$$
$$\frac{dx_2}{dt} = -\alpha x_2 + \alpha K_r x_4 + U sin 314t \tag{7}$$
$$\frac{dx_3}{dt} = \beta K_s x_1 - \beta x_3 - x_5 x_4 \tag{8}$$
$$\frac{dx_4}{dt} = \beta K_s x_2 - \beta x_4 + x_5 x_3 \tag{9}$$
$$\frac{dx_5}{dt} = \frac{3p^2 K_r}{2\sigma L_s J}(x_2 x_3 - x_1 x_4) - \frac{p}{J} M_z \tag{10}$$

where $\sigma = 1 - \frac{L_m^2}{L_s L_r}, K_s = \frac{L_m}{L_s}, K_r = \frac{L_m}{L_r}, \alpha = \frac{R_s}{\sigma L_s}, \beta = \frac{R_r}{\sigma L_r}$. The state variables x_i represent the following physical quantities $x_1 = \psi_{s\alpha}, x_2 = \psi_{s\beta}, x_3 = \psi_{rs\alpha}, x_4 = \psi_{rs\beta}, x_5 = \omega$. The electromagnetic torque generated by the motor is described by the following relation

$$M_m = \frac{3p^2 K_r}{2\sigma L_s J}(x_2 x_3 - x_1 x_4) \tag{11}$$

The mechanical speed Ω and electrical speed ω are related to each other in the form $\Omega = \omega/p$. The relation between the nominal power P_n, the nominal torque M_n and the nominal speed Ω_n is of the form:

$$M_n = \frac{P_n}{\Omega_n}$$

At the power in [W] we get the torque in [Nm].

The Simulink models of the motor corresponding to both state space descriptions are presented in Fig. 1 and 2. The parametr R_r is included for the purpose of simulation of the additional impedance included in series with the rotor resistance. Its value means the multiplication coefficient of the actual rotor resistance. For example $R_r = 1$ means nominal state of the rotor (no additional resistance), $R_r = 2$ means that the total (actual) rotor resistance assumes double value of its nominal value (inclusion of additional resistance equal the nominal value of the rotor resistance).

3 Program of numerical experiments

1. Simulate the start of the motor at different load M_z (for example $M_z = 0.5M_{max}, M_z = M_{max}, M_z > M_{max}$). Observe the change of speed and torque. Use the model **sil_indk.mdl**.

2. Simulate the change of the load at the steady state mode of the motor. Try the values of M_z changing from zero to the value exceeding the maximum torque. Compare the changes of the steady state speed at different loads.

3. Simulate the transient of the speed and torque of the motor at changing the supply voltage to zero at different load of the motor.

4. Simulate start of the motor at nominal load by inclusion additional rotor resistance. Start from $R_r = 4$, and successively reduce the value of additional resistance to zero (first $R_r = 3$ then $R_r = 2$ and finally $R_r = 1$ - additional resistance equal zero).

5. Simulate start of the machine at different load (for example $M_z = 0.5M_{max}, M_z = M_{max}, M_z > M_{max}$) using the second model **sil_inds.mdl**.

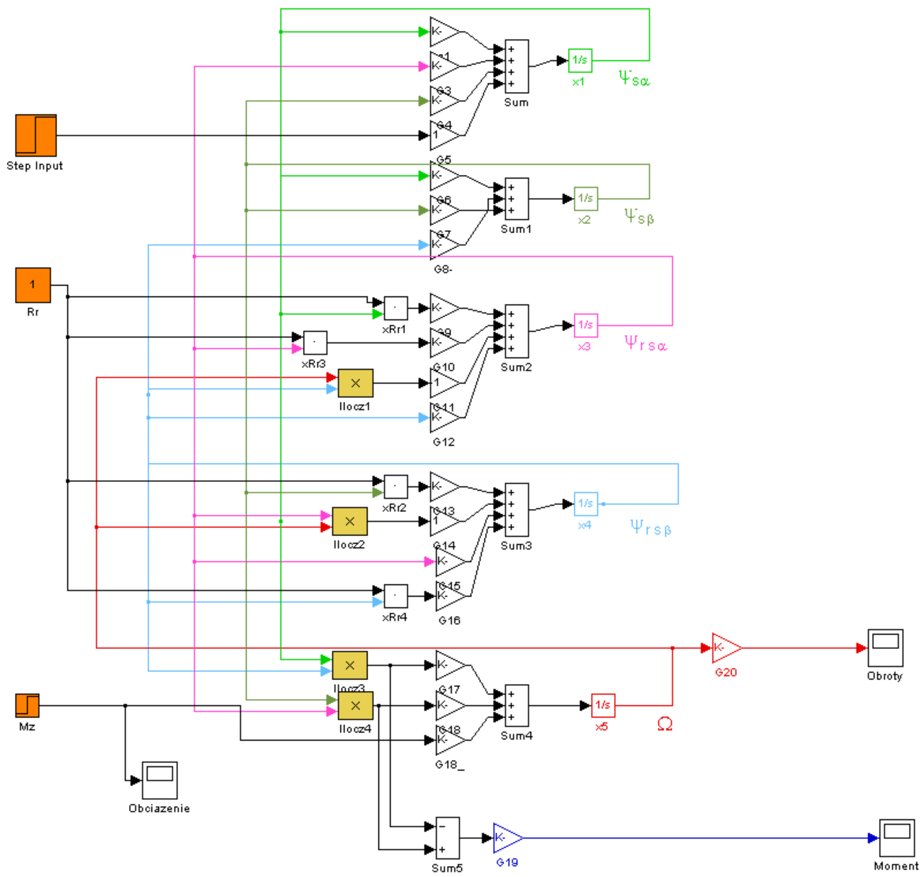

Figure 1: *Model of the induction motor associated with the with the synchronous speed at* $\omega_k = 314$

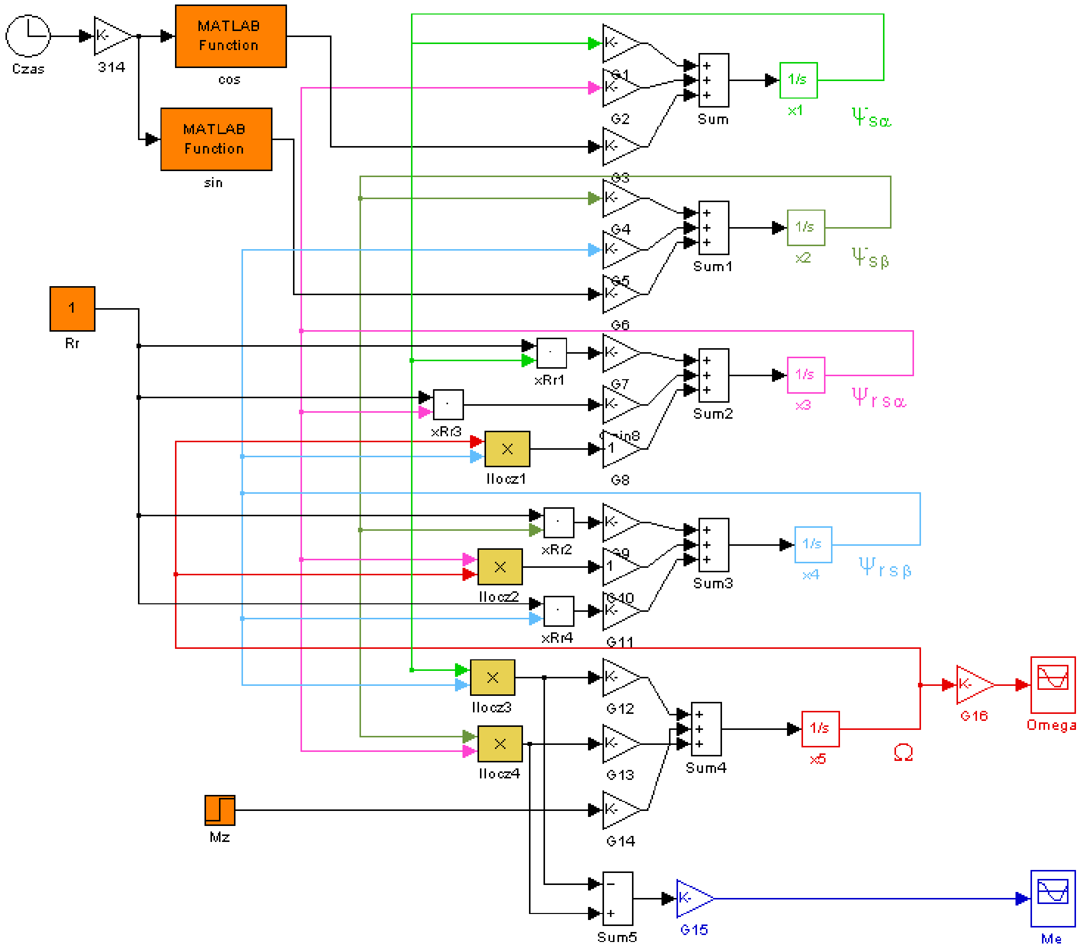

Figure 2: *Model of the induction motor connected with the coordinate system associated with the stator*