# SIMULATION OF AN ACTUATOR & DRIVE OF A WIRE DRAWING MACHINE'S MECHATRONIC SYSTEM USING MATLAB/SIMULINK

**Goce Tasevski, Zlatko Petreski, Dejan Šiškovski**

*Institute for Mechanics, Faculty of Mechanical Engineering, "Ss. Cyril and Methodius" University in Skopje, P.O. box 464, 1000 Skopje, Republic of Macedonia*
goce.tasevski@mf.edu.mk

A b s t r a c t: Simulation of a mechatronic system actuator, implemented in a wire drawing machine, developed in Matlab/Simulink environment is presented in this paper. AC induction motor with vector control drive is chosen as an actuator. Mathematical model of the actuator is expressed in *d-q* reference frame rotating at synchronous speed. Diagrams for calculation of the important parameters for the simulation of the actuator were constructed. Simulation results from the model behaviour were discussed in comparison with the specified parameters by the manufacturer of the existing actuator integrated in such mechatronic system.

Key words: actuator; induction motor; simulation; Matlab/Simulink; mechatronic system

## СИМУЛАЦИЈА НА АКТУАТОР ОД МЕХАТРОНИЧКИ СИСТЕМ НА МАШИНА ЗА ИЗВЛЕКУВАЊЕ НА ЖИЦА СО УПОТРЕБА НА MATLAB/SIMULINK

А п с т р а к т: Направена е симулација и анализа на динамичкото однесување на еден актуатор од мехатроничкиот систем на машина за извлекување на жица со употреба на Matlab/Simulink. Како актуатор е избран АС индукционен мотор со векторско управување. Математичкиот модел на актуаторот е претставен во референтен систем *d-q* кој ротира со синхрона брзина. Направени се дијаграми за пресметка на важните параметри за симулација на актуаторот. На крајот се дискутирани резултатите од симулацијата во споредба со дадените параметри од производителот за постојниот актуатор вграден во таков мехатронички систем.

Клучни зборови: актуатор; индуктивен мотор; симулација; Matlab/Simulink; мехатронички систем

## 1. INTRODUCTION

Improving performance of wire drawing machines, in terms of high drawing speed, has been usually achieved by the advances in the area of the die materials [1]. With the development of the mechatronic systems and functionalities nowadays, wire drawing machines could also increase the performances by introducing modern sensors and control units in the system itself. With better monitoring of the motor parameters new advanced control algorithms could be developed in order to better control the system behaviour and increase drawing speeds.

Mechatronic system of a modern wire drawing machine is presented in Figs.1 and 2. Dancer arms or tuner rolls are used as sensors to indicate the current tension in the wire. These signals values are compared with reference position values pre-set in the PLC controller. If any error occurs, PID controller together with variable frequency controllers gives command signals to the actuators, which are responsible for transforming the output of the control system into a controlling action on the mechanical system [2], [3], in order to maintain the wire tension.

One of the most important parts in the wire drawing machines are the motors that drive the blocks with different speeds to reduce the wire diameter. To increase performance of the machine, it is extremely important to develop a model of the entire system including the motors themselves, so

that the engineers have clear picture of the parameter influence during the wire production. Choosing the right motor type for this technology remained an engineering challenge even today.
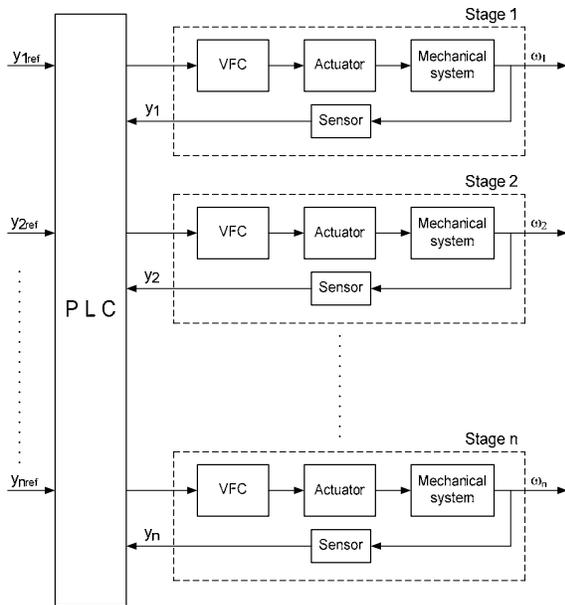


**Fig. 1.** Mechatronic system of a wire drawing machine

Green and Kramer [4] have compared the differences between AC and DC actuators applied to the wire drawing machines in terms of line speed, dancer control, efficiency and power consumption, and maintenance. They have pointed out that modern AC drives with advanced vector control algorithms are able to offer performances which are as good as equivalent DC drive. Therefore, AC actuators and drives are making serious inroads into applications where previously only DC actuators would have been considered.

Matlab/Simulink is established engineering tool when it comes to modelling of dynamic systems. Here, as well, this platform has been used to simulate a vector controlled AC induction motor, as an actuator from wire drawing machine. Input motor parameters that will be used in simulation, such as nominal power, nominal speed, nominal voltage and nominal frequency, given by the manufacturer, are shown in Table 1.

In this paper, in section 2, the actuator mathematical model is developed in detail. The Matlab/Simulink implementation is given in section 3, and in section 4 the simulation results are presented. At the end some conclusions and final remarks are given.

T a b l e  1

*Parameters from AC induction motor's nameplate*

| Induction motor parameters | Value |
| --- | --- |
| Nominal power | 30 kW |
| Nominal voltage | 380 V |
| Nominal frequency | 50 Hz |
| Nominal current | 56.6 A |
| Nominal speed | 1468 rpm |
| Electromagnetic torgue | 190.9 N m |

## 2. ACTUATOR MODEL

AC induction motors could be mathematically modelled in many different ways. The model used in this paper utilizes the concept of vector control, which is the most popular control technique of AC induction motors. The concept of vector control is based on the methodology of control of separately excited DC motors, where field flux produced by the field current is perpendicular to the armature flux produced by the armature current. Vector control seeks to recreate these orthogonal components in the AC machine in order to control the torque producing current separately from the magnetic flux producing current [5]. This control is usually performed in the reference frame (*d-q*) attached to the rotor flux space vector. Analysis and design of the induction motor is traditionally done through the per-phase equivalent circuit [6], [7], shown in Figures 2 and 3.
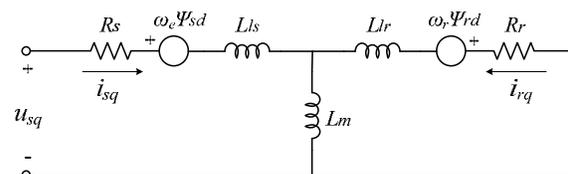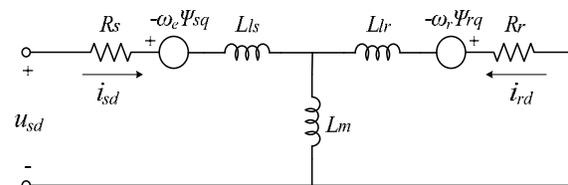


**Fig. 2.** *q*-axis circuit



**Fig. 3.** *d*-axis circuit

In Figures 2 and 3, *Rs* and *Rr* represent the stator and rotor winding resistances, *Lm* is the

magnetizing inductance of the motor and *Lls* and *Llr* are the stator and rotor leakage inductances.

Considering the direct and quadrature axis (*d-q*) reference frame rotating at synchronous speed $\omega_e$, the model of the induction machine, as stated in [8] and [9], is given by the following equations:

Stator voltage equations:

$$u_{sd} = R_s i_{sd} + \frac{d}{dt}\Psi_{sd} - \omega_e \Psi_{sq}$$
$$u_{sq} = R_s i_{sq} + \frac{d}{dt}\Psi_{sq} + \omega_e \Psi_{sd} \tag{1}$$

Rotor voltage equations:

$$u_{rd} = 0 = R_r i_{rd} + \frac{d}{dt}\Psi_{rd} - \left(\omega_e - \omega_r\right)\Psi_{rq}$$
$$u_{rq} = 0 = R_r i_{rq} + \frac{d}{dt}\Psi_{rq} + \left(\omega_e - \omega_r\right)\Psi_{rd} \tag{2}$$

Stator and rotor flux linkage equations:

$$\Psi_{sd} = L_s i_{sd} + L_m i_{rd}$$
$$\Psi_{sq} = L_s i_{sq} + L_m i_{rq}$$
$$\Psi_{rd} = L_r i_{rd} + L_m i_{sd}$$
$$\Psi_{rq} = L_r i_{rq} + L_m i_{sq} \tag{3}$$

Electromagnetic torque:

$$T_e = 1.5 p \frac{L_m}{L_r}\left(\Psi_{rd} i_{sq} - \Psi_{rq} i_{sd}\right) \tag{4}$$

### 3. MATLAB/SIMULINK IMPLEMENTATION

A standalone 3-phase induction motor with vector control drive is simulated in this part of the paper. The motor model is needed for more accurate modelling of the complex wire drawing machine's mechatronic system. Establishing accurate

model of the mechatronic system is essential in increasing performances of the machine. As the motor being one of the main components of the mechatronic system, modelling the motor that would be implemented in the machine is challenge by itself.

The motor modelled for the purpose of this paper has the following characteristics stated by the manufacturer: nominal power of the actuator is 30 kW, AC source phase-to-phase rms voltage value is 380 V, and the frequency is 50 Hz. The idea of the model and simulation is to confirm the motor parameters (nominal current, nominal speed and electromagnetic torque) given by the manufacturer, shown in Table 1. Matlab/Simulink model of the actuator, based on the mathematical model developed in section 2 is presented in Figure 4.

To develop the model in MATLAB/Simulink, electrical and mechanical parameters of the motor are required. Based on the data given by the manufacturer, it was concluded that those information are not sufficient to estimate the basic parameters of the motor needed to be imported in the MATLAB/Simulink model. Since it has been used a motor that has power 30 kW, with no detailed information, it was decided to find this values based on the following methodology.

MATLAB/Simulink library contains a limited set of induction motor models with prescribed nominal power. Using the data of the existing models, diagrams for rotor and stator resistance, leakage stator and rotor inductance, mutual inductance, inertia and friction coefficient, in relation to the motor power were constructed and are given below in Figures 5 to 10. Trend lines were used in order to obtain mathematical expressions that are used to calculate the values of the necessary parameters.
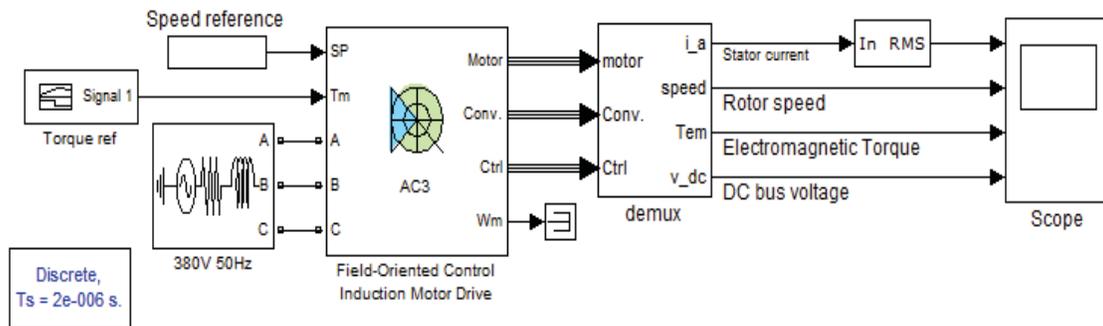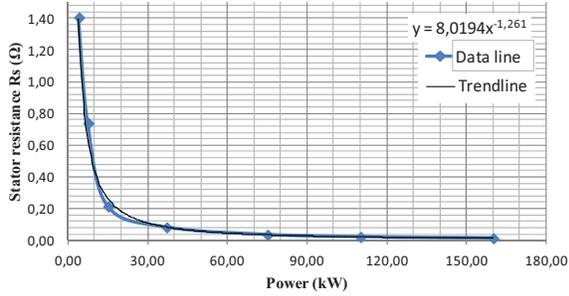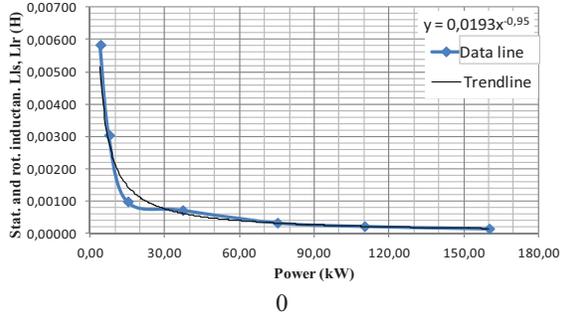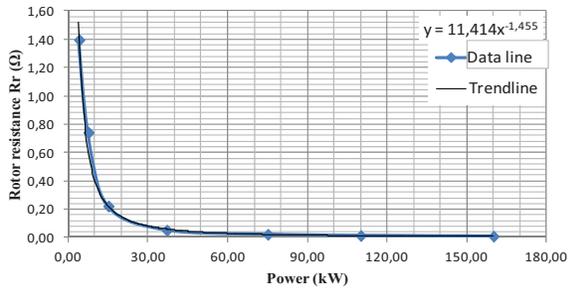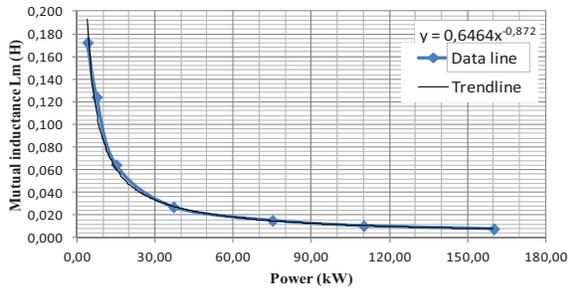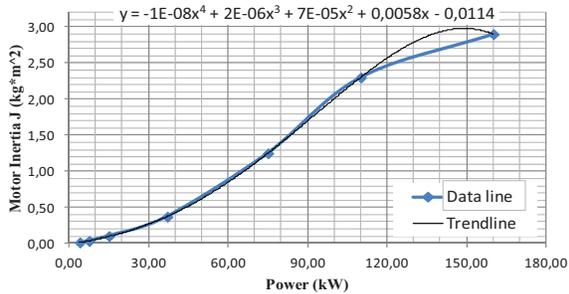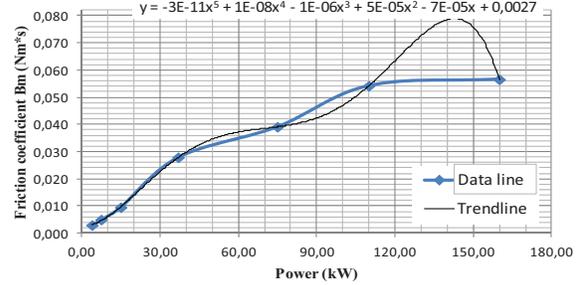


**Fig. 4.** Matlab/Simulink model of AC induction motor

**Fig. 5.** Determination of stator resistance *Rs*



**Fig. 6.** Determination of stator and rotor inductances *Lls, Llr*



**Fig. 7.** Determination of rotor resistance *Rr*



**Fig. 8.** Determination of mutual inductance *Lm*



**Fig. 9.** Determination of motor inertia *J*



**Fig. 10.** Determination of friction coefficient *Bm*

Based on the diagrams for determination of the motor parameters, the parameters for the 30 kW motor were extracted and are given in Table 2.

T a b l e  2

*Electrical and mechanical parameters
of the simulated actuator model*

| Motor parameters | Value |
|---|---|
| Stator resistance | 0.11 Ω |
| Rotor resistance | 0.0809 Ω |
| Leakage stator inductance | 0.000762 H |
| Leakage rotor inductance | 0.000762 H |
| Mutual inductance | 0.0333 H |
| Inertia | 0.02715 kg·m$^2$ |
| Friction | 0.025971 Nm·s |

In the model, load torque was selected as a mechanical input in order to get the actuator speed as output, based on the following differential equation, which describes the mechanical system dynamics [10],

$$T_e = J\frac{d}{dt}\omega_r + B\omega_r + T_m \qquad (5)$$

where $J$ – motor inertia; $\omega_r$ – rotor speed; $T_e$ – electromagnetic torque; $T_m$ – load torque; $B\cdot\omega_r$ – friction torque.

General scheme of the induction motor's drive is shown in Figure 11.

Reference speed of the actuator is set point in the Matlab/Simulink model. The rest of the settings used in the model are given in Table 3.
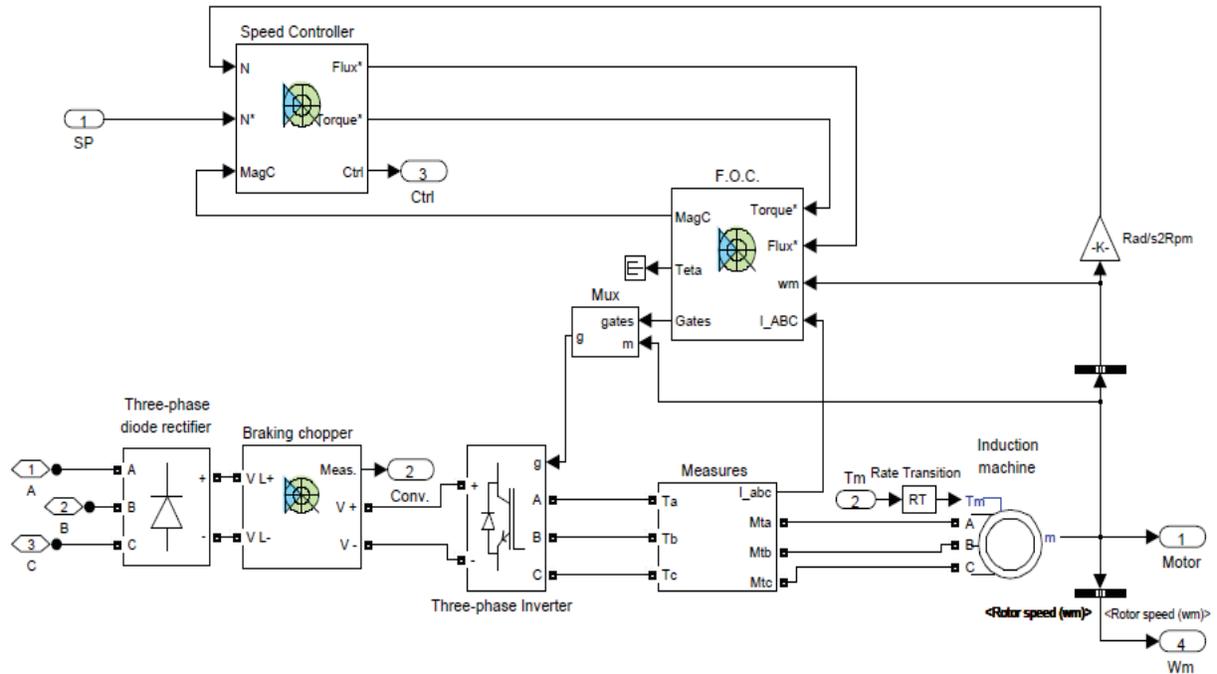
**Fig. 11.** Scheme of induction motor's drive

The dynamic response of the rotor speed and electromagnetic torque can be adjusted by the proportional and integral gains from the PI controllers in the speed and flux controllers. Speed controller and field oriented controller schemes are shown in Fig. 12 and Fig. 13, while Fig. 14 shows flux controller scheme. Tuning the parameters from speed and flux PI controllers is done by using trial and error method, and best fit parameters are inserted in Table 3, as well.

T a b l e 3

*Parameters for speed and flux controller*

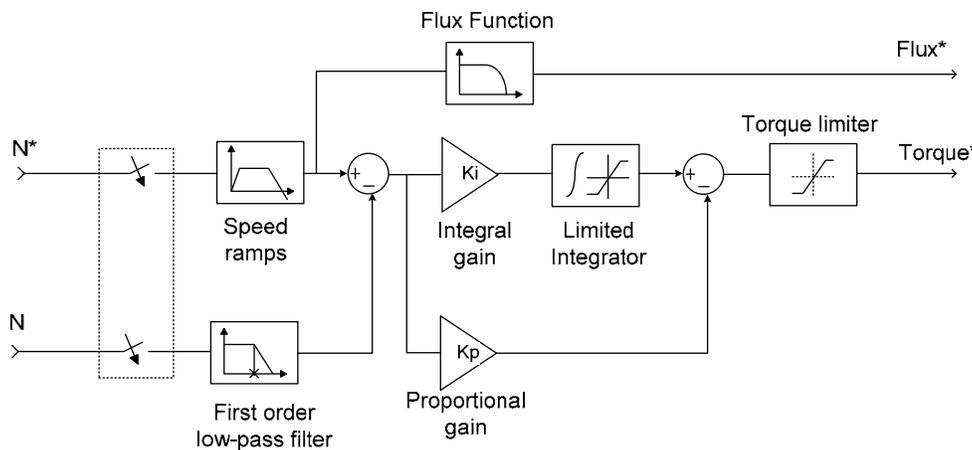| Speed controller parameters | Value |
| --- | --- |
| Acceleration ramp | 500 rpm/s |
| Deceleration ramp | 500 rpm/s |
| Proportional gain | 10 |
| Integral gain | 2000 |
| Flux controller prameters | Value |
| Proportional gain | 50 |
| Integral gain | 200 |



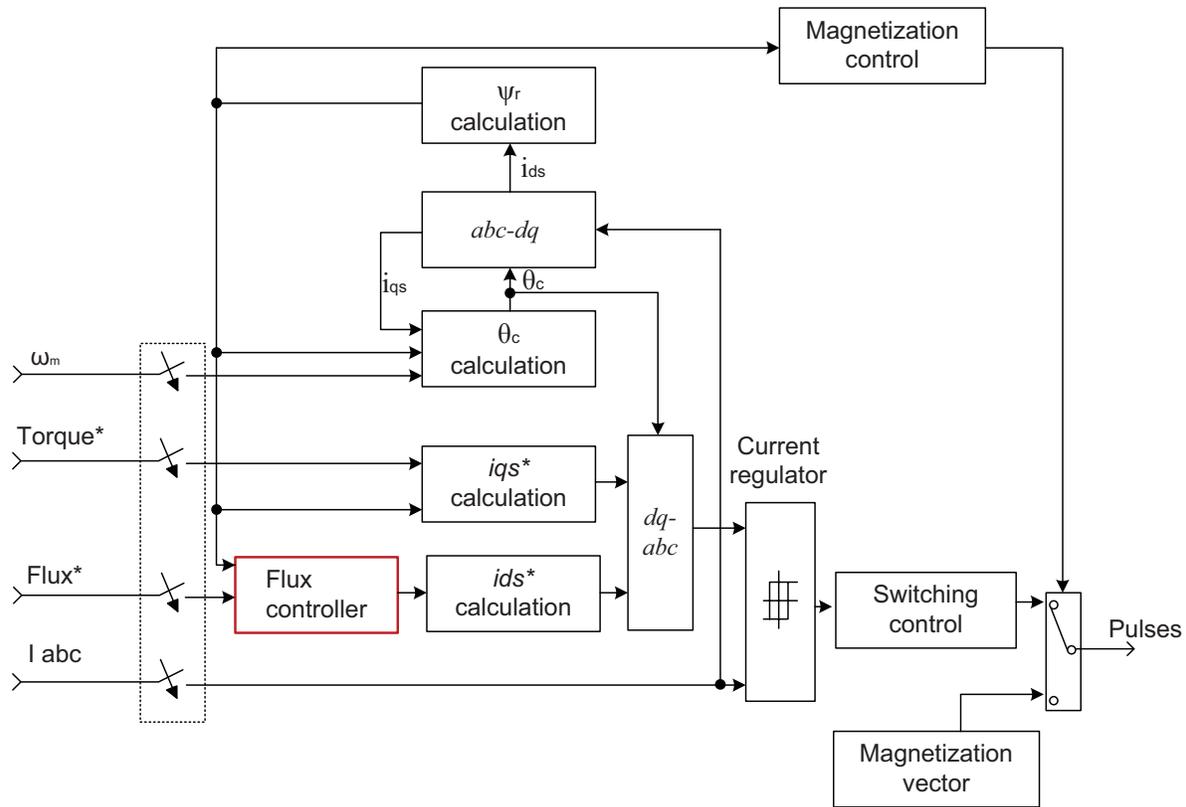**Fig. 12.** Scheme of speed controller

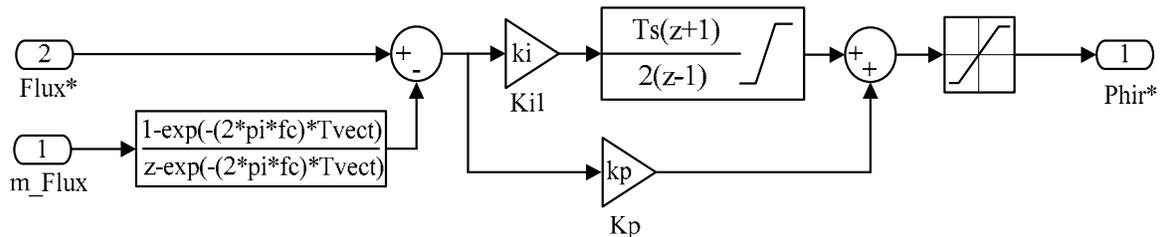**Fig. 13.** Scheme of field oriented controller



**Fig. 14.** Scheme of flux controller

## 4. SIMULATION RESULTS

The simulation of the motor behaviour was done in the Simulink environment and the results are given in Fig. 15.

At time $t = 0$ s, the speed set point value is 1468 rpm. Applied load torque should reach 190 Nm at $t = 3$ s, after that period, maintained a constant value.

The actuator reaches its maximum speed in little less than 3 s, according to the acceleration ramp which is set to 500. Static error of the speed is reduced in range from 0.05 to 0.1 rpm due to the large integral gain of the speed controller so the reference and actual rotor speed of the actuator is identical (second diagram from Figure 15).

Stator current oscillates while the load torque reaches its set point value at $t = 3$ s. Then, it maintains a value of 60 A. Differences between load torque and electromagnetic torque can be reduced by adjusting the flux controller parameters.
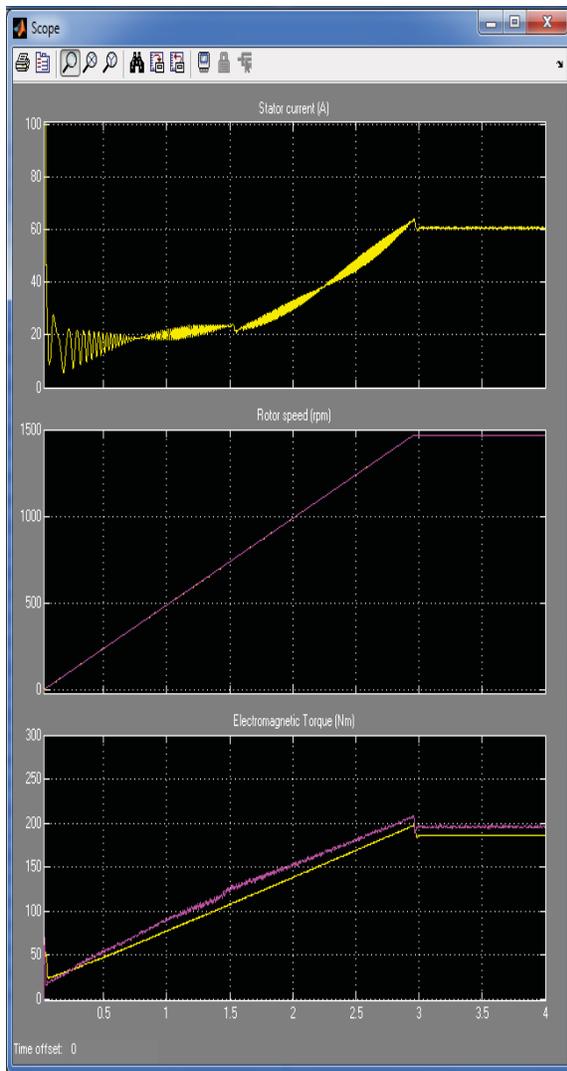
**Fig. 15.** Results from the simulation

## 5. CONCLUSIONS

In this paper an actuator and drive from a wire drawing machine's mechatronic system were simulated using Matlab/Simulink. Matlab/Simulink environment was tested and proven to be powerful tool in the process of modelling and analyzing dynamic behavior of induction motor.

The necessary parameters for the simulation were obtained by constructed diagrams based on existing previously defined motor models in Matlab/Simulink library.

The simulation results were compared with the manufacturer data given in the specification of the motor. For the proposed input values: nominal power, nominal voltage, nominal frequency and nominal speed, the output values for the nominal current, the electromagnetic torque and the rotor speed are in sufficient accuracy range with the value prescribed from the manufacturer.

Modelling the motor behavior, as accurate as possible, is important task that allows developing complex models of mechatronic systems. By confirming the motor parameters, as shown in this paper, a solid model of the motor behavior has been constructed and could be upgraded with the other functional blocks.

## REFERENCES

[1] N. Wright: *Wire Technology: Process Engineering and Metallurgy*, Elsevier Inc, 2011.

[2] W. Bolton: *Mechatronics: A Multidisciplinary Approach*, Pearson Education Limited, 2008.

[3] R. H. Bishop: *Mechatronics: An Introduction*, CRC Press, Talyor & Francis Group, 2006.

[4] R. Green, J. Kramer: Applying AC drives to multibench wiredrawing, *Proceedings of the Annual Convention of the Wire Association International*, pp. 92–96, 1995.

[5] NEC Corporation: *An Introduction to Vector Control of AC Motors Usng the V850* (2002), http://www.scribd.com /doc/53620037/U16483EE1V0AN00.

[6] D. Y. Ohm: Dynamic model of induction motors for vector control (2000), http://www.drivetechinc.com

[7] S. Shah, A. Rashid, M. K. L. Bhatti: Direct Quadrate (D-Q) Modelling of 3-Phase Induction Motor Using Matlab/Simulink, *Canadian Journal on Electrical Engineering*, **3** (5), 237–243 (2012).

[8] L. Wang, B. Su: Modeling and Simulation of Vector Control System of Variable Frequency Speed Regulation in Electric Actuator, *Proceedings of the Second International Conference on Computer Modelling and Simulation*, pp. 308–311, 2010.

[9] J. Lepka: *3-Phase AC Induction Motor Vector Control Using 56F805, Freescale Semiconductor*, Inc. Motorola, 2003.

[10] *User's guide: Simulink for use with Matlab, Math Works* (1999).