STUDY OF AUTOMATED PRESSURE TURBO SYSTEM IN DINAMIC MODE

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ABSTRACT: *The paper inhere describes an automated turbo hydraulic centrifugal pump system, comprising an electrical part (frequency convertor and asynchronous motor) and hydraulic part (centrifugal pump, upper and lower tanks, pressure water pipe system, exhaust valves and an automated level control with a negative feedback for level). A mathematical model has been built for the electrical and the hydraulic part of the system and this model has been used as a base for compiling an analog model in the Mathlab Simulink program environment. Results are presented for thy operation of the system in different dynamic modes.*

KEY WORDS: automated system, frequency convertor, asynchronous motor, centrifugal pump, pressure water-pipe system, dynamic mode.

INTRODUCTION

The operating conditions of automated centrifugal pump systems in transient mode are too unfavorable. This is mainly due to hydraulic shocks in the pipeline.

Pumps are chosen to cover the maximum flow rate of the consumer. With variable flow, the pump's energy parameters deteriorate significantly, resulting in significant energy losses. In some cases, the process that is served by the pumps requires a wide range of flow rates[7, 8, 9].

The aim of the regulation is to provide maximum efficiency of the pump system at variable hydraulic parameters of the consumer. The characteristics of the turbine pumps are directly related to the speed of rotation. The most energy-efficient method for regulating turbo pumps is the frequency control method [2].

Frequency and voltage are being changed when frequency convertors are used to supply asynchronous and synchronous motors.

The use of frequency convertors allows a smooth start, stop and regulation of pump’s speed while maintaining maximum efficiency [2].

In [1], the development of the dynamic processes in an automated system including a centrifugal pump, pressure pipeline, a two-way water turbine and a synchronous generator were studied.

The main direction in the development of electric drives is the implementation of energy-efficient solutions that can reliably fulfill the assigned technological regimes. Squirrel cage induction motors have a simple construction and small mass-size dimensions per unit of installed capacity [3, 4].

Frequency control methods provide a wide range of speed regulation options and also maintaining of high energy performance.

A frequency-control based on an inverter type frequency convertor is used to drive asynchronous motor, coupled with an automated hydraulic turbo system.

SETUP OF THE AUTOMATED PRESSURE TURBO SYSTEM

The setup of the automated pressure turbo system, that has been studied, is presented in fig. 1.

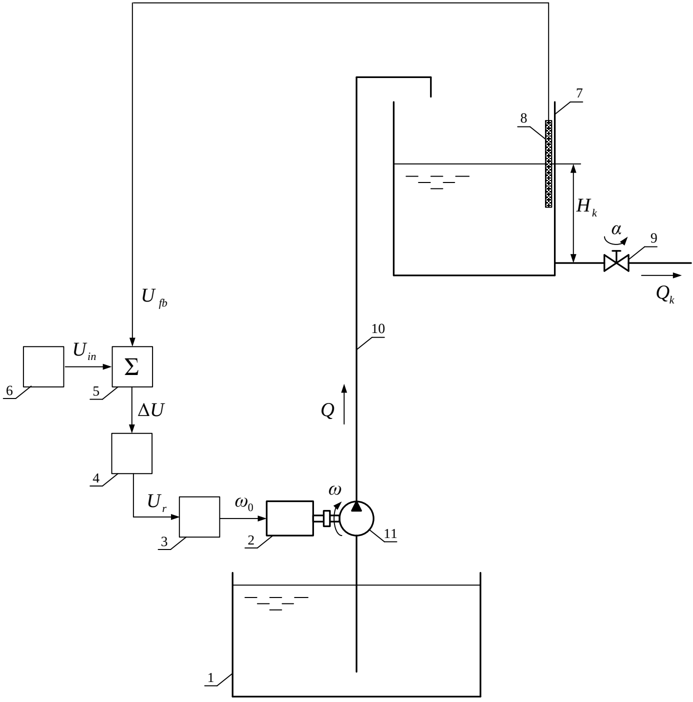


Figure.1. Setup of an automated pressure turbo system, where: 1 – lower tank; 2 – asynchronous motor; 3 – frequency convertor; 4 – automatic regulator (controller); 5 – summing device; 6 – setting device; 7 – upper tank; 8 – level sensor; 9 – outlet valve; 10 – pressure pipeline; 11 – turbo pump.

Designations used in Fig. 1 are as follow:

U_{in} - setting voltage;

U_{fb} - feedback voltage;

ΔU - summing device voltage;

U_r - electronic regulator’s output voltage;

ω_0 - frequency convertor’s output angular speed;

ω - angular rotation speed of the centrifugal pump shaft;

Q - output volume flow of the centrifugal pump;

H_k - water head in the upper tank;

Q_k - volume flow through the outlet valve 9;

α - outlet valve 9 angle of rotation.

MATHEMATICAL MODEL OF THE ELECTRICAL PART

As widely used in practice, an asynchronous electric motor’s inverter control system consists of a three-way bridge transistor circuit, which forms the phase voltages, based on the principle of the sinusoidal pulse width modulation (Fig. 2) [2], [5-6].

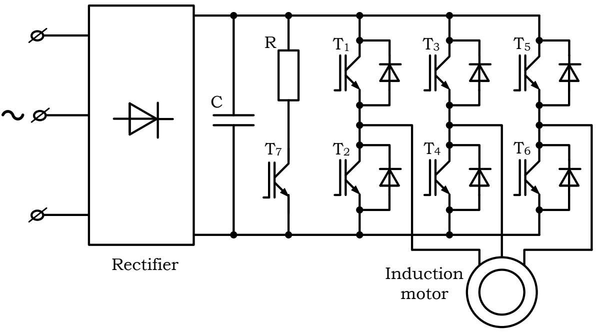


Figure 2. Typical frequency inverter control system for asynchronous motors

In the generalized structural diagram of the studied automated hydraulic system[10], the frequency convertor is presented with an aperiodic unit with the smallest time constant, compared to the other dynamic units in the system. In the operation section of the mechanical characteristic, induction motor’s electromagnetic part can also be represented with sufficient precision as an aperiodic unit. The mechanical part of the system is represented with an integrator [1]. All modeled parameters are calculated in first approximation.

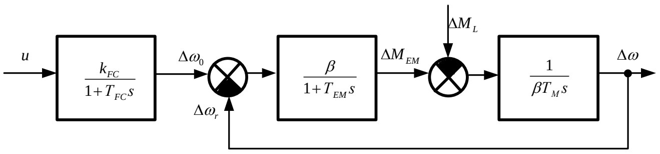


Figure.3. Generalized structural diagram of the studied automated hydraulic system

Magnitudes, participating in the structural diagram in Fig. 3 are as follow:

u - voltage adjusting the voltage and frequency, according to the law of frequency control;

k_{FC} - frequency convertor proportional coefficient;

T_{FC} - frequency convertor time constant;

$\Delta\omega_0$ - rotating electromagnetic field angular speed;
$\Delta\omega_r$ - rotor’s angular speed;
β - mechanical characteristic’s hardness module;
T_{EM} - electromagnetic time constant;
ΔM_{EM} - equivalent electromagnetic torque;
ΔM_L - load torque;
T_M - mechanical time constant;
s - Laplace’s operator

The frequency convertor proportional coefficient is determined by its regulation characteristic and its time constant - from the semiconductor valves’ speed, which depends on the particular chosen solution. The mechanical characteristic’s hardness module in regard with the asynchronous electric motor is determined by:

$$\beta = \frac{d\Delta M_{EM}}{d\Delta\omega_r} \tag{1}$$

In case linearity is assumed in the mechanical characteristic, β can be determined by:

$$\beta = \frac{M_N}{\Delta\omega_0 - \Delta\omega_{rN}} \tag{2}$$

ω_{rN} - nominal angular speed of the asynchronous electric motor;
M_N - induction motor’s nominal torque.

Electromagnetic time constant is calculated using the parameters of induction motor’s equivalent circuit:

$$T_{EM} = \frac{x_{1N} + x'_{2N}}{\omega_{0N} R'_2} \tag{3}$$

x_{1N} - equivalent stator loop reactance;
x'_{2N} - equivalent rotor loop reactance;
ω_{0N} - rotating magnetic field nominal angular speed in case of rated frequency of the power supply;
R'_2 - equivalent rotor loop active resistance.

MATHEMATICAL MODEL OF THE HYDRAULIC PART

For the mathematical model describing the dynamics of the system, in first approximation is obtained:

1. Equation of the turbo pump:

$$\Delta H = k_\omega \Delta\omega - k_Q \Delta Q \tag{4}$$

ΔH - head at the outlet of the pump;
k_ω , k_Q - coefficients.

2. Equation for the flow through the pressure water pipeline:

$$\frac{L}{A_T g}\frac{d\Delta Q}{dt} + k_f \Delta Q = \Delta H \tag{5}$$

L, A_T - length and area of the pressure pipeline;
k_f - coefficient, reflecting the hydraulic losses;
g - gravity of earth.

3. Equation for the alteration of the head in the upper tank:

$$A\frac{d\Delta H_k}{dt} = \Delta Q - \Delta Q_k \tag{6}$$

A - cross-section area of the upper tank.

4. Equation for the passed through the outlet valve 9 flow:

$$\Delta Q_k = k_\alpha \Delta\alpha + k_k \Delta H_k \tag{7}$$

k_α , k_κ - coefficients.

5. Equation for load torque of the pump:

$$\Delta M_L = k_1 \Delta Q + k_2 \Delta H - k_3 \Delta\omega \tag{8}$$

k_1 , k_2, k_3 - coefficients.

6. Equation of the electronic PI regulator:

$$\Delta U_r = k_r \left(\Delta U + \frac{1}{T_I}\int \Delta U\, dt \right) \tag{9}$$

T_I, k_r - time constant and gain factor of the electronic regulator.

7. Equation of the summing unit:

$$\Delta U = \Delta U_{in} - \Delta U_{fb} \tag{10}$$

$\Delta U_{fb} = k_{fb}\, \Delta H_k$;

k_{fb} - feedback coefficient;

NUMERICAL EXPERIMENT

On the basis of the developed mathematical model, an analogue model of the system is compiled in the program environment of Mathlab Simulink (Fig. 2).

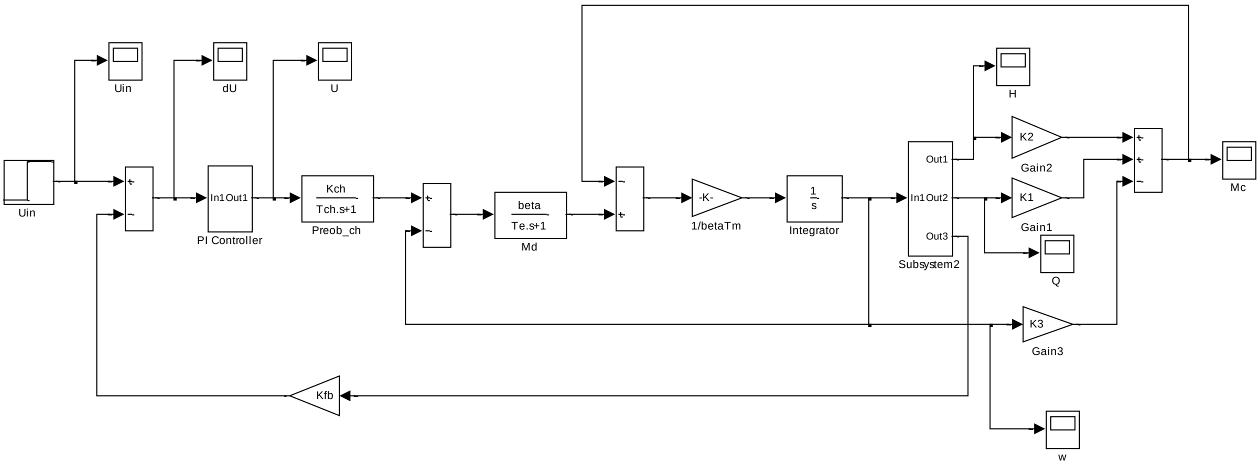
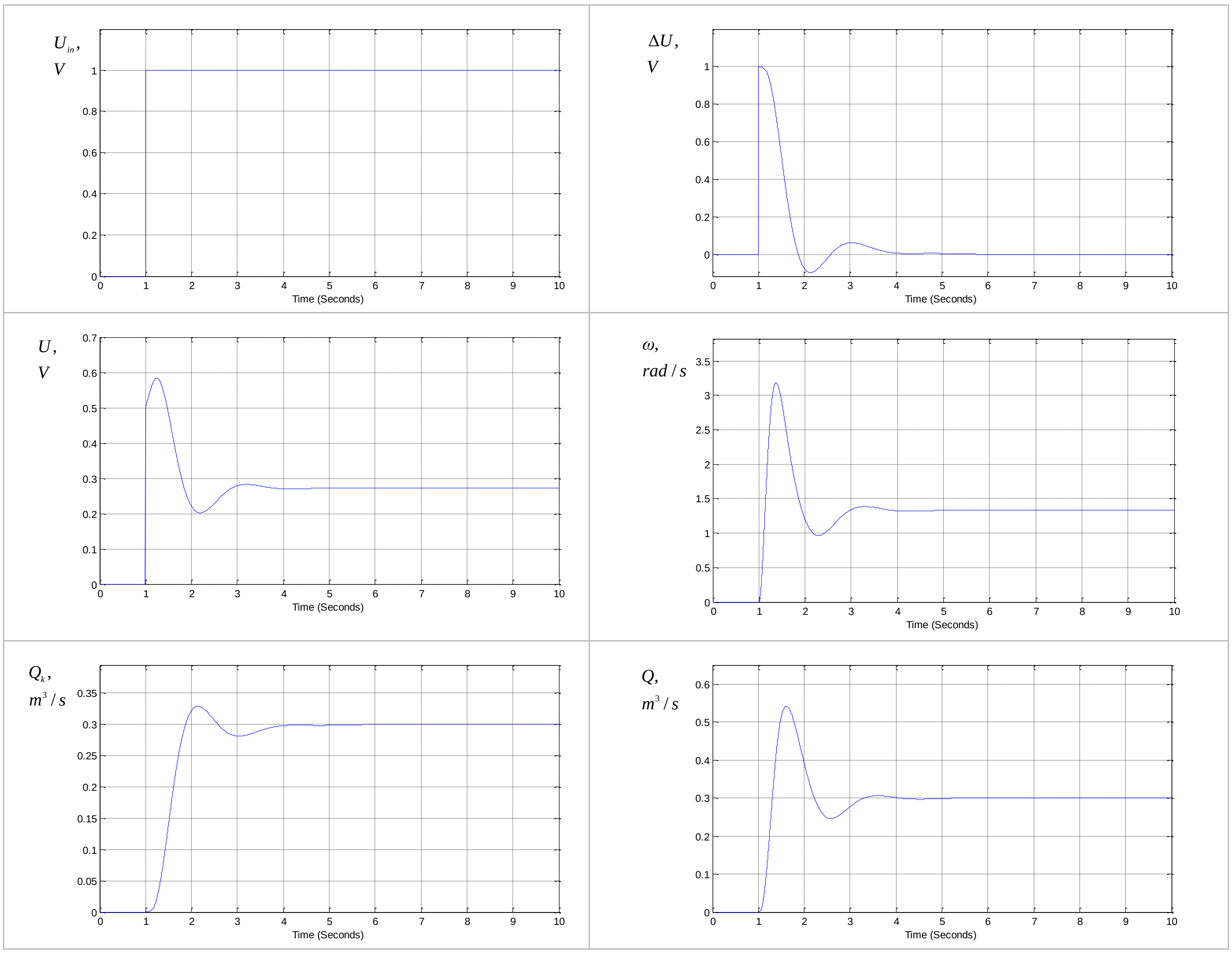


Figure 4. **A**nalogue model of the system in the program environment of Mathlab Simulink.



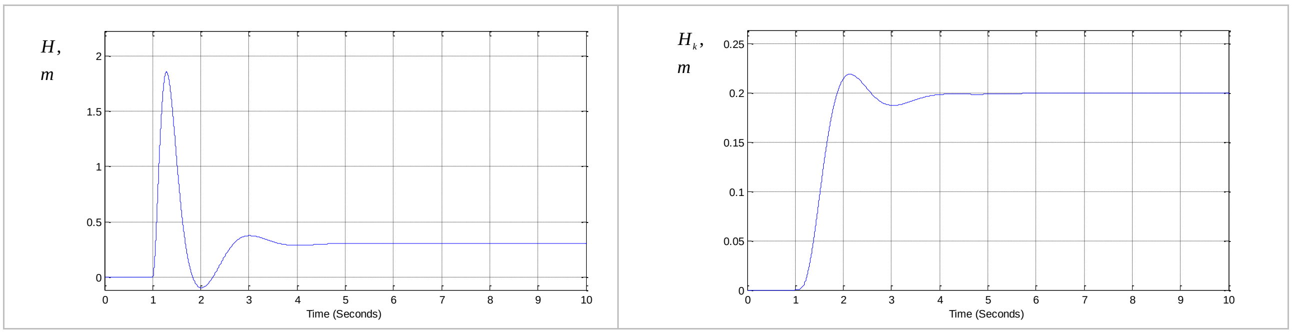


Figure 5. Transient processes in case of variation of the input magnitude U_{in}

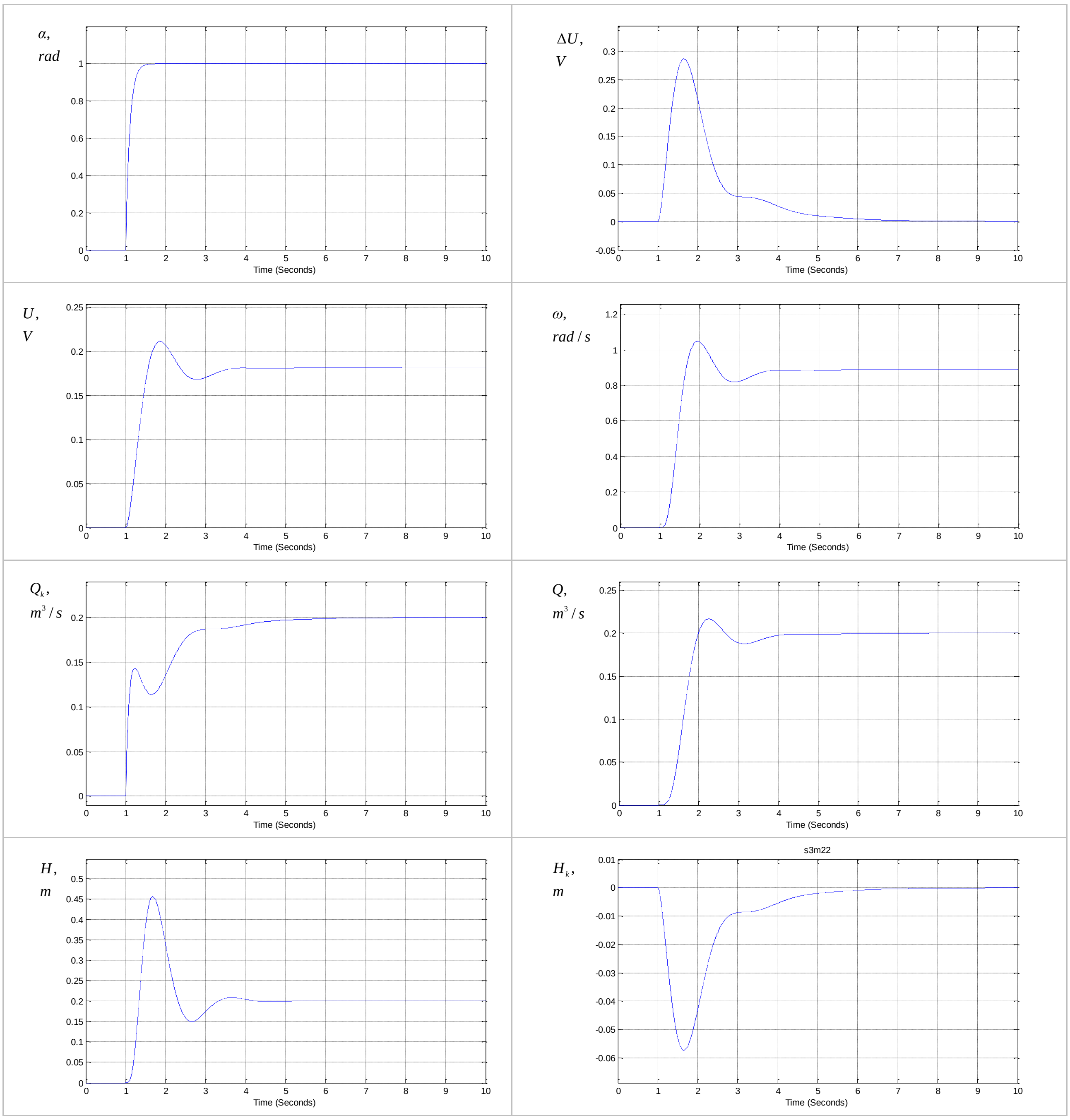


Figure 6. Transient processes in case of changing the disturbing influence α

Fig. 5 represents graphical results of the numerical experiment in the case of variation of the input magnitude U_{in} and Fig. 6 – in case of changing the disturbing influence α.

The automated hydraulic turbo system operates, maintaining constant head $\Delta H_K = const$ in the upper tank. In cases of disturbances in the system (open, close or step changes in the position of the outlet valve 9) transient processes occur in the hydraulic and respectively in the electrical parts of the overall automated system.

Table 1 presents values of some of the most important parameters of the system, relevant for the performed simulation

Table 1

T_I	4.2 s	k_1	0.31 sN/m^2	k_{fb}	1.75 V/m
k_r	0.5	k_2	0.29 N	k_k	0.6
T_M	0.1 s	k_3	0.05Nms/rad	l	2 m
T_E	0.05 s	k_α	5.1 10^{-6} m^3	ρ	1000kg/m^3
K_{FC}	5.0	L	10 m	μ	0.62
T_{FC}	0.001s	β	0.582	A_T	1 m^2

CONCLUSIONS

The developed mathematical model of an automated turbo system enables the studying of the resulting dynamic processes as a result of different operating modes and disturbances, introduced in the system.

In order to obtain a more acceptable character of the transient processes it is necessary to perform parametric optimization of the automated turbo system, following predefined quality criteria.

As a result of the system optimization, a better quality of the transient processes is achieved, both in terms of varying the angular speed of pump’s shaft and varying pressure pipeline’s head and flow.

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