

Stability Control System for Electric Locomotives KZ8A with Asynchronous Traction Motors

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Abstract

Background/Objectives: This paper studies fundamentals of classical, of dynamic modes of the engine to the analog and discrete regulators and stability of linear systems. The overall goal is to define, analyze and evaluate classical and Simulink information measures pertained to data processing by low-power electronic devices, diagrams of processes in the functional model. **Methods/Statistical Analysis:** We construct a functional model of the system with analog and digital parts and compare them to dynamic conditions. A continuous part of the system's actuator is described by the transfer function. This transfer function was verified on the stability by the algebraic stability criterion, namely the criterion of Hurwitz. We use the fundamentals of the method of Lyapunov functions for studying the robust stability of the system for electric locomotives with asynchronous traction motors. **Findings:** There is a virtual model of the induction motor that has been built on the program MatLab by blocks libraries SimPowerSystems of Simulink. We study dynamic mode power electronic devices by taking in the transient functional patterns collected from the virtual elements. This paper analyzes PID-control processing and synthesis of the studied system with nonlinear control law. Our findings enable existing and future communication, sensing, information fusion, computing and processing stability control systems. Consistent tools and practical schemes facilitate developments of novel engineering solutions, technical readiness and technological capabilities. Conditions of robust stability obtained in the form of a linear system of inequalities for uncertain parameters of objects and set the parameters of the controller. The paper demonstrates that the system has steady stationary states both in negative and in positive area of change of uncertain parameters of object control. This research presents that the implementation of the law contributes to the control in the shortest possible time to bring the electric control system to the steady state, which highly good affects the operation of the electric locomotive. **Application/Improvements:** The obtained results allow to build high performance control system via increased potential robust stability. This approach provides dynamic security and performance of the system for any changes to uncertain parameters of the control object.

Keywords: Asynchronous Traction Motor, Control System, Lyapunov Function, PID, Stability

1. Introduction

The transport sector plays an important role in the economy of Kazakhstan because of its raw material orientation and vast territory. The basis of the transport system of the country - it is the railways, which in 2015 provided 51.9% of total turnover of the country. JSC "National Company" Kazakhstan Temir Zholy" (KTZ) is the sole owner and operator of the rail infrastructure, the largest operator of railway rolling stock and locomotive fleet in Kazakhstan.

Improving the efficiency of rail freight is currently impossible without timely update existing fleet of electric rolling stock and improves its technical level. In view of the severe operating conditions of the railways and the continuing annual increase in traffic most promising views of locomotives for these conditions are electric locomotives with asynchronous traction drive. Series KZ8A developed by the French company Alstom Transport in accordance with the terms of reference of KTZ. The locomotive is implemented with asynchronous traction drive control¹.

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2. Design and Modeling of Asynchronous Motor

2.1 Simulation of Dynamical Processes Specific to Asynchronous Traction Motors

Digital automatic control system comprises a microprocessor electrically (digitally) lights, a power converter with Pulse Width Modulation (PWM) for controlling the actuating motor and also the engine load. The output of the digital part is a step voltage, the variation of which is largely dependent on the spacing of the sampling T_s .

With a relatively small step sampling system is considered continuous. Quite often, a continuous part of the actuator is described by the transfer function of the form:

$$W = \frac{1}{T_1 s * (T_0 s + 1)} \quad (1)$$

Define time constant following values: $T_1 = 1$ and $T_0 = 0$, 1 s. We construct a functional model of the system with analog and digital parts and compare them to dynamic conditions. Figure 1 uses the new blocks³.

Unit fixes the input signal at the beginning of the interval of quantization and maintains this value at the output until after quantization interval. Then, the output changes abruptly to a value of the input signal at the next step of quantization.

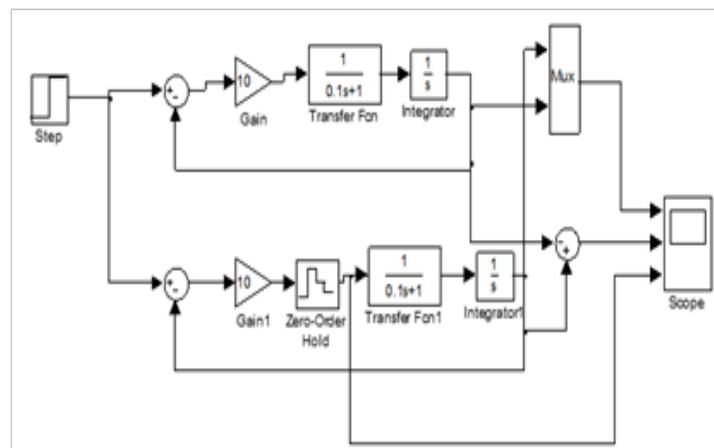


Figure 1. The functional model of the system with analog and digital control.

After running the model to get a temporary process diagrams (Figure 2).

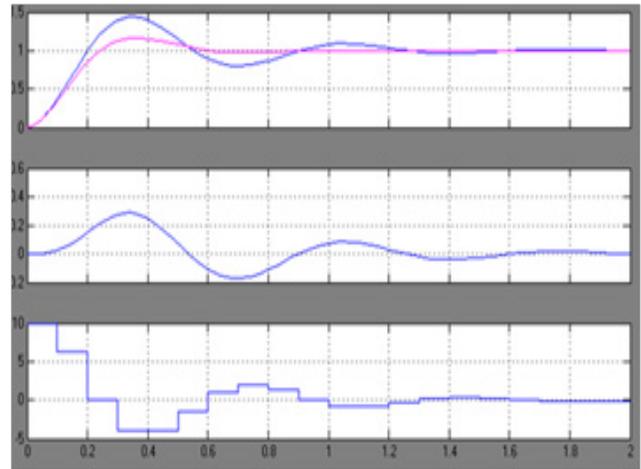


Figure 2. Timing diagrams of processes in the functional model of the system with analog and digital control.

The first of these reflects the nature of the change at the output of the analog signals (purple) and discrete (blue) channel and the second - the difference between the two previous signals (absolute error, time-varying), the third - the control signal after extrapolator. It can be seen that the error is 40%.

We researched the model analyzed the PID controller⁴ (Figure 3). After starting the get the timing charts with different values of dynamic parameters (Figure 4). The error has decreased from 40% to 22%, the transition process has fallen by more than 3 times (compare Figure 2).

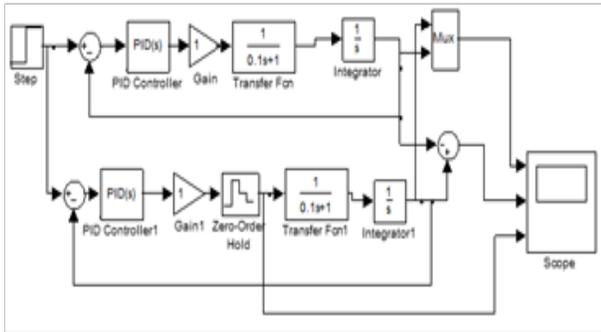


Figure 3. The functional model of the system with analog and digital control and PID-regulators.

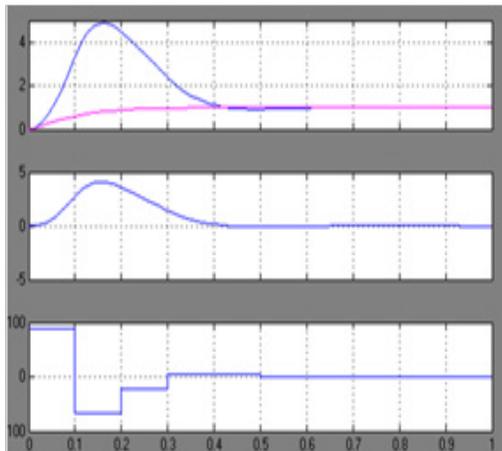


Figure 4. Timing diagrams of processes in the functional model of the system with analog and digital control and PID-control.

Thus, by blocks libraries SimPowerSystems Simulink and it is possible to analyze dynamic mode power electronic devices by taking in the transient functional patterns collected from the virtual elements. Available at the library virtual model of various types of electric motors are applicable for the analysis of the processes of their start-braking.

2.2 Study on the Stability of the Algebraic Stability Criterion of the System

Verify the transfer function (1) on the stability of the algebraic stability criterion, namely the criterion of Hurwitz

to determine the stability necessary to construct a matrix of the coefficients of the characteristic equation⁵.

Continuous part of the actuator is described by the transfer function (1), which consists of a delay element of the first order (2) and the integrator (3):

$$w_1 = \frac{1}{T_0s + 1} \quad (2)$$

$$w_2 = \frac{1}{T_1s} \quad (3)$$

Thus, we have the characteristic equation of the second order:

$$a_0\lambda^2 + a_1\lambda + 1 = 0 \quad (4)$$

By Hurwitz criterion, necessary and sufficient conditions of stability are the inequalities:

$$\begin{cases} \Delta_1 = a_1 > 0 \\ \Delta_2 = \begin{vmatrix} a_1 & a_3 \\ a_0 & a_2 \end{vmatrix} > 0 \end{cases} \quad (5)$$

Substituting for the condition $T_0 = T_1 = 0$ and 1 (4), we obtain:

$$0,1\lambda^2 + \lambda + 1 = 0$$

By Hurwitz criterion (5) the system is stable.

$$\begin{cases} \Delta_1 = 1 > 0 \\ \Delta_2 = \begin{vmatrix} 1 & 0 \\ 0,1 & 1 \end{vmatrix} > 0 \end{cases}$$

The starting point for viewing the Bode diagram is w_c cut-off frequency, which is equal to the frequency at which the amplitude is 1, i.e. 0 dB point. To assess the stability of the frequency response is necessary to compare two frequencies: The cutoff frequency and critical frequency (w_c, w_{cr})⁶. On the cut-off frequency response crosses the unit level and at the critical frequency FHCH crosses the $-\pi$ (-180°) (Figure 5). If the cutoff frequency is below the critical frequency, the system will be stable. Thus, the stability condition takes the simple form $w_c < w_{cr}$.

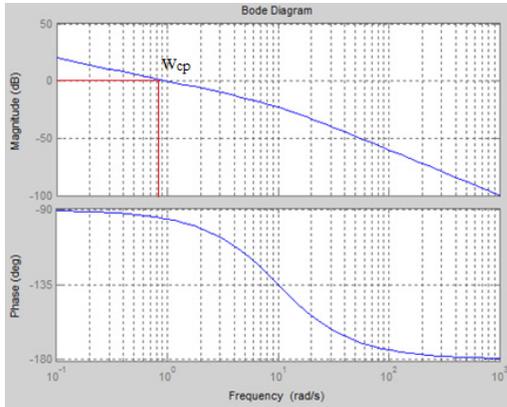


Figure 5. Bode Digram.

3. Stability Control of Nonlinear Systems based on Lyapunov Function Method

As scientific novelty, we investigate the stability of the control system of asynchronous traction motor, built in a class of structurally stable mappings of Lyapunov function method⁷⁻⁸.

Automatic control system equation represented in the state space (6).

$$A = \begin{bmatrix} 0 & 1 \\ 0 & -\frac{1}{T_0} \end{bmatrix}, B = \begin{bmatrix} 0 \\ \frac{1}{T_1 T_0} \end{bmatrix}, u = k_p x_1, C = \begin{bmatrix} 1 & 0 \end{bmatrix} \quad (6)$$

The expanded form of the equation of state space is written:

$$\begin{cases} \frac{dx_1}{dt} = x_2 \\ \frac{dx_2}{dt} = -\frac{x_1^3}{T_1 T_0} + \frac{k_p x_1}{T_1 T_0} - \frac{x_2}{T_0} \end{cases} \quad (7)$$

Find the steady state of the system (7):

$$\begin{cases} x_{1s} = 0 \\ x_{2s} = -\frac{x_{1s}^3}{T_1 T_0} + \frac{k_p x_{1s}}{T_1 T_0} - \frac{x_{2s}}{T_0} \end{cases} \quad (8)$$

We find the stationary state of the system (7):

$$x_{1s} = x_{2s} = 0 \quad (9)$$

Other stationary state of the system (7) will be determined by solution of the equation.

$$-x_{1s}^2 + k_p = 0, x_{2s} = 0$$

A negative k_p ($k_p < 0$), this equation has an imaginary solution that can meet the physical capabilities of any situation.

When $k_p > 0$ equation admits these stationary states⁹⁻¹¹.

$$x_{1s} = \sqrt{k_p}, x_{2s} = 0 \quad (10)$$

$$x_{1s} = -\sqrt{k_p}, x_{2s} = 0 \quad (11)$$

These state of the system (10) and (11) of the system (7) to merge (9) for the parameter values $k_p = 0$, branch off at $k_p > 0$. To study the robust stability of the stationary states of (9), (10), (11) use the fundamentals of the method of Lyapunov functions, we find the components of the gradient vector.

$$\frac{\partial V_1(x_1, x_2)}{\partial x_1} = 0, \frac{\partial V_1(x_1, x_2)}{\partial x_2} = -x_2$$

$$\frac{\partial V_2(x_1, x_2)}{\partial x_1} = \frac{x_1^3}{T_1 T_0} - \frac{k_p x_1}{T_1 T_0}, \frac{\partial V_2(x_1, x_2)}{\partial x_2} = \frac{x_2}{T_0}$$

Full time derivatives of the components of the vector - the Lyapunov function is:

$$\frac{dV_1(x)}{dt} = -x_2, \frac{dV_2(x)}{dt} = -\frac{(x_1^3 - k_p x_1)^2}{T_1^2 T_0^2} - \frac{x_2^2}{T_0^2}$$

The total time derivative of a scalar Lyapunov function can be written:

$$\frac{dV(x)}{dt} = -\frac{(x_1^3 - k_p x_1)^2}{T_1^2 T_0^2} - \left(\frac{1}{T_0^2} + 1\right)x_2^2 \quad (12)$$

The total time derivative of the Lyapunov function is negative definite function.

Components of the Lyapunov function can be obtained as:

$$V_1(x) = -\frac{1}{2}x_2^2, V_2(x) = \frac{1}{4}\frac{x_1^4}{T_1T_0} - \frac{1}{2}\frac{k_p x_1^2}{T_1T_0} + \frac{1}{2}\frac{x_2^2}{T_0}$$

Lyapunov functions in scalar form represented in the form:

$$V(x) = \frac{1}{4}\frac{x_1^4}{T_1T_0} - \frac{1}{2}\frac{k_p x_1^2}{T_1T_0} + \frac{1}{2}\left(\frac{1}{T_0} - 1\right)x_2^2 \quad (13)$$

Terms stability of the zero steady state (9), we obtain a negative view of certain features (12) of the conditions for positive definite functions (13):

$$\frac{1}{T_1T_0} > 0, -\frac{1}{T_1T_0} > 0, \frac{1}{T_0} - 1 > 0$$

This condition is satisfied when $T_1 > 0, T_0 > 0$, so the zero equilibrium state of the system is stable at low values of the coefficient $k_p < 0$, and the other stationary states do not exist.

3.1 The Stability of the Steady State (10)

We investigate the stability of the steady state (10). For this condition Equation (7) is recorded with respect to the steady state (10):

$$\begin{cases} \frac{dx_1}{dt} = x_2 \\ \frac{dx_2}{dt} = -\frac{x_1^3}{T_1T_0} - \frac{\sqrt{k_p}x_1}{T_1T_0} - \frac{x_2}{T_0} \end{cases}$$

We find the components of the gradient vector components of the vector - Lyapunov functions.

$$\frac{\partial V_1(x_1, x_2)}{\partial x_1} = 0, \frac{\partial V_1(x_1, x_2)}{\partial x_2} = -x_2$$

$$\frac{\partial V_2(x_1, x_2)}{\partial x_1} = \frac{x_1^3}{T_1T_0} + \frac{\sqrt{k_p}x_1}{T_1T_0}, \frac{\partial V_2(x_1, x_2)}{\partial x_2} = \frac{x_2}{T_0}$$

Full time derivative of the vector - the Lyapunov function obtained in the form:

$$\frac{dV(x)}{dt} = -\frac{(x_1^3 + \sqrt{k_p}x_1)^2}{T_1^2T_0^2} - \left(\frac{1}{T_0} + 1\right)x_2^2 \quad (14)$$

The total derivative (14) of vector Lyapunov function are signs - negative function.

By gradient construct the Lyapunov function:

$$V(x) = \frac{1}{4}\frac{x_1^4}{T_1T_0} + \frac{1}{2}\frac{k_p x_1^2}{T_1T_0} + \frac{1}{2}\left(\frac{1}{T_0} - 1\right)x_2^2 \quad (15)$$

The condition of positive definiteness of the function (15) was obtained in the form.

$$\frac{1}{T_1T_0} > 0, \frac{1}{T_0} - 1 > 0, T_0 > 0, T_1 > 0, k_p > 0 \quad (16)$$

Hence, from (16) that the steady state (10) is asymptotically stable. For state Equation (7), relative to the steady state (10), $x_{1,s} = -\sqrt{k_p}, x_{2,s} = 0$.

3.2 The Stability of the Steady State (11)

For this case, the equation of state in deviations recorded:

$$\begin{cases} \frac{dx_1}{dt} = x_2 \\ \frac{dx_2}{dt} = -\frac{x_1^3}{T_1T_0} + \frac{\sqrt{k_p}x_1}{T_1T_0} - \frac{x_2}{T_0} \end{cases}$$

We find the components of the gradient vector components of the vector - Lyapunov functions^{12,13}.

$$\frac{\partial V_1(x_1, x_2)}{\partial x_1} = 0, \frac{\partial V_1(x_1, x_2)}{\partial x_2} = -x_2$$

$$\frac{\partial V_2(x_1, x_2)}{\partial x_1} = \frac{x_1^3}{T_1T_0} - \frac{\sqrt{k_p}x_1}{T_1T_0}, \frac{\partial V_2(x_1, x_2)}{\partial x_2} = \frac{x_2}{T_0}$$

Full time derivative of the vector - the Lyapunov function obtained in the form:

$$\frac{dV(x)}{dt} = -\frac{(x_1^3 - \sqrt{k_p}x_1)^2}{T_1^2T_0^2} - \left(\frac{1}{T_0} + 1\right)x_2^2 \quad (17)$$

The total derivative (17) of vector Lyapunov function are signs - negative function. By gradient construct the Lyapunov function:

$$V(x) = \frac{1}{4} \frac{x_1^4}{T_1 T_0} + \frac{1}{2} \frac{k_p x_1^2}{T_1 T_0} + \frac{1}{2} \left(\frac{1}{T_0} - 1 \right) x_2^2 \quad (18)$$

The condition of positive definiteness of the function (18) was obtained in the form.

$$\frac{1}{T_1 T_0} > 0, \frac{1}{T_0} - 1 > 0, T_0 > 0, T_1 > 0, k_p > 0 \quad (19)$$

Hence, from (19) that the steady state (11) is asymptotically stable under the conditions (19). For state equation (7), relative to the steady state (11), $x_{1s} = -\sqrt{k_p}$, $x_{2s} = 0$.

Using the one-parameter structure - stable displays¹⁰ for building management systems asynchronous traction drive shows that the unstable system (with proportional control law) for any unspecified parameter values not only stabilized, but is not limited to changes in uncertain parameters.

4. Conclusion

Mastering the production of asynchronous traction electric drive is an important milestone in the development of the domestic industry. Kazakh producers begin to produce one of the most high-tech elements of the modern electric locomotive, which substantially reduces the cost of operation and maintenance of the locomotive. This will allow the production of rail transport in Kazakhstan reach a new level of competitiveness.

Asynchronous traction drive - a modern high-tech product, which will greatly affect the performance of the engine allowing you to increase the electric power at low weight. It also facilitates the monitoring of engine performance. Traction drives and control systems are intended for acquisition of electric KZ8A, which are manufactured and operated in Kazakhstan.

The introduction of a new generation of electric contributes to the local economy by offering highly competitive new-generation products, which is characterized

by higher performance and fully complies with the local conditions.

In this work it has been built a virtual model of the induction motor on the program MatLab. Thus, by blocks libraries SimPowerSystems Simulink and it is possible to analyze dynamic mode power electronic devices by taking in the transient functional patterns collected from the virtual elements. Available at the library virtual model of various types of electric motors are applicable for the analysis of the processes of their start-braking. Changing the dynamic properties of devices and systems is carried out through the use of the PID and select the settings that determine the contribution to the control signal proportional, integral and differential components.

This study shows that the use of the law contributes to the control knobs in the shortest possible time to bring the electric control system to the steady state, which favorably affects the operation of the locomotive.

Use of the developed approach to create Lyapunov's functions allows demonstrating that the system has steady stationary states both in negative and in positive area of change of uncertain parameters of object control.

The results obtained from designing of control systems with the increased potential of robust stability allow providing dynamic safety and operation of control systems on the stage of their design and operation.

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