

# Electronic emulator of linear dynamic systems

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## Abstract

The aim of this article is development and realization of electronic emulator of dynamic systems with setting of parameters from PC. This emulator is the first prototype, which is meant to prove the possibility of emulating the behavior of dynamic systems by microprocessor.

The main goal of research is creating of equipment, which can emulate a behavior of pneumatic muscle with sufficient accuracy. Dynamic of pneumatic muscles is significantly non-linear and changeable in the dependence on environmental conditions. Hence control of its position is complicated and consequently using of pneumatic muscles is restricted. This research is called to expand and simplify using of pneumatic muscles.

**Keywords:** Runge-Kutta method; dsPIC30F3010; measuring of dynamic characteristics

## 1 Introduction

Pneumatic Artificial Muscles (PAMs) were invented in late 1950's by J.L.McKibben. They are able to extend or to contract by influence of pressured air. This principle came from the biological features of human muscles. This similarity gives an opportunity to precisely reproduce human moves. Also, pneumatic muscles are lightweight, their construction is simple and they can be used in delicate operations.

On the other hand, they have certain disadvantages that restrict their using in automation of technical processes. Due to physicality of air and properties of used material, pneumatic muscles behave distinctly non-linearly. Moreover, it changes its behavior in dependence on environmental conditions (ambient temperature, humidity and pressure of air). Consequently they require non-trivial control system. Pneumatic muscles, as any pneumatic system, need compressed air generator.

The main goal of research is to create an emulator that will observe a behavior of pneumatic muscle, identify it and repeat its behavior with sufficient precision. The first prototype of electronic emulator, which is the main aim of this article, emulates the behavior of linear dynamic systems. Dynamical characteristics of two systems were verified: first-order system and second-order system.

## 2 Description

The first prototype of electronic emulator of pneumatic muscles was developed on the base of signal microprocessor dsPIC30F3010. Fig. 1 helps to understand a principle of working with emulator.

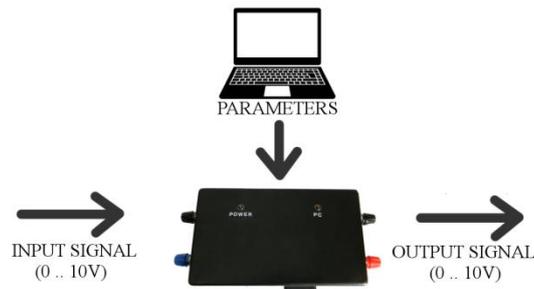


Figure 1: Connection of the electronic emulator

User has to define parameters of desired system from PC.

Program for connection emulator to PC was designed in MATLAB (Fig. 2). This software was chosen because of its two advantages. First of all, creating of applications with Graphical User Interface in MATLAB is easy and comfortable. Second advantage is possibility of using internal math functions.

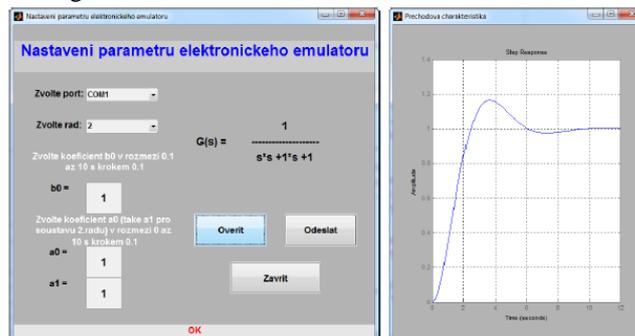


Figure 2: Application in MATLAB for defining of parameters

User chooses parameters of desired system, then he or she can check transient and transfer function of system, which will be emulated. Last step is sending parameters to emulator via COM port.

Then user can disconnect serial cable. Emulator will behave as a dynamic system with defined parameters. If we sent an electric signal on the input of emulator, we can observe the response on its output.

### 3 Structure of electronic emulator

Structural scheme of electronic emulator is shown on Fig. 3. Bold lines show power supply of particular electrical components inside emulator. Different components need different power supply voltages. That is a reason why voltage regulators are used in the scheme.

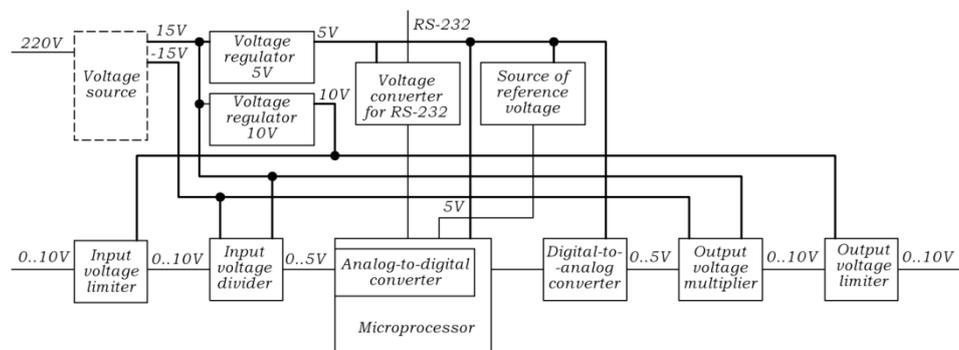


Figure 3: Structural scheme of electronic emulator

In order to enable transfer of data via serial port, special voltage converter has to be used. It converts high-level voltage from serial port of a PC into low-level voltage of UART module of microcontroller.

Source of reference voltage is used to increase the precision of built-in analog-to-digital converter. Microcontroller doesn't contain digital-to-analog converter, that's why external one has to be used.

Voltage multiplier and voltage divider are used to extend the range of input and output signal. On the other hand, they doubly reduce a precision of analog-to-digital converter and consequently an accuracy of all emulator.

Voltage limiters are used to protect input and output from overload or misconnection.

Schema of emulator contains an external voltage source that transfer mains voltage into  $\pm 15$  V. This voltage is needed to feed voltage divider and voltage multiplier. Other essential voltage levels are converted from the level 15 V inside the schema of emulator. This solution simplifies the work with emulator, because no additive voltage source is needed.

## 4 Programming of Microcontroller

Block diagram, which simplistically describes a run of a program in microcontroller, is shown in Fig. 4.

Parameters of emulated system (coefficients of transfer function and an order of emulated system) are stored in EEPROM memory of microprocessor. These parameters are copied to operating memory and then used for computations. Also program chooses an appropriate function in dependence on desired order of dynamic system.

Changing of parameters is provided by interruption of processor. For user it means that he or she just have to connect emulator to PC and to send new parameters.

Converting of input signal is provided by built-in analog-to-digital converter. Than computation of response by the fourth order method of Runge-Kutta is provided. In fact, microprocessor calculates numerical solution of a differential equation with constant coefficients. For instance, for a differential equation of the first order emulator provides computations with following recurrent formula:

$$y_{i+1} = y_i + \frac{h}{6} \cdot [k_1 + 2 \cdot (k_2 + k_3) + k_4], \quad (1)$$

Here

$$k_1 = f(x_i, y_i),$$

$$k_2 = f\left(x_i + \frac{h}{2}, y_i + \frac{h}{2} \cdot k_1\right), \quad (2)$$

$$k_3 = f\left(x_i + \frac{h}{2}, y_i + \frac{h}{2} \cdot k_2\right),$$

$$k_4 = f(x_i + h, y_i + h \cdot k_3),$$

$$h = \frac{b - x_0}{n}, \quad (3)$$

$$x_i = x_0 + i \cdot h. \quad (4)$$

Where  $f(x, y)$  is solving of Cauchy problem.

This algorithm can be relatively easy extended for higher order of differential equations [4].

Next step of block diagram is writing a result of computation to the output of microprocessor. This result is transferred into the 16-bit digital word and hence it is sent on the output via SPI module.

Then program waits for overflow of the internal timer. This timer is used for providing emulator with constant sample time. Testing of program showed, that sampling period 10 ms is fully enough for computation. Program of microcontroller runs in cycle, it can be interrupted only with transferring of desired parameters from PC.

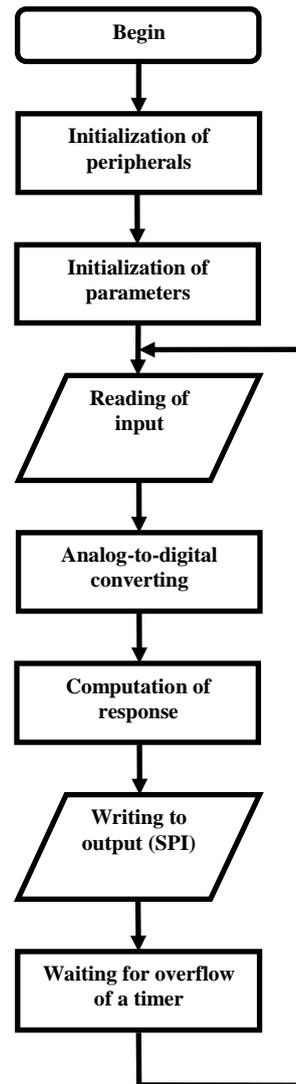
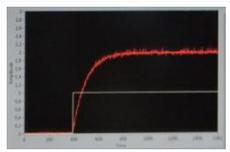
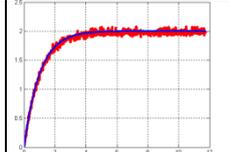
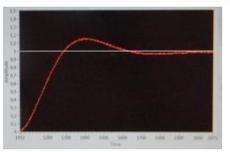
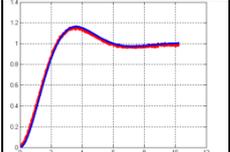
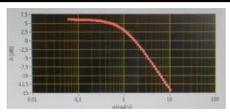
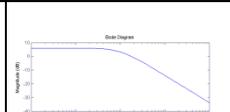
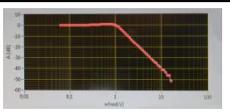
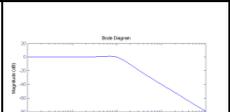
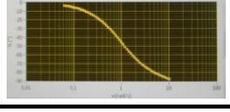
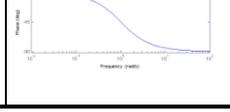
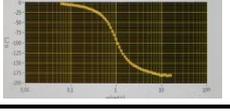
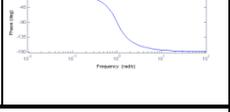
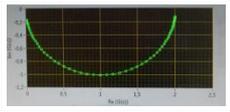
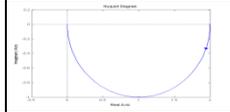
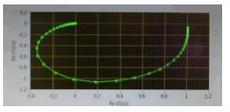
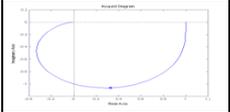


Figure 4: Simplified flowchart of program

## 5 Testing

Functionality of electronic emulator was verified by testing its dynamical characteristics in LabVIEW. Summary of testing is shown in Tab. 1.

Table 1: Summary testing of electronic emulator

Output from electronic emulator	Theoretical process (MATLAB)	Output from electronic emulator	Theoretical process (MATLAB)
$F(s) = \frac{2}{s + 1}$		$F(s) = \frac{1}{s^2 + s + 1}$	
Transient characteristic			
			
Bode characteristic			
			
			
Nyquist characteristic			
			

## 6 Conclusion

Electronic emulator was successfully produced and tested. It was proved, that behavior of linear dynamical systems can be emulated by microprocessor with sufficient speed. Results of testing show, that accuracy of emulation is good, but not sufficient. In the next prototype of electronic emulator this parameter has to be raised.

The list of transfer functions, which can be emulated, is very short. Extension of computational possibilities of emulator is the main field of work for further development.

Using a single-chip microprocessor PIC as a main unit of emulator is efficient in the view of speed and price. On the other hand, programming of routines for interconnection of peripherals is very time-consuming. Hence it has to be more efficient to use single-board microcontroller for reducing the time of prototyping of the next version of electronic emulator. Moreover, single-board microcontroller demands less of further electronic components than single-chip microprocessor.

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