Design a Simple Hardware in the Loop Test-bed Platform for Educational Purposes

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Abstract – **In this paper a simple hardware in the loop testing platform for educational purposes is considered. Dynamic model of speed servo is developed and implemented to the test-bed platform. Such system is purposed for testing physical controller. Different scenarios are defined at the test-bed platform side. Used equipment is general purposes and can be utilized for controller implementation as well as virtual plant model. Simulations are performed under different conditions and results are presented graphically using virtual instruments on the designed front panels.**

Keywords – **Speed servo, Dynamic model, Hardware In the Loop.**

I. INTRODUCTION

Systems are created to solve problems. One can think of the systems approach as an organized way of dealing with a problem. System development life cycle means combination of various activities. In other words we can say that various activities put together are referred as system development life cycle, Fig.1.
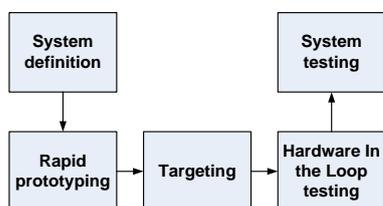
Fig. 1. System development life cycle

As the complexity of the hardware being controlled increases, the complexity of the embedded system that is designed to control the hardware is increased. In the System analysis and design terminology, the system development life cycle means model development and design and hardware and software implementation. Simulation is a technique that is used increasingly in the development and test of complex real-time embedded systems. Depending of facts that objects in the simulation process may be real and/or virtual, there is a few different types of approach, model in the loop (MIL), software in the loop (SIL) and hardware in the loop (HIL). Model in the loop is a real time simulation technique purposed for dynamical model testing. The Objectives of this type of

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simulation are intended to functional validation and calibration of sub-system, models, evaluation interactions between subsystems, refinement of plant models. The main objectives of software in the loop simulation are functional validation of controller software architecture and verification of software implementation against model. The HIL simulation includes a mathematical model of the process and a hardware device you want to test.

System level testing is one of the major expenses in developing a complex product that incorporates embedded computing. The need to minimize time to market while simultaneously producing a thoroughly tested product presents tremendous challenges. Increasing levels of complexity in system hardware and software are making this problem more severe with each new generation of products. Additionally, any significant changes made to an existing product's hardware or software must be thoroughly regression-tested to confirm that the changes do not produce unintended effects [1].

Hardware in the Loop (HIL) simulation is becoming more prevalent tool for design, testing, adjustment and perfected stage of the electronic system development [2]. The practice of engineers abounds with examples of how the software controller, the part of the system software and hardware failures can lead to system failures, destruction of equipment and in some cases loss of life. These facts stand as a reminder that the testing technology must constantly improve and apply new technology to improve testing, increase test coverage and reduce the cost of testing.

In real HIL simulation system is replaced by a virtual model that operates in real time. Hardware in the loop simulations are increasingly used to evaluate the performance of the controllers. Software simulation results to develop a control system prepared in advance. In this case generally reduces the calculation time. The complexity of the equipment being tested is included in testing by adding a mathematical model that is about dynamic system. This mathematical model is stated as a simulation facility that is us the equipment that simulates. The HIL testing reduces the costs and risks, increasing reliability and quality, lower prices and has introduced changes more efficient development. The purpose of HIL simulation is to provide an effective platform for the development and testing of embedded real-time systems. As advanced HIL test method allows the prototype of the new equipment to be examined under a wide range of realistic conditions are safe and economically feasible.

In this paper we consider design phases of a simple test-bed platform for hardware in the loop simulation. Section two describes the theoretical background and development phases of dynamic model of components which speed servo consist off. The next section shows the implementation phases of dynamic model to the target HIL platform as a virtual model.

Experimental results and conclusions are presented in the last two sections.

II. DYNAMIC MODEL OF SPEED SERVO

2.1. *Modeling of DC permanent magnet motor*

One of the most used actuators in control systems is a direct current (DC) motor. The general output variable of this actuator can be angular speed or angular displacement motion, but, coupled with wheels or drums and cables, can provide translation motion. In most applications the speed or position of the shaft of these motors must be accurately controlled. In order to design such velocity and position control systems it is necessary to obtain, analytically or experimentally, a mathematical model for the motor or system to be controlled.

Dynamic analysis and simplest process remains very complex if we want to give him a complete description [3]. Therefore, first and foremost when making mathematical model is to choose those assumptions that will simplify the description of the process. Usually, for this purpose a system that analyzed is divided into simple articles, subsystems suitable for analysis, and the total description is obtained by making the descriptions of all subsystems. The dynamic model of permanent magnet DC motor is shown in the following figure,
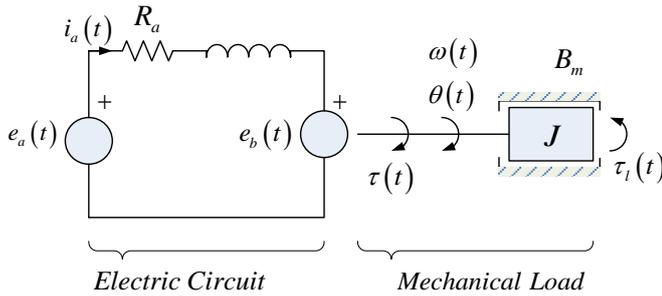
Fig. 2. Equivalent circuits for modeling of DC motor

Where the circuit element represents the motor model parameters are described in Table I.

TABLE I
MOTOR MODEL PARAMETER DESCRIPTION

$e_a(t)$	Applied armature voltage
$i_a(t)$	Armature current
$e_b(t)$	Back electromotive force
R_a	Armature resistance
L_a	Armature inductance
$\theta_m(t)$	Angular position
$\omega_m(t)$	Angular velocity
J	Rotor Inertia
B	Viscous friction

$\tau_m(t)$	Motor torque
$\tau_l(t)$	Load torque

Permanent magnet motor model presented above can be described by the two differential equations, one for electrical part and one for mechanical part. The differential equation for the armature electrical circuit is:

$$R_a i_a(t) + L_a \frac{di_a(t)}{dt} = e_a(t) - e_b(t) \tag{1}$$

The equation of motion, i.e. mechanical equation:

$$J_m \frac{d^2\theta_m(t)}{dt^2} + B_m \frac{d\theta_m(t)}{dt} = \tau_m(t) - \tau_l(t) \tag{2}$$

Interconnection between electrical and mechanical equations is realized by torque equation (3),

$$\tau_m(t) = K_\tau i_a(t) \tag{3}$$

and back electromotive force equation (4).

$$e_b = K_b \omega_m(t) \tag{4}$$

Replacing the motor torque (3) and back electromotive force (4) in electrical (1) and mechanical (2) equations, and applying Laplace transform, gives the following dynamic equation in the Laplace domain:

$$(sL_a + R_a) I_a(s) = E_a(s) - K_b \Omega_m(s)$$
$$(sJ_m + B_m) \Omega_m(s) = K_\tau I_a(s) - T_l(s) \tag{5}$$

System of equations (5) can be used for generating the block diagram for dynamic system description presented at the Fig. 3.

Fig. 3. Block diagram of the DC motor system

2.2. *Modelling of tachogenerator*

In certain speed of rotation of the rotor of tachogenerator, the rms value of the induced voltage can be explained by a linear equation:

$$E_{TG} = c_{TG}n \qquad (6)$$

The expression (6) shows that the rms value of the output voltage of tachogenerator in idle mode is a linear function of speed of rotation n. It follows that tahogenerator can be modeled with a simple block - multiplication by a constant.

2.3. *Modelling of a speed servo*

Combining the models development above and utilizing control circuitry we can obtain the complete model of DC servo shown on Fig. 4.

Fig. 4. Dynamic model of DC servo

Block 'A' stands for amplification, i.e. controller and 'TG' represents block of tachogenerator. The rest of the consisting components in block diagram of DC servo are described earlier.

Fig. 5. Transfer function block diagram of DC servo

Block diagram of DC servo dynamic system model is presented on Fig. 5. During the following consideration the left side will be realized as a real controller and the right side which represent a controlled plant, in this case combination of DC motor and tachogenerator, will be implemented in a real hardware as a virtual model.

III. HIL TEST-BED DESIGN

The core platform of the presented hardware-in-the-loop approach is the Virtual Test Bed (VTB). The VTB is a dedicated environment for simulation and virtual prototyping of complex systems. The VTB allows for handling natural power flow, signal and data coupling between inter-connected devices and offers a combination of both topological and mathematical expressions in model formulation for a comprehensive and efficient modelling process. The VTB also supports multiple layers modelling, wherein each layer can describe a different model complexity or a different behaviour. In addition to the powerful capabilities for modelling, the VTB is endowed with mechanisms for both wrapping and co-simulating with models developed in LabVIEW environment [4].

3.1. *Controller design*

The subject of this subsection is the development of the digital controller for power electronic circuit for governing speed servomechanism consisting of actuator - electric DC motor and angular velocity sensor. Motion control task can be realized by pulse-width modulation utilizing a bridge circuit configuration for powering the electric motor. Based on information obtained by the angular velocity sensor controller will change the width of the pulses in order to maintain a constant pre-specified speed of rotation. The prepared prototype controller implemented in Ni6008 acquisition card [5] will be connected to test hardware, the same type card, and scenarios in different operating conditions would be given interactively through a personal computer, Fig. 6.

Fig. 6. Connection of used hardware

Block diagram of proposed controller incorporating PWM (Pulse Width Modulation) generator and feedback control with PID (Proportional Integral Derivative) circuit is presented on the Fig. 7.

Fig. 7. Controller block diagram

294

Pulse width modulated signal can be obtained by a comparison of instantaneous value of sow-tooth signal and referent voltage. Varying the referent voltage results with the different duty cycle of PWM signal.

3.2. Virtual model implementation

In the case of testing with the principle of Hardware in the loop, the real object of control is replaced by a virtual model implemented in the hardware [5]. Block diagram of the virtual model developed in the previous section, implemented in this phase is given in Fig.8.
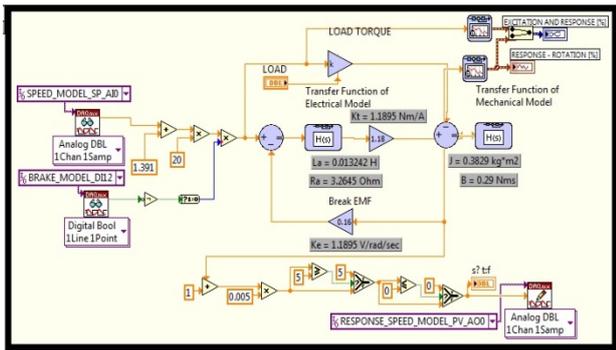
Fig. 8. Block Diagram of virtual plant model

Output signals of controller are input signals in virtual model and vice versa. Analogue signals are normalized according to acquisition card limits.

IV. EXPERIMENTAL RESULTS

Real time controller and virtual plant implemented in different hardware are undergone of testing. Different scenarios are generated and applied to the virtual model and results of experiment are presented on the next figures.

Experiments start with no load condition. Step response of the system with the absence of load torque is presented on the Fig. 9. It is obvious the behavior of second order system response with a vanishing oscillations. After some time since starting the resulting speed is equal to required speed.
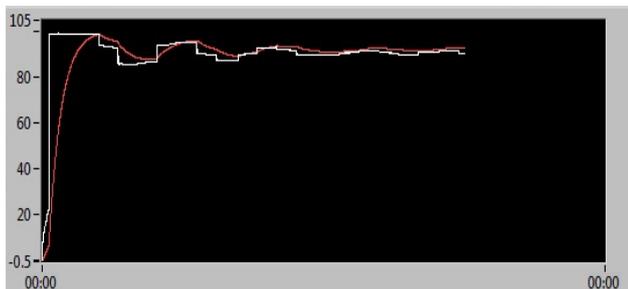
Fig. 9. No load torque step response

The results of another two starting scenarios are presented on the Fig. 10 and Fig. 11. The first scenario is application the

load torque during motor starting, and removing it after reaching set point, i.e. nominal motor speed.
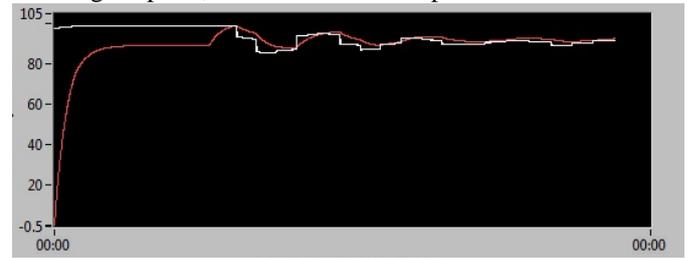
Fig. 10. Applied load torque during motor starting
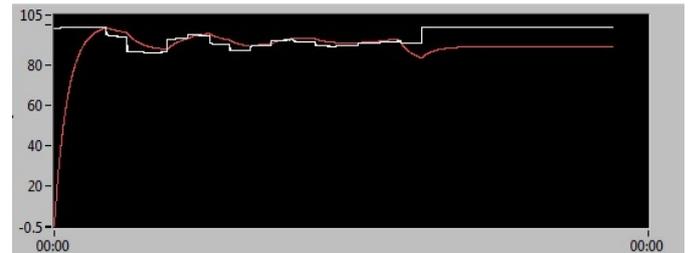
Fig. 11. Applied load torque after motor starting

At the moment of starting, controller responds with the increased excitation voltage as a reaction of applied external load torque to reach the given set point. When external load torque disappear the controller excitation voltage goes down followed by some decreasing oscillations due to the system order. The next figure shows scenario where the external load torque is applied after motor starting. At the moment of increased load torque the motor speed slow down, but after controller reaction with increased excitation voltage the motor speed reach its nominal value, set point.

V. CONCLUSION

HIL simulation is a technology where powerful modern electronic systems and their ancillary components are replaced with digital simulation in real time based on the physical model. This simulation is used to test the components as digital controller, which instead of being connected to real equipment under control is associated with HIL simulator and digital controller being tested feels like a real control system.

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