

Hardware-in-the-loop Simulation of Mechanical Loads for Mechatronic System Design

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ABSTRACT

Current Hardware-in-the-loop simulations are designed for testing Electronic Control Units, simulated digitally, in a physical experimental setup. This paper presents another alternative for using Hardware-in-the-loop simulator for testing active and passive mechanical loads, simulated physically on direct drive motors, under computer control. Based on the model of the active or passive mechanical load, the direct drive motor under digital control is used to emulate the load torque of a passive load not yet available in a physical form.

Keywords: hardware-in-the-loop, mechatronics, control, testing

1. INTRODUCTION

Mechatronic systems are usually very complex systems consisting of different mechanical, electrical and electronic components. Building such system could be time demanding process and is usually very expensive. Design of each component requires careful testing, which is in the most cases slow, repetitive and done under difficult conditions. If conducted on real hardware, the testing is expensive and it takes time to be set up. Hardware-in-the-loop (HIL) testing is one way to avoid all these problems [1], [2].

Current HIL simulations focus on fast track development of particular subsystems, mostly for automotive industry as, for example, electronic control unit for engine control system, development of ABS subsystem, steering and suspension subsystem development etc. [3] to [6].

In this paper, we are presenting another alternative for use of HIL simulations. Fast development of mechatronics systems requires the design of all components and evaluation of different potential parts of the system. Here we are focusing on fast development of a plant or a part of a plant. Not all parts of the system (plant) are immediately available. Before a part is purchased, several different similar products may be considered as potential match. Before spending money and buying an unknown product, simulation can be used to predict which product is the best for particular need

considering all internal and external conditions. For that purpose Hardware-in-the-loop simulation tests are used and this paper is showing some of preliminary results.

2. EXPERIMENTAL SETUP

The HIL experimental setup presented in this paper is designed as modular unit, able to be transformed to suit particular experimental needs. In the most basic configuration, the setup consists of two motors coupled together with a removable shaft. Motor holders are designed in a way that allows mounting of different motors. The motors used at this time are Pittman 9232S001, as shown in Figure 1.

One of the motors is the actuator while the second motor has the function to simulate the load. In this paper, in order to verify the proposed concept, the tests are carried out with both the load motor and the actual load. Load motor and real load are tested under same conditions for comparison.

Motors are connected by removable shaft. Two different shafts designed for this purpose can connect these motors. One is designed as a rigid shaft and connects motors with flexible couplings. Second shaft is a flexible shaft, containing a spring in the middle. This configuration adds non-linearity into the system and will be used in a later research phase. Both shafts have 8 mm diameter and can be connected to the motor shafts by flexible and rigid coupling.

DC motors in this setup are driven by PA228 power amplifiers, which convert input voltage into current, used to control torque of the actuator and of the simulated load [7]. These motors are equipped with optical encoders, both with 3 channels and 500 counts per revolution. The system is controlled by dSPACE process computer, which is connected to a host PC. Control programs, written in C programming language, are loaded from PC to the dSPACE computer. Real time dSPACE operating system provides very efficient solution for control and monitoring of Hardware-in-the-loop experiments.

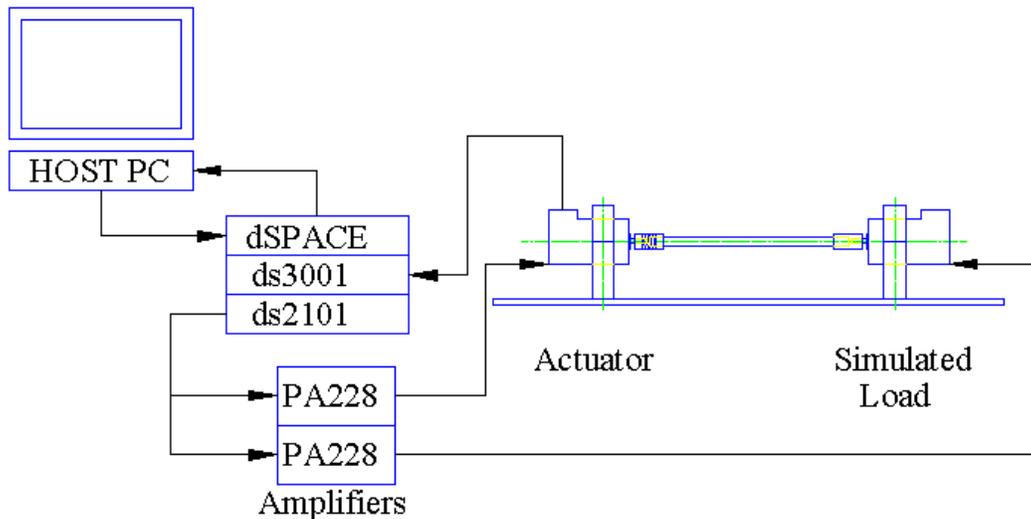


Figure1, HIL setup with simulated load

3. MODELING

For the HIL experimental set up, the plant is considered to be the load of the system. The load can be passive or active and linear or non-linear. If the load is passive, inertia and viscous friction are of major interest. Passive linear load can be modeled by

$$T_L = J_L \frac{d\omega}{dt} + B_L \omega \quad (1)$$

where J_L is inertia of the load, B_L is viscous coefficient and ω is angular velocity of the shaft. For non-linear loads the model is different due to additional non-linear factors. As an example for proving the concept, a fan can be used as a non-linear model

$$T_L = J_L \frac{d\omega}{dt} + B_{L1} \omega + B_{L2} \omega^2 \quad (2)$$

where B_{L2} represents a non-linear coefficient of viscous friction. If the load is active then separate excitation exists and a suitable model is required.

The load is connected to the actuator by a shaft. The inertia of the shaft is usually neglected but, in case of relatively large applied torques, elasticity of the shaft has to be added into calculations. The stiffness of the rigid shaft can be calculated by the following equation

$$K_S = \frac{G * J}{L} \quad (3)$$

where G is shearing elasticity modulus, J is shaft inertia and L is length of the shaft. The actuator's dynamics can be described by

$$U = L \frac{di}{dt} + R * i + K * \omega \quad (4)$$

$$K * i = J \frac{d\omega}{dt} + B * \omega + T_L \quad (5)$$

where J and B represent inertia and viscous coefficient of the actuator motor and K is motor constant.

Considering a linear load model, the overall model can be written as a transfer function

$$\frac{\omega(s)}{U(s)} = \frac{J_L K^* s^2 + B_L K^* s + K K_S}{R J_L^* s^3 + (R J_B + R J_L B + K^2 J_L)^* s^2 + (R J K_S + R B_B + R J_L K_S + K^2 B_L)^* s + (R B K_S + R B_L K_S + K^2 K_S)} \quad (6)$$

Once the dynamics of the load is known, it is possible to simulate it using a direct drive DC motor. While the actuator motor is running according to various control schemes, the motor, which simulates the load, is under current command, according to the load dynamic model. If the simulator motor has a larger inertia than the one of the load it simulates, then the motor has to be subject to a pre-calculated current to account for the inertia of the load. Similarly, viscous friction can be handled. Direct drive DC motors have the advantage of direct torque control by input current.

For successful development of current scheme, the inertia and viscous friction of the load are essential. In the case that the dynamic characteristic of the load (J and B) are

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not known, a frequency response method for the determination of inertia and viscous friction coefficient can be used. First, the frequency response of the load is obtained from the experimental Bode diagram. After drawing appropriate asymptotes, it is possible to determine the natural frequency as well as the damping ratio of the system. From those characteristics the moment of inertia and viscous friction coefficient for the unknown load can be calculated.

4. EXPERIMENTAL RESULTS

The concept proposed in this paper was tested for a passive load, represented in this case by a non-energized brushless motor Parker 7521.250. The motor was connected to the actuator by flexible shaft using flexible and rigid couplings. The rotor of the Parker motor can be considered a passive load since that motor did not receive any signal during the experiment. The actuator, Pittman 9232, received a test signal generated by dSPACE real time computer. The signal was obtained with a C program written on host computer and downloaded to dSPACE. This first experiment was conducted with the purpose to obtain the velocity characteristic of the system consisting of the actuator and the known passive load. The results for this experiment are shown in Figure 2. The Real-time Trace was designed for displaying the results for both setups, with actual passive load, shown in Figure 2 and for simulated load, shown in Figure 3. Real-time Trace contains scopes for td, the signal sent to the actuator, pdm is position of the shaft and td_tq is torque sent to the actuator (proportional to the current), t1 is signal sent to the motor simulating the load Vdmf represents velocity characteristics of the system and t1_tq is torque sent to the motor simulating the load.

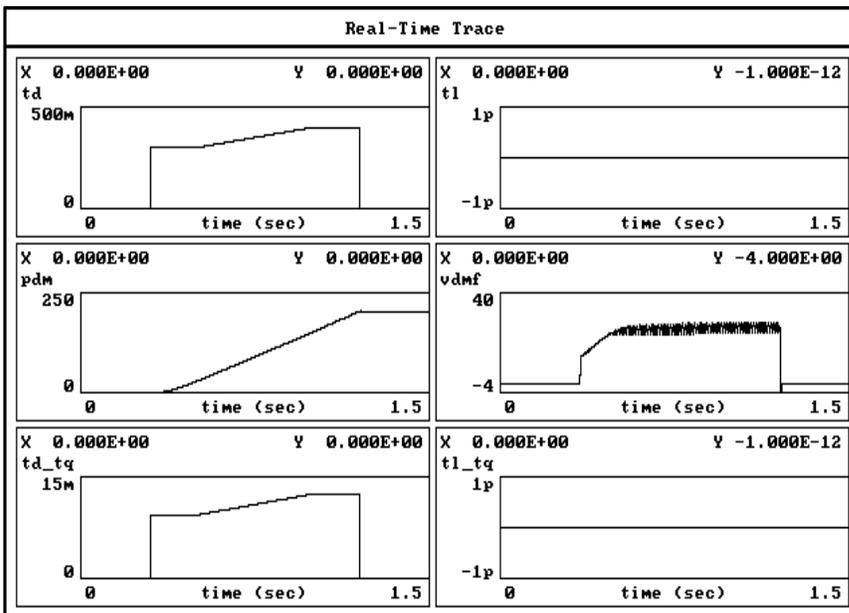


Figure 2. Results for system with actual passive load

Current scheme for the motor simulating the load was created using the known dynamics of the Parker motor. DC motor used for load simulation is another Pittman 9232 motor under model based control, which emulates the real load, the non-energized Parker motor. The same control signal is sent to both the actuator and the motor simulating the load.. This motor simulating the load actively participated in the experiment by manipulating its own dynamics by modulating the current command to simulate real load. When the real load has high viscous friction and inertia values, the motor simulating the load provided with supplementary current command applied in the opposite direction. By applying an opposing torque to the actuator torque the simulator motor has higher moment of inertia and viscous friction. In this case, the simulator motor provides a torque in the same rotational direction with the actuator.

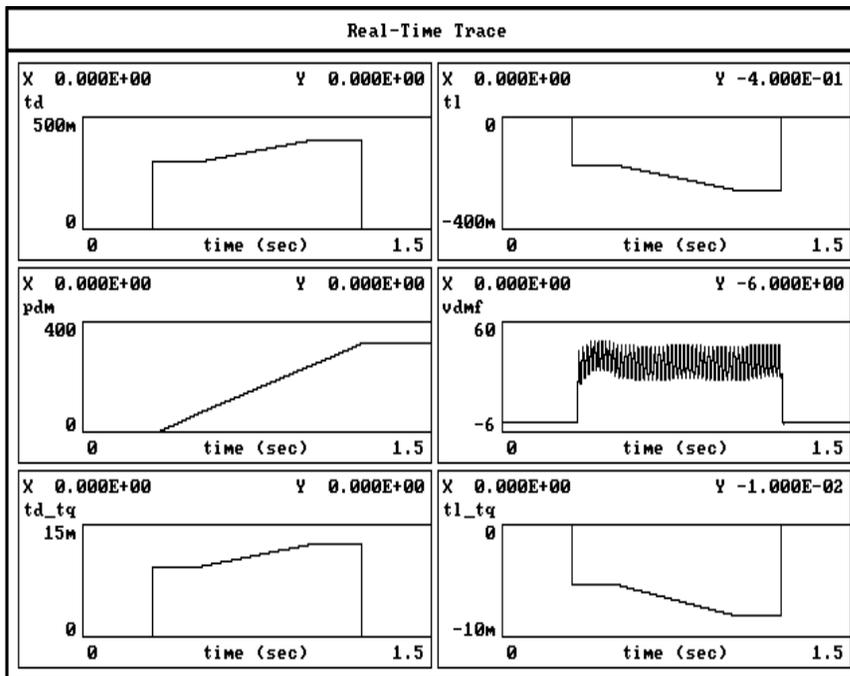


Figure 3. Results for system with simulated load

The results shown in Figure 3 on the left hand side for the actuator are the same as in Figure 2, while the results on the right hand side for $t1$ and $t1_tq$ for the motor simulating the load and $Vdmf$ for the system illustrates the performance of the proposed HIL experimental setup. $t1$, the signal sent to the motor simulating the load

5. CONCLUSIONS

Preliminary results justify the concept of using HIL simulations for mechatronic systems design for both active and passive loads. The major advantage of using this method for fast Mechatronics system development is the possibility of doing experimental study with only part of the actual components available. For example, in automotive industry, new wheel designs could be tested using the concept of the proposed method. Also, other types of motors, for example stepper or AC motors could

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be tested mechanically by simulating them using advanced direct drive motors. Limitations of this method are associated with the performance of the motors used for HIL experimentation and the accuracy of the dynamic model used to simulate an actual load.

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