AC 2009-736: SYSTEM DESIGN AND INTEGRATION FOR REPEATED IMPACT TESTS

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Abstract

The design and integration of an impact-testing machine is particularly for the test of an object which is repeatedly dropped down from a specified height. Four linear actuators with two on each of the two magnetic rails are used to lift up an object weighing up to70 lbs. Each actuator is powered and controlled by an industrial amplifier. A Programmable Logical Controller (PLC) is applied to activate these four actuators simultaneously and repeatedly. Accelerometers using an National Instruments (NI) data acquisition system are used to measure the impact force during the tests. Students gain design and implementation experiences from the developing of the system.

1. Introduction

A collision between two bodies which occur in a very small interval of time, and during which the two bodies exert on each other relatively large forces, is called an impact[1]. The following impact-force equation can be used to illustrate the physical situation.

$$F = m\frac{\Delta V}{\Delta t}$$

(1)

Where F represents the impact force; m represents the mass of the object; m is the mass of the object; ΔV represents the velocity change between the initial velocity and the velocity after impact; Δt represents the impact time, which is very small when impact occurs. During the impact, the struck object behaves as if it were more brittle than it is, and the majority of the applied force goes into fracturing the object. As illustrated in Equation (1), impact force can be greatly reduced when Δt increases. This can be achieved through the design of a soft contact during the impact. A machine which can create impact motions is needed to test the performance of the impact absorbing device.

The design for this machine is to provide an impact-testing facility for either biomechanical devices or electronic equipment when operated in the repeated impact environment, which may include a boat on various sea state motions[2], electronic equipment on a boat[3], and nailing task motion[4], etc. The system can be applied to perform the test of the equipment when operated in such a dynamic environment, and also to evaluate impact-absorption devices. The impact force is measured through the use of accelerometers. The whole system includes mechanical design, electrical control, PLC programming, and data acquisition for accelerometers.

2. Mechanical Design

Figure 1 shows the mechanical design of the system. To lift up the object, the servo-control ThrusTube[5] motors from Copley Controls Corp. are used as linear actuators or motors, which have excellent performances on high speed and acceleration, reliability and controllability, and

low audible noise. Each motor weighs five lbs and has a built-in position feedback delivering up to 12 micron repeatability. It is mechanically mounted on the ThrusTube guide (Figure 1) with the center of the motor passing through a 3-ft-long with 1.5-inch diameter magnetic rail. When the motor is powered, the coil in the motor will generate an electro-magnetic force of 44 lbs when interacting with the magnetic rail. The speed of each motor can reach up to 15 ft/s. The design uses two parallel magnetic rails, with each rail supports two motors in series. The object mounting plate, which is used to hold the testing object, is bolted directly to the motors. The dimension of the apparatus is 72" high, 15" wide and 15" deep.
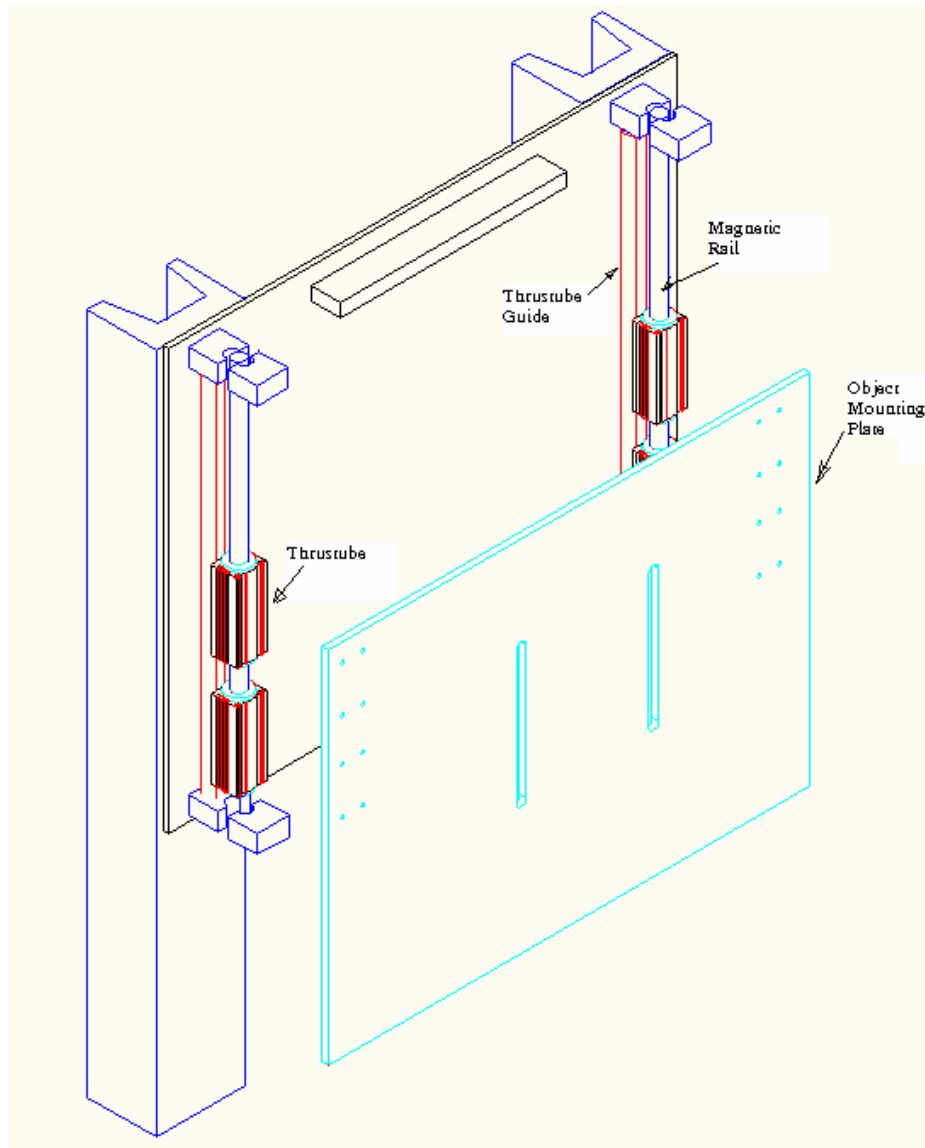
Figure 1: Mechanical Design of the Impact Machine.

To determine the number of linear motors needed for this system, Figure 2 shows a simple free body diagram[1] for the calculation. In this figure, "F" represents the total force created by the linear motors; "a" represents the acceleration of the testing object; W_o represents the weight of

the testing object; "N" represents the number of linear motors and "W_L" represents the weight of each linear motor.

The following two equations can be created:

$$F - (W_o + NW_L) = \left(\frac{W_o + NW_L}{32.2}\right)a \qquad (2)$$

$$F = 44N \qquad (3)$$

Equation (3) is formed because each linear motor can generate 44 lb of external force when the motor is moving at a maximum speed of 15 ft/s. By substituting Equation (3) into Equation (2) and assuming that the upward acceleration is equal to 32.2 ft/s^2, N can be found as 3.58. Therefore four motors are chosen in this design. Because a ball-bearing is used in each motor when moving along the ThrusTube guide, the friction force between motors and guides is ignored.
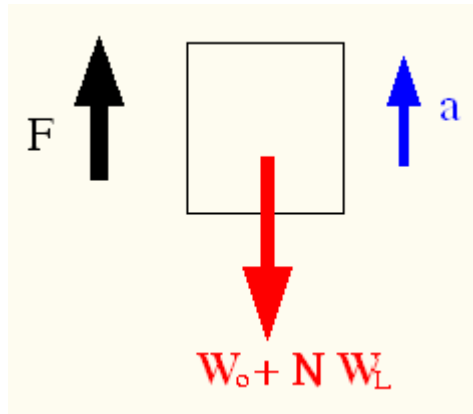
Figure 2: Free Boy Diagram to Calculate the Number of Linear Actuators.

3. Electrical Control

3.1. Flow Chart of the Control System

Figure 3 shows the flow chart of the electrical control. The motion of each motor is controlled by an amplifier, which can store sixteen motion profiles (0 to 15)[6]. A programmer can set up the parameters of each motion profile in an amplifier by using the CME communication software and an RS-232 cable. To choose one of the saved motion profiles in each running, the amplifier reserves four input ports (0 to 3) for this purpose. A PLC program is created to choose the motion profiles. To achieve the goal that the four linear motors must be able to move simultaneously during each action, the four amplifiers must receive the commands sending from the PLC controller[7] at the same instant. Since there are four amplifiers in this system, a PLC

output distribution box (Figure 3) is created for this purpose to distribute the PLC output signals concurrently to the four amplifiers. The green lines sending from the PLC output distribution box to the amplifiers are used to choose the motion profiles defined in each amplifier, which provides the communication with PLC, power supply, and linear motors. As shown in Figure 3, each amplifier uses following connection with the motor: J2 (motor signal to the motors), J3 (motion profile selection from PLC for each running), and J4 (feedback signals from the motor to the amplifier)[6].

3.2. PLC Program

Figure 4 shows a PLC program used to activate two motion files with the first motion set up to lift up the object and second motion to drop down the object. In this case, internal relays M000 and M001 are connected to two Normally-Open push buttons with M000 the "Start" button, and "M001", which is a Normally-Closed relay, the "Stop" button. When the Start button is pressed and released, the system will remain on until the Stop button is pressed[6]. The program control in Rung 2 guarantees that the first motion (linked to the output Q0000 in the PLC program) is always activated first. When the first motion is completed, the second motion (linked to the output Q0001 in the PLC program) is then activated and Q0000 will be deactivated. In this program, Q000 is to activate Motion Profile 1. When Q000 is off and Q001 is on, Motion Profile 2 is chosen. Motion Profile 0 is set to be the initial state where the motor is in its lowest position with system powered on. The motion cycle will be repeated until the Stop button is pressed. The program is created in the PC and can be downloaded to the PLC controller through the use of an RS-232 cable.

### 3.3. Total Traveling Time and Displacement for Each Motion

To set up the traveling time for each motion profile, Figure 5 shows a diagram of velocity vs. time setup in a motion profile. The total traveling distance can also be calculated through this diagram. In this case, calculation the total traveling time is shown as following:

  Accelerating time of the motor: 0.05 seconds.
  Constant-traveling time of the motor: 1 second.
  Decelerating time of the motor: 0.05 seconds.
 **The total traveling time**: 1.1 seconds.

The total traveling distance can be calculated as following:

$$S = \frac{3 X 0.05}{2} + 3X1 + \frac{3 X 0.05}{2} = 3.15 \ ft. \tag{4}$$

The information of the total traveling time will be inputted to the timer set up in the PLC program so that the motion can be completed before the second motion is called. Information of the total traveling distance can be inputted in the motion profile.
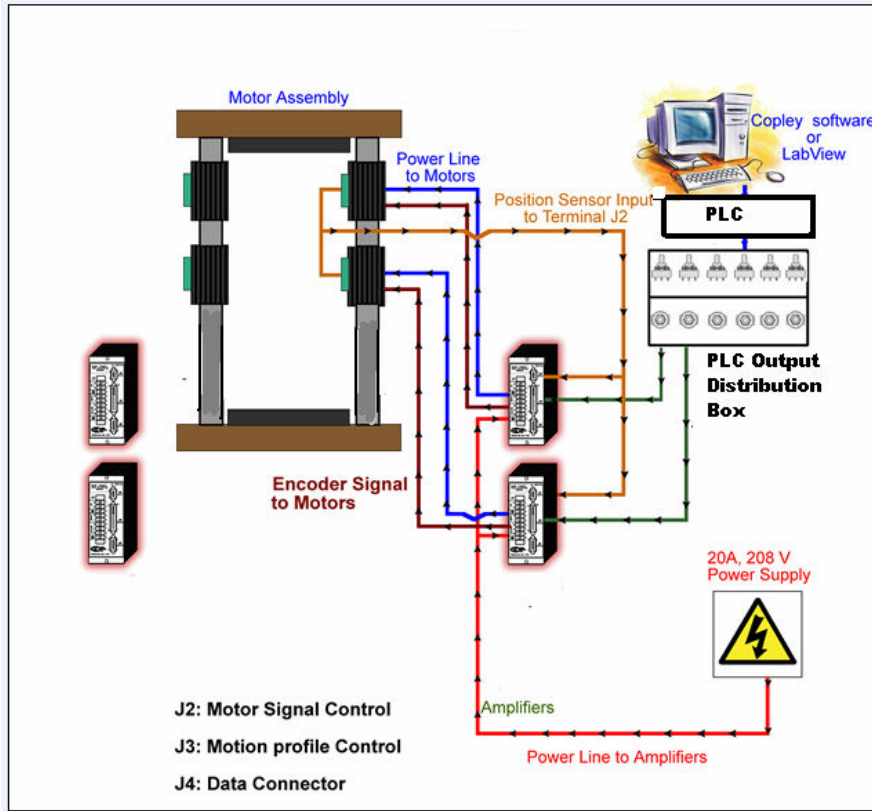
Figure 3: Electrical Control Flow Chart.
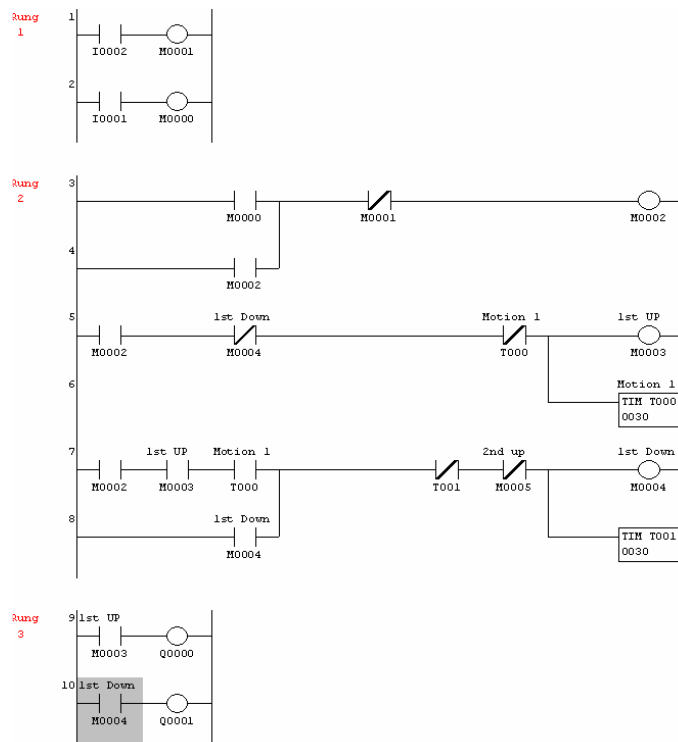
Figure 4: A PLC Program to Control Two Motions Sequentially and Repeatedly
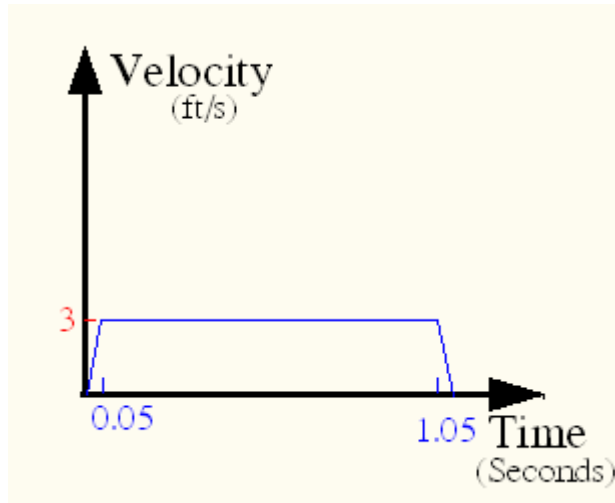
Figure 5: Velocity vs. Time Diagram for the Moving Object.

4. Data-Acquisition Programming

Figure 6 shows the flow chart of the data acquisition control. The sensor used in this impact test is an accelerometer, which is mounted on the testing object. The output signal from the device is sent to an NI USB 6251[8] data acquisition system with the pin connection shown in Figure 7. It shows that the device has sixteen analog inputs to take the output signals from the accelerometer[9]. To read the signal from the accelerometer, the "Measurement & Automation Explorer" in the NI USB 3251 must be activated. The sampling rate of the sensor can reach up to 600 Hz. A LabVIEW program downloaded to the PC is to read the analog signals, expressed in voltages, from the accelerometer and convert them to the number of Gs. Figure 8 shows one of the results obtained from the tests.
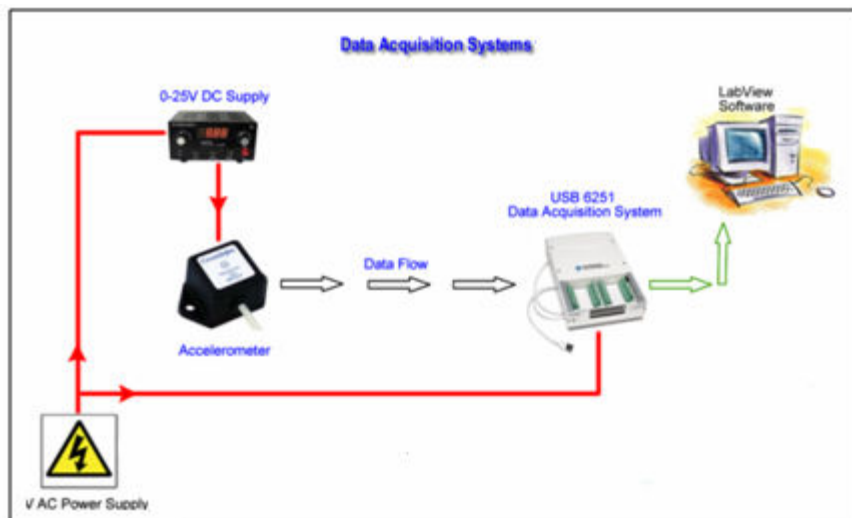
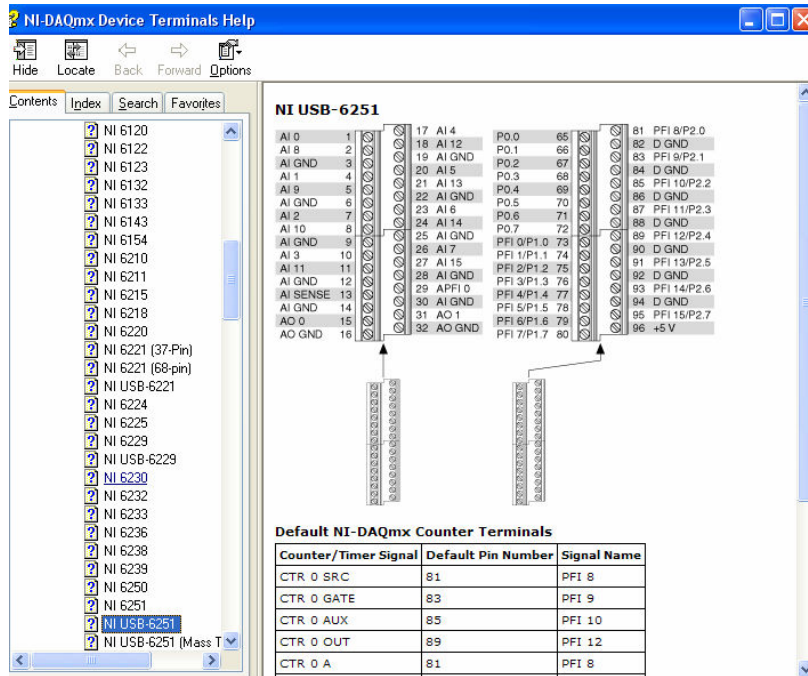**Figure 6:** Flow Chart of Data Acquisition System.

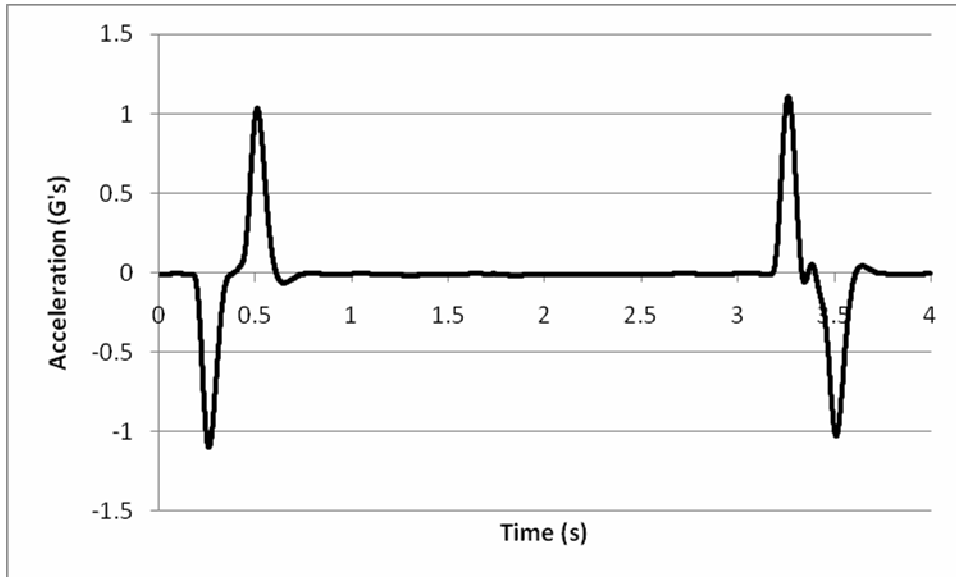**Figure 7:** NI USB 6251 Pin-connection diagram.

**Figure 8:** Output of Gs from LabVIEW Program.

5. Implementation and Tests

The following steps are applied to implement the system:

(1) Install Copley Motion controller software in the PC and store motion profiles at each amplifier through the use of an RS 232 cable between PC and amplifier.

(2) Create a PLC program in the PC.
(3) Download the PLC program from PC to PLC controller.
(4) Make sure that the bearings of the ThrusTubes do not make any uneven resistance when moving the motors up and down manually. If the problem occurs, some adjustments will have to be taken.
(5) Electrically wire and test for the PLC output distribution box.
(6) Electrically wire and test the outputs from the PLC to the inputs of the PLC output distribution box.
(7) Power on the whole system.
(8) Test the motion of each individual ThrusTube and make sure the correct motion profile is selected.
(9) Activate the LabVIEW program for the accelerometer.
(10) Press the Start button on the PLC to start the testing.
(11) Press the Stop button when testing is completed.
(12) Deactivate the LabVIEW program.

Figure 9 shows the fabrication of the machine and the testing a knee brace[10], which can be used to reduce the impact force for a person when jumping from a certain height. After several running tests and adjustments, the machine is running consistently and repeatedly. Figure 10 shows that the impact motion can generate approximately 11.9 Gs.
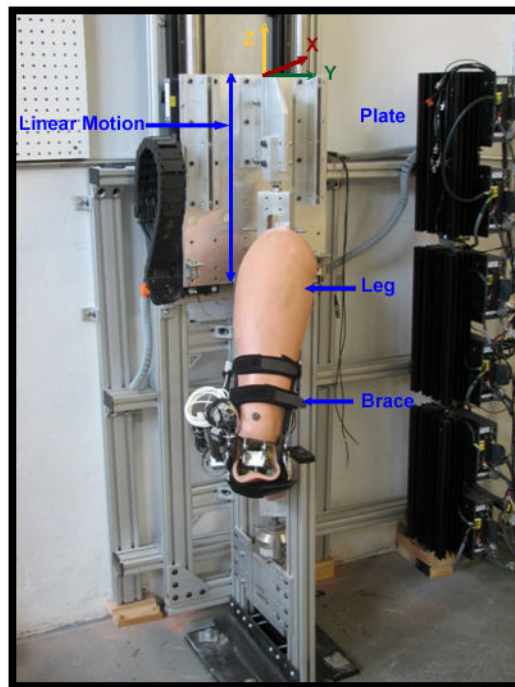
Figure 9: Knee Brace Test on the Impact Machine.
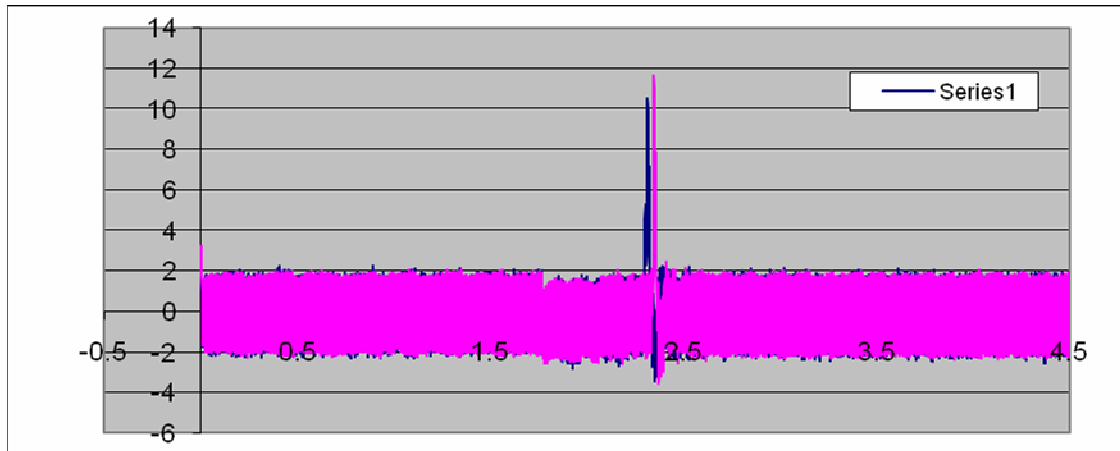
Figure 10: Maximum of 12 Gs recorded in this reading.

6. Summary

Students can gain the following practical experiences when developing the system:

(1) Dynamic analysis of the mechanical system.

(2) Assembly magnetic parts (of the magnetic rails.)

(3) Align the motion between the object mounting plate and ThrusTubes' bearing guide.

(4) Set up motion profiles in the amplifier.

(5) Create PLC programs to choose motion profiles with timers.

(6) Wire the PLC distribution box.

(7) Wire from PLC outputs to the PLC distribution box.

(8) Wire and program data acquisition system.

The machine developed in this project is only a 1-DOF machine. Therefore, the size of the testing object and machine's lifting capacity are very limited. To solve this problem, the next stage of the development is to build a large 6-DOF Stewart Simulator.

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