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## **AC 2011-663: REACTIVATION OF A SIX-DEGREE-OF-FREEDOM REPEATED IMPACT MACHINE USING PROGRAMMABLE LOGICAL CONTROLLER (PLC)**

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# Reactivation of a Six-Degree-of-Freedom Repeated Impact Machine Using Programmable Logical Controller (PLC)

## Abstract

Reactivation of a six-degree-of-freedom impact machine using Programmable Logical Control (PLC) is presented. The output from the machine is the history of accelerations collected from accelerometers attached at the testing article and a load cell mounted at the rubber pad where the impact occurs. Readings of the acceleration and impact force are sent to a PC for analysis through a data acquisition device (USB 6251) and Labview software provided by National Instrument (NI). Result shows that the machine can repeatedly generate an impact force up to eleven Gs. Demonstration of the project can be used as one of labs in the courses of Automation and Controls and Introduction to Robotics.

## 1. Introduction

The course of Automation and Controls offered in the Mechanical Engineering Technology Program has the objective of teaching students:

- (1) Pneumatic components and pneumatic circuit designs.
- (2) Feedbacks from electrical sensors and related ladder diagrams.
- (3) Introduction to Programmable Logical Controllers (PLC) and PLC<sup>1</sup> programs.
- (4) Integration of pneumatic, electrical, and/or hydraulic components with PLC programs.

To let students have hands-on applications in this course, a two-hour/week lab is also offered to train the students to integrate mechanical, pneumatic, and electrical components with ladder diagrams or PLC programs. The lab basically includes three main sessions: (1) four weeks of pneumatic applications, (2) four weeks of pneumatic components, electrical sensors, and ladder diagrams, and (3) five weeks of PLC programming using IDEC<sup>2</sup>, TRiLOGI<sup>3</sup>, and Allen Bradley<sup>4</sup> PLCs.

This project presents a control scheme using PLC programming to reactivate a repeated six-degree-of-freedom impact machine which is a gift from a government department. Impact is defined as 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. The following impact-force equation can be used to illustrate the physical situation<sup>5</sup>.

$$F = m \frac{\Delta V}{\Delta t} \quad (1)$$

Where  $F$  represents the impact force;  $m$  represents the mass of the object;  $\Delta V$  represents the velocity change between the initial velocity and the velocity after impact;  $\Delta t$  represents the impact time, which is very small when an 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), the impact force can be greatly reduced when  $\Delta t$  increases. This can be achieved through the design of a soft contact during the impact. An impact machine can generate impact motions to test the performance of the impact absorbing device. Repeated-impact machine can be applied in the testing of biomechanical devices or electronic equipments when operated in the repeated impact environment, such as various sea-state motions, electronic equipments on a boat, and nailing task motions<sup>6</sup>, etc. Outputs of the system are the impact Gs from all six degrees of freedom including three translations (X, Y, and Z) and three orientations (roll, pitch, and yaw)<sup>7</sup>.

Figure 1 shows the machine before it was transported to the department. The apparatus is made of six magnetic rails which are connected with a triangular platform, with each rail supports four linear thrust tubes connected in series. The motion of each thrust tube is powered and controlled by an individual industrial amplifier which can store sixteen pre-set motion profiles. When the machine was just arrived, the department faculty had difficulty running the machine, as the original multi-axis controller was missing. Reactivation of the machine is important because several research projects for electronic equipment and devices installed on boats are waiting for the machine to perform the testing. To save the reactivation cost without using expensive multi-axis motion controller, a PLC controller is applied and demonstrated in this paper.



**Figure 1:** The 6-DOF Machine at the Original Site.

## 2. Linear Thrust Tubes

The servo-control ThrusTube<sup>8</sup> 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 2) with the center of the motor passing through a six-ft-long and 1.5-inch diameter magnetic rail. When the motor is powered, the coil in the motor can generate an electro-magnetic force of 44 lbs with the speed can reach up to 15 ft/s. Each arm is equipped with four ThrusTube motors.



**Figure 2:** The Linear ThrusTube Mounted on the Rail

## 3. Amplifiers for Thrust Tubes

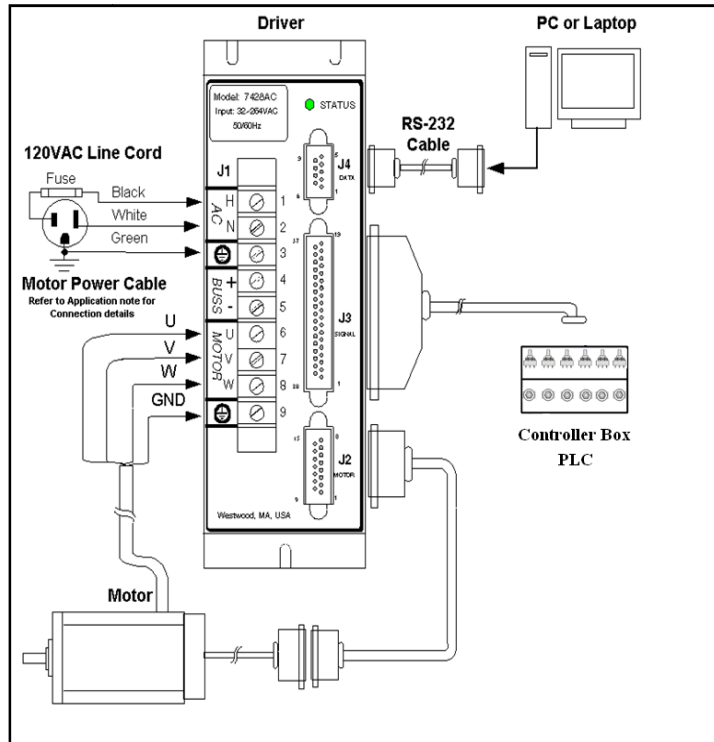
An amplifier is used to control the motion of each ThrusTube. Figure 3 shows the connection of the amplifier. When it receives signals through the J3 connection with a PC, it performs the following tasks:

- a. Offers sixteen motion profiles which were stored through a RS-232 cable with a PC.
- b. Receives the command from the main program to choose one of the sixteen motion profiles for the motion. Figure 4 shows an example of setting up a motion profile for a typical trapezoid velocity control. In this case, the PLC program serves as the main program to choose the desired motion profile.
- c. Provides the power for the motor with an encoder feedback and temperature monitoring during the motion.

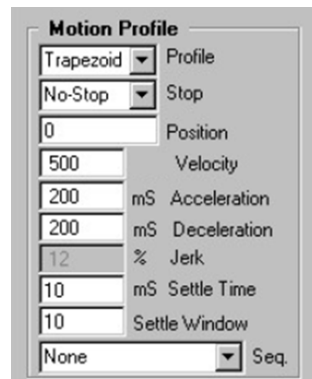
#### 4. Control Processes

Figure 5 shows the control processes of reactivating the machine by using the following steps:

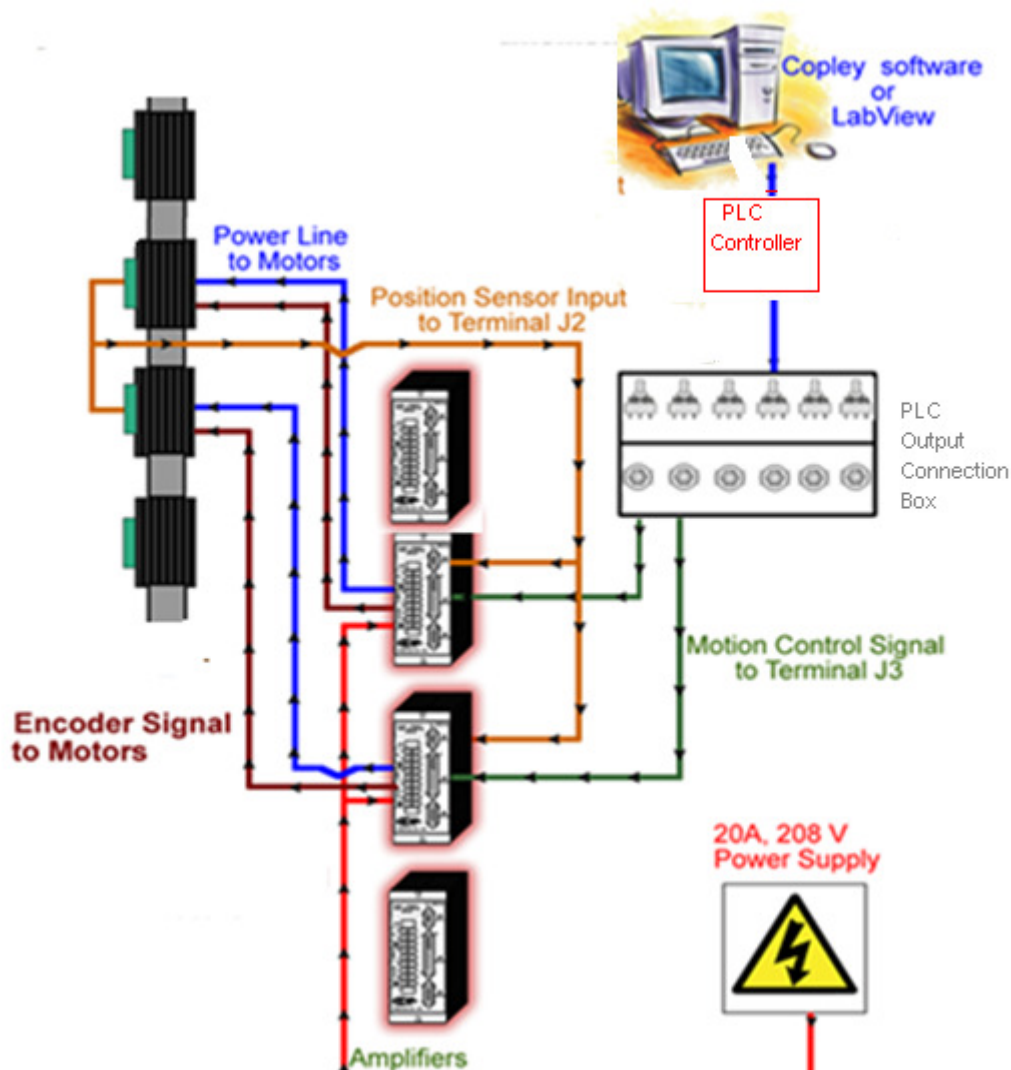
- a. Power on the amplifiers.
- b. Connect amplifiers with a PC through a RS-232 cable.



**Figure 3:** The Amplifier Connection



**Figure 4:** An Example of a Motion Parameter Setup

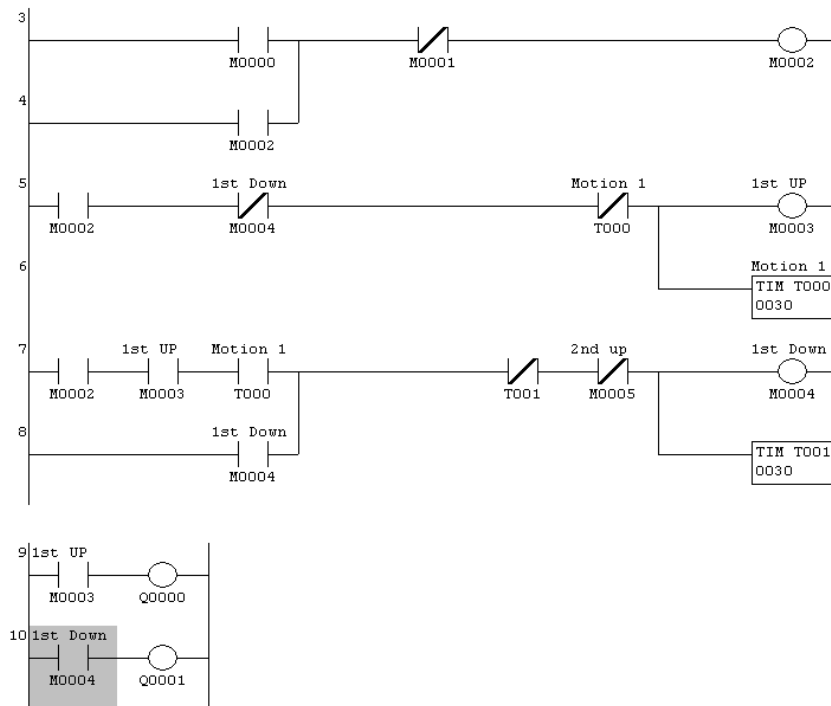


**Figure 5:** Flow Chart of the Control System.

- c. Set up sixteen profiles for each amplifier. Since four amplifiers (and motors) are used in one arm or in a group, they must store the same motion profiles.
- d. Write PLC programs which will choose one of the sixteen motion profiles for each movement of the arm. Figure 6 shows a simple program for an up-and-down motion. The traveling time is set at three seconds for both motions. The machine will move up (Q0 in Figure 6) first and then after three seconds, it will be moving down (Q1 in Figure 6). The motion will be automatically repeated until a reset button is pressed. Figure 7 shows a PLC program to control nine motion profiles in sequence. Therefore, four outputs (Q0, Q1, Q2, and Q3) are required. Again, the motion will repeat automatically until a reset

button is pressed. The traveling time for each motion was set at three seconds or 4.5 seconds depending on the traveling time at each motion profile.

- e. A PLC Output Connection Box, shown in Figure 5, was made to transmit the signals from the PLC (Outputs Q0 to Q3) to the twenty four amplifiers. Example of the circuit wiring from PLC Output Q<sub>0</sub> to the J3 pin connection of each amplifier is shown in Figure 8.
- f. The amplifier will send a signal and the power to activate each linear ThrusTube, according to the setup of the motion parameters.



**Figure 6:** A Simple Up-And-Down Motion.

## 5. Data-Acquisition Programming

Figure 9 shows the flow chart of the data acquisition control. The sensor used in this impact test is an accelerometer<sup>9</sup> mounted on the testing object. The output signal from the device is sent to an NI USB 6251<sup>10</sup> data acquisition system which has sixteen analog inputs to take the output signals from the accelerometer. To read the signal from the accelerometer, the “Measurement & Automation Explorer” in the NI USB 6251 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 10 shows that an 11.5 Gs can be achieved from the tests.



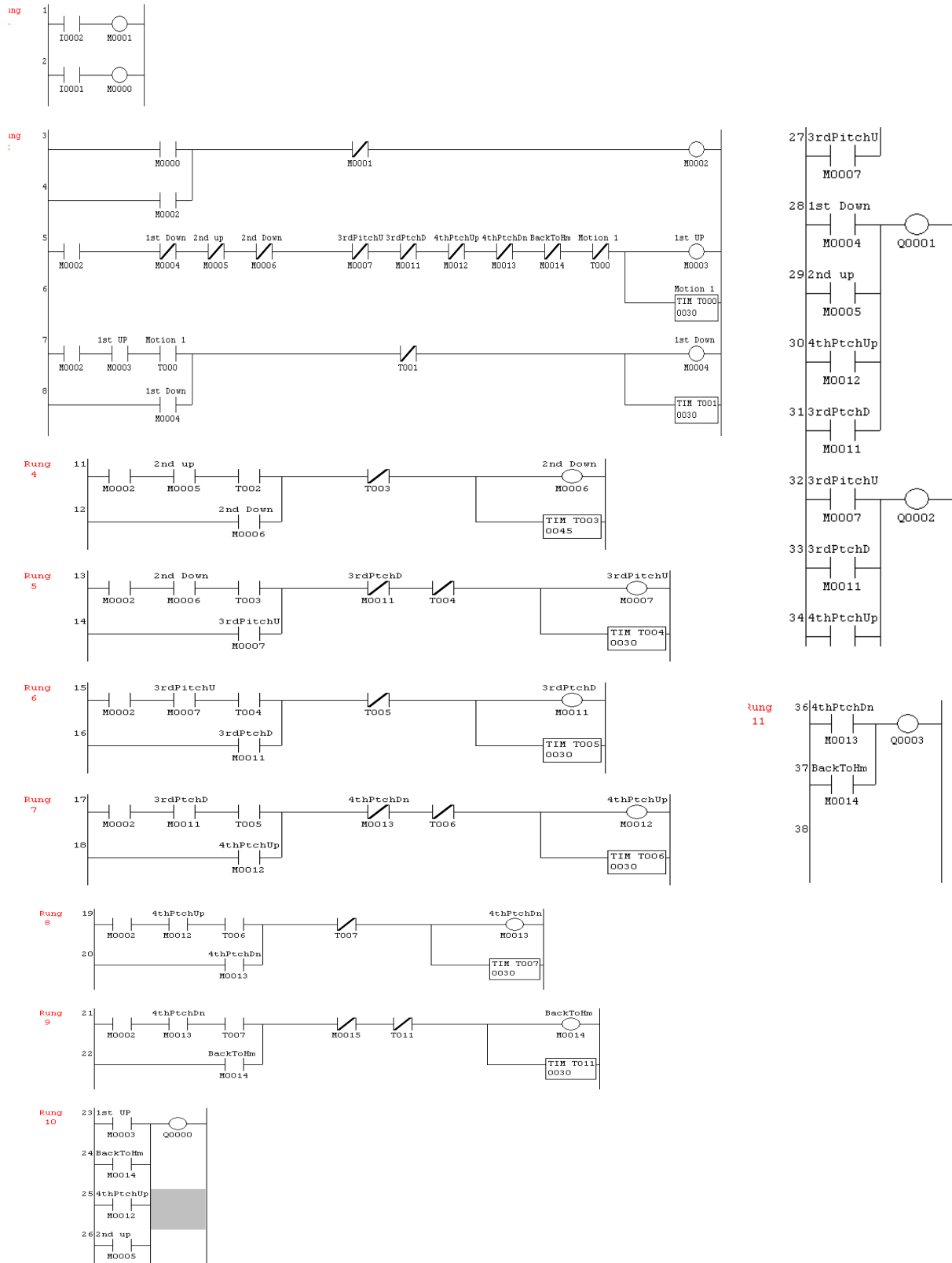
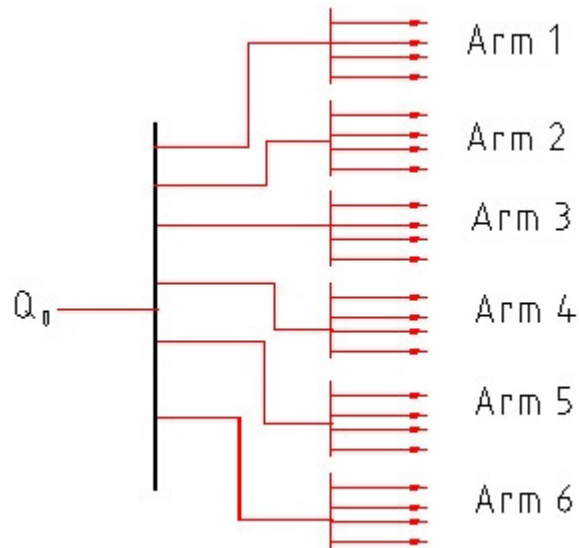
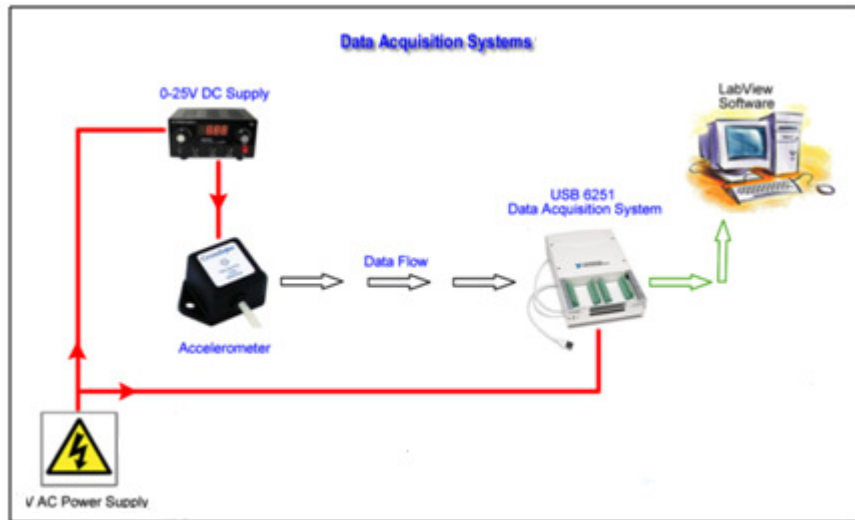


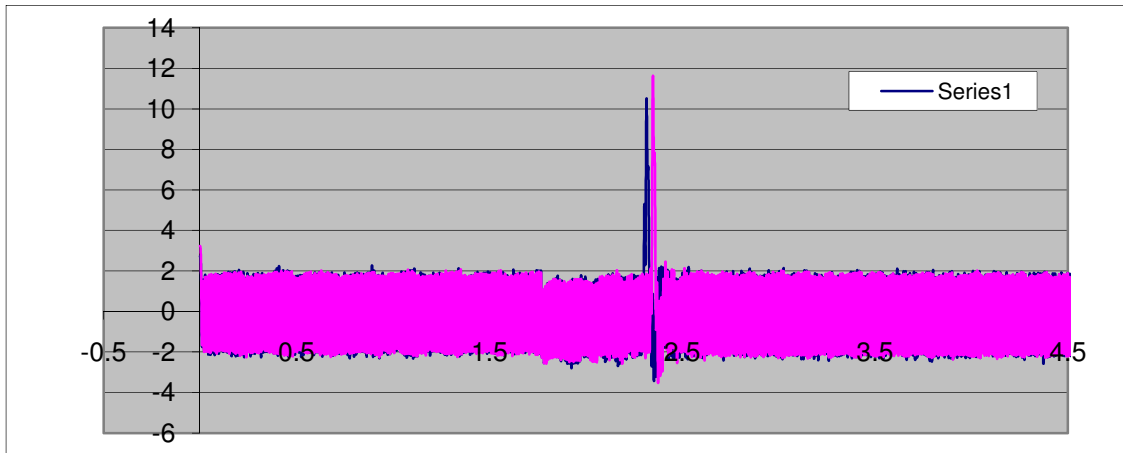
Figure 7: The PLC Program for the Control of Nine Motions.



**Figure 8:** Circuit Wiring from PLC Output  $Q_0$  to the J3 Connection of Each Amplifier.



**Figure 9:** The Flow Chart of Data Acquisition System



**Figure 10:** An 11 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) Set up motion profiles in each amplifier.
- (3) Create PLC programs to choose impact motions.
- (4) Wiring experience for PLC Output Connection Box and J3 connection located at each amplifier.
- (5) Wiring accelerometers and NI Labview programming for data analysis.

The machine can generate various waving motions including up and down, roll, and pitch. In addition to research projects, the machine is also used as a demonstration in automation control and robotic classes.

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