MICROCOMPUTER BASED INSTRUMENTATION

FOR STUDENT DESIGNED WHEEL BALANCING MACHINE

Emin Yilmaz
Department of Technology
University of Maryland Eastern Shore
Princess Anne, MD 21853

Abstract

Wheel Balancing Machine was a design project for the Mechanical Systems Design course for Mechanical Engineering Technology students. A group of students worked on designing and manufacturing it. The machine consists of a frame, an electric motor, a belt driven shaft, an anchoring system to attach the wheel to the shaft, and associated instrumentation.

The goal of instrumentation is to (a). measure the amount of the force caused by the non-uniform distribution of wheel mass, (b). convert it to an equivalent counterweight to be placed on the wheel rim to balance the wheel and (c). identify the angular position on the rim where to place the weight. A shaft encoder is used for measuring the angular position and an accelerometer is used to measure the angular acceleration due to unbalance force on the wheel. Measured acceleration is, then, converted to unbalance force by the software.

A microcomputer with data acquisition system is used to simultaneously acquire both signals, calculate the angular position of the counterweight to be placed on the rim and calculate the amount of the counterweight to be used to balance the wheel. Data acquisition system consists of a Data Translation DT2805, 12 bit, multi purpose, 16 channel, low level signal data acquisition board and ASYST Data Acquisition, Analysis and Display Software. Although not implemented yet, the computer shall be able to start the wheel balancing machine, take the measurements, do the calculations, and stop the wheel. Angular position is displayed continuously after the dynamic data is acquired. Angular position reading is used to position the wheel manually to attach the counterbalance weight at the computer calculated position on the rim.

Although programming of data acquisition and saving the acquired data with LabTech/Control was easier, accomplishing calculations and other tasks fast enough turned out to be impossible due to processing speed limitations of the software.

The purpose of this paper is to give readers an overview of the instrumentation that we used and convey the experiences that we had for the student designed and constructed wheel balancing machine. Advantages and disadvantages of Graphical User Interface based Data Acquisition programs, like LabTech/Control shall be discussed. Other uses of the Microcomputer Based Instrumentation in other courses shall be summarized.

Introduction

Our data acquisition system consists of an IBM-AT compatible computer, two plug-in type data acquisition cards and two different data acquisition software. The basic system was purchased in 1989 using a National Science Foundation grant for improvement of our Materials Testing Laboratory[1]. Since then the computer was upgraded, one additional card and a software was purchased. Use of the system was also extended to several laboratory experiments in one another course[2], student design projects and research experiments[3].

Hardware and Software for the Data Acquisition System

What type of system and which hardware and software to use for a Data Acquisition System is a big decision and is covered elsewhere[4]. Our system consists of a TDK 486-33 computer, a Data Translation[5] DT2805, low level, 12 bit data acquisition board, a Cyber Research[6] DAS1601, low level, 12 bit data acquisition board, ASYST software[7], and LabTech/Control software[8]. Specifications for Data Acquisition Boards is given in Table 1. DT2805 board has a DT707 screw terminal box which can support thermocouple inputs with a reference junction occupying analog input channel "0". Two screw terminal connectors are required for DAS1601 board. One screw terminal is attached to the board's Analog to Digital(ADC)/ Digital to Analog(DAC) connector, and the other one is attached to the board's Input/ Output(I/O) ports connector. Throughput speeds with single channel input on DT2805 and DAS1601 are up to 6 KHz and 100 KHz respectively. ADC inputs on DAS1601 can be configured as single or differential inputs. DT2805 has differential ADC inputs only. The gains on the boards can be set by software for each channel. Major specifications for the boards are given in Table 1.

Table 1. Major Technical Specifications for Data Acquisition Boards

Board	Resolution ADC/DAC	ADC Channels Diffe./Single	# of DAC Channels	Programmable Gains	I/O bits Port0/Port1
DT2805	12/12	8/-	2	1,10,100,500	8/8
DAS1601	12/12	8/16	2	1,..,100,500	8/-

ASYST and LabTech/Control are used for data acquisition, analysis and display. ASYST is a DOS based program. It was purchased in 1989. LabTech/Control was purchased in 1994. It was available in Windows and DOS versions. Since the Windows version loaded very slowly and we had problems in switching the drivers for two cards that we own, we purchased DOS version. ASYST is a high level programming language. Although it is very flexible, learning a new programming language is a time consuming job.

LabTech/Control (LT/C) is a graphical user interface(GUI) based program. In the LT/C user drags a few icons to prepare a flow chart for data acquisition, storage, control, analysis and display. GUI (graphics or Icon) based software programs are very easy to learn, thus, more time may be spent on measurements rather than programming. However, LTC is very slow when the analysis and display functions are used. With 4 icons on the screen (analog input, digital input, external trigger and file storage), at "normal speed", the maximum acquisition rate is about 1500 Hz. "High speed" mode of LTC does not support any simultaneous analysis and display functions. Therefore, it cannot be used for most high speed applications. It's 1500 Hz (1500 samples per second) data acquisition rate at "normal speed" mode is well below Wheel Balancing Machine requirements of about 7200 Hz.

Wheel Balancing Machine Project

Students in The Mechanical Engineering Technology program are required to take at least one Systems Design course during the last year of their program. As part of the requirement for this course, students are assigned to design a system or systems that require use of knowledge that they have acquired in lower level courses. Sometimes they are assigned a group project if the project is large enough.

The Wheel Balancing Machine project was assigned to one student about two years ago. But since it required manufacturing and we ran into some technical difficulties, it turned out to be a long project. During last two years three additional students worked on it to complete the project. The first student designed the project and did some manufacturing. The second student completed the manufacturing. The last two students worked on the instrumentation. I did most of the computer programming work using LabTech/Control and ASYST software. I shall need one more student to remanufacture parts of the system to closer tolerances to improve the accuracy of measurements to conclude the project. I am hoping that at the end of Spring 1998 semester we shall have an accurate wheel balancing machine in operation.

Wheel Balancing Machine Instrumentation

The machine consist of a shaft driven by a ½ hp, 1725 rpm electric motor at about 600 rpm. The wheel is attached to the end of the shaft. An accelerometer, attached to the machine frame is used to measure the unbalance force in the wheel. A brush type encoder attached to the shaft and the frame is used to measure the location of the unbalance force in the wheel. A photo interrupter is used to trigger the acquisition of accelerometer signal and is used as a reference point for the wheel. A schematic diagram of the instrumentation is given in Fig. 1.

The accelerometer is attached to the frame of the machine to indirectly measure acceleration due to unbalance in the tire as tire rotates at about 600 rpm(10 rev/sec). Accelerometer output signal can be related to the counterbalance weight to be placed at the rim radius by:

$$m = (a*M)/(w*w*R) \qquad (1)$$

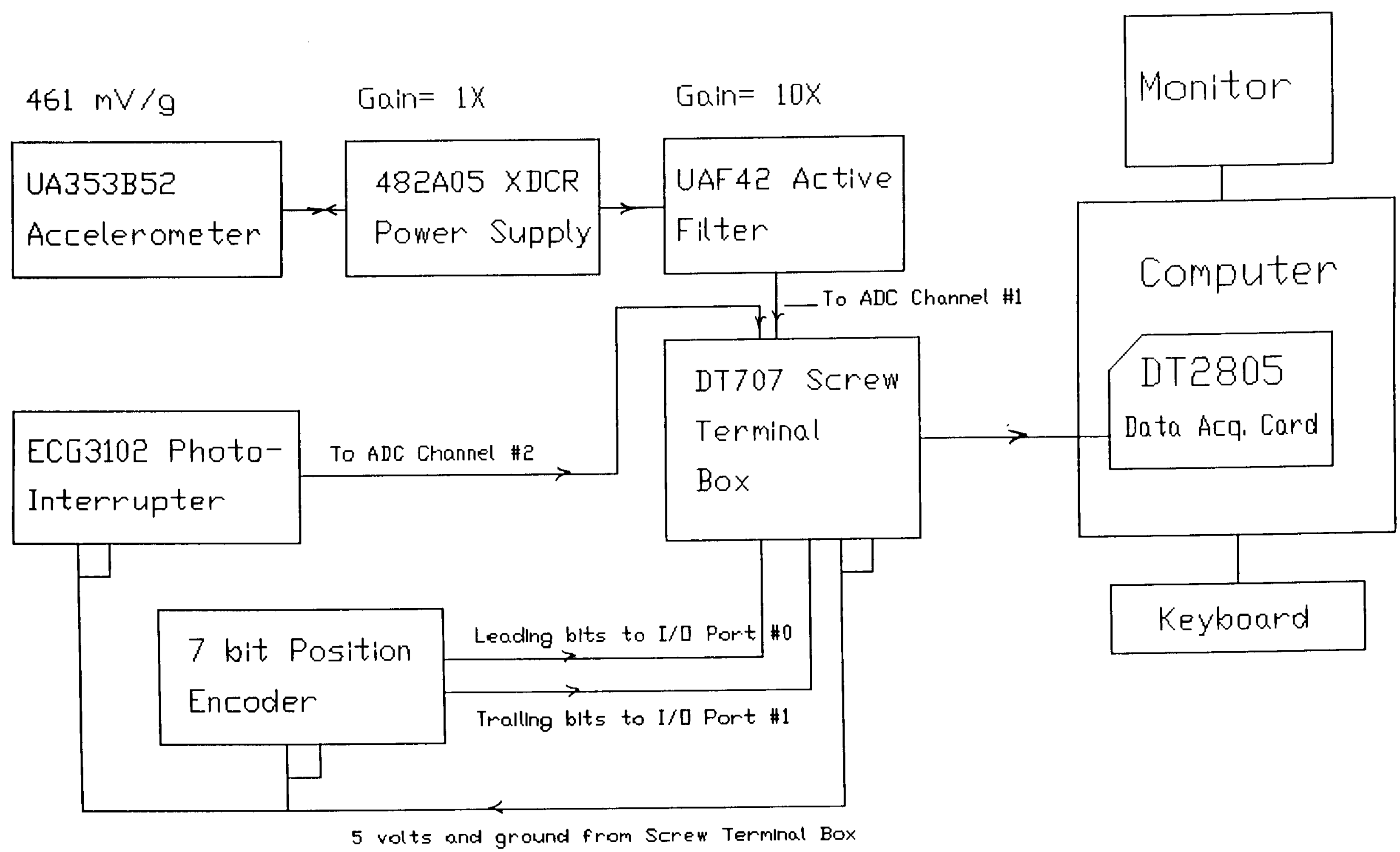

Figure 1. Schematic Diagram of Wheel Balancing Machine Instrumentation

where

m = counterbalance weight
a = measured acceleration
M = Total weight of the system
w = angular velocity of wheel
R = rim radius at which mass "m" is placed

Accelerometer output voltage can be found by:

$$V = A*S*a \qquad (2)$$

where

A = total amplification of accelerometer signal
S = sensitivity of accelerometer (usually in mV/g)
g = standard gravitational acceleration

Using equation (2) in equation (1) one obtains:

$$m = (V*M)/(A*S*w*w*R) \qquad (3)$$

As seen in equation (3), since "w", "A", "M", and "S" are constants, "m" is directly proportional to "V" and inversely proportional to "R". Therefore, one can calibrate the system by placing a known unbalance weight at the rims of different sizes of balanced wheels and measuring the output signal in volts for each of them. Thus

$$m = K*V \qquad (4)$$

where

K = calibration constant for a balanced wheel of rim size R.

Technical specifications for the PCB[9] accelerometer used for the wheel balancing machine is given in Table 2.

Table 2. Technical Specifications for PCB Accelerometer

Model No	: U353B52
Sensitivity	: 461 mV/g
Natural frequency	: 16.5 kHz
Range	: 10g
Resolution	: 0.0004g
Frequency Response	: 10Hz - 1kHz ~flat

An active filter is used to filter the noise. The filter amplifies the signal 10 times and it was designed using Burr-Brown UAF42 integrated filter circuit. Schematic diagram of the designed filter is given in Fig.2.

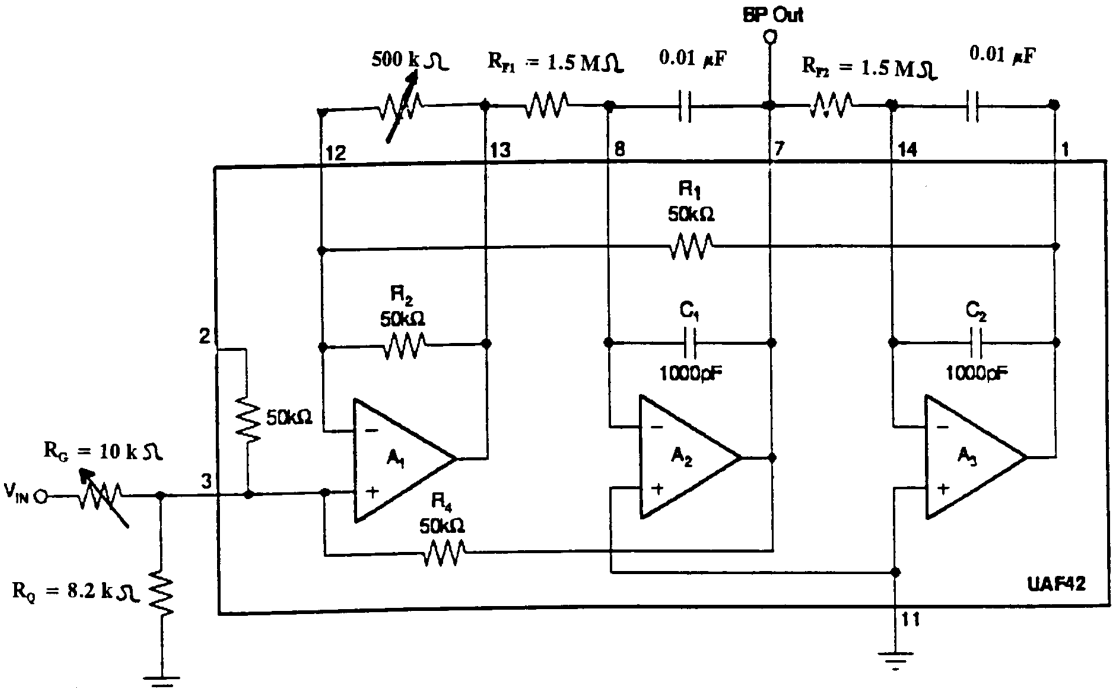

Fig. 2. Schematic Diagram of UAF 42 Active Band Pass Filter

For a 14 inch wheel, equation (3) gives a calculated sensitivity of 14.4 mV/oz for our system (R=7.5 in, M=150 lbs, N=593.5rpm, w=62.15 rad/s, S=461mV/g). Since commercial wheel balancing machines are sensitive to about 0.25 oz, our system should be capable of detecting 3.6mV output or an acceleration of about 0.008g to match the sensitivity of the commercial machines. Table 2 indicates that we have 20 (=0.008/0.0004) times more sensitive transducer.

The DT2805 data acquisition board amplifies the incoming signal from the filter by a factor of 10. Therefore, the actual accelerometer signal is amplified by a total factor of 100.

To be able to measure the angular position within one degree resolution, a data acquisition rate of 3600 Hz (=360 deg/rev * 600 rev/min / 60 sec/min) is required. Since two channels are used, required throughput rate of the system has to be at least 7200 Hz. Since LabTech/Control could not support this rate at "normal speed" mode, ASYST software was used. Signals were sampled at intervals of 0.14041 msec [=60/(593.5*360*2)]. This is equivalent to acquiring data every one degree of revolution of the wheel. Computer acquires accelerometer signal first then it acquires reference signal(half a degree later). Reference signal is used to trigger the start of acquisition to synchronize the accelerometer signal with wheel reference point (=angular position at zero degrees).

A reference or trigger voltage is generated by an ECG-3102 photo interrupter module and a 10 cm diameter, 1 mm thick opaque plexiglass slotted wheel. The slotted wheel is connected to the wheel shaft. The photo interrupter module is attached to the frame and consists of a light emitting diode (LED) and a photo transistor. When the slot of the wheel is aligned with the LED and the photo transistor, LED light is received by the photo transistor to generate a negative pulse. The circuit diagram of the trigger voltage generator(photo interrupter) is given in Fig. 3.

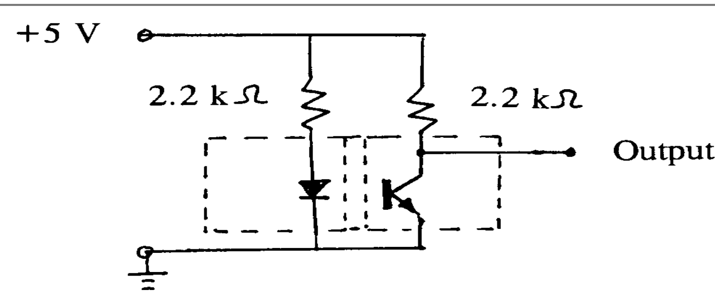

Figure 3. Schematic Diagram of ECG-3102 Photo Interrupter Circuit

After acquiring the data, the computer calculates the mass of the counter weight to be placed on the wheel and it's location. The calculated counter weight value and the position is displayed in DEGREES/OUNCES window on the screen. At this time continuous reading of the wheel reference position is enabled and is displayed in the DEGREES/NUMBER window on the screen. When the wheel is stopped, the operator positions the wheel to the angle value shown in the DEGREES/OUNCES window by rotating it with hand and attaches the indicated weight to the rim at 90 degrees position. The screen display of ASYST program for the Wheel Balancing Machine is given in Fig.4.

The Locheed Martin Librascope[10] model 713-20-7 digital position encoder is of V-Scan type. V-Scan is an encoder interpolation method. The term V-Scan is derived from the geometric placement of the sensors which resembles a "V". The encoder consists of two sensors per bit. The least significant bit has only one sensor. To prevent ambiguity in decoding, the state of a bit is determined by the state of the next lower significant bit on the other channel. ASYST program reads both channels, 7 bits each, and decodes it into a correct binary number. The binary number is converted to its equivalent decimal value and is displayed as a decimal value and as an angular position. Resolution of a 7-bit encoder is 2.8125 (=360/128) degrees. The

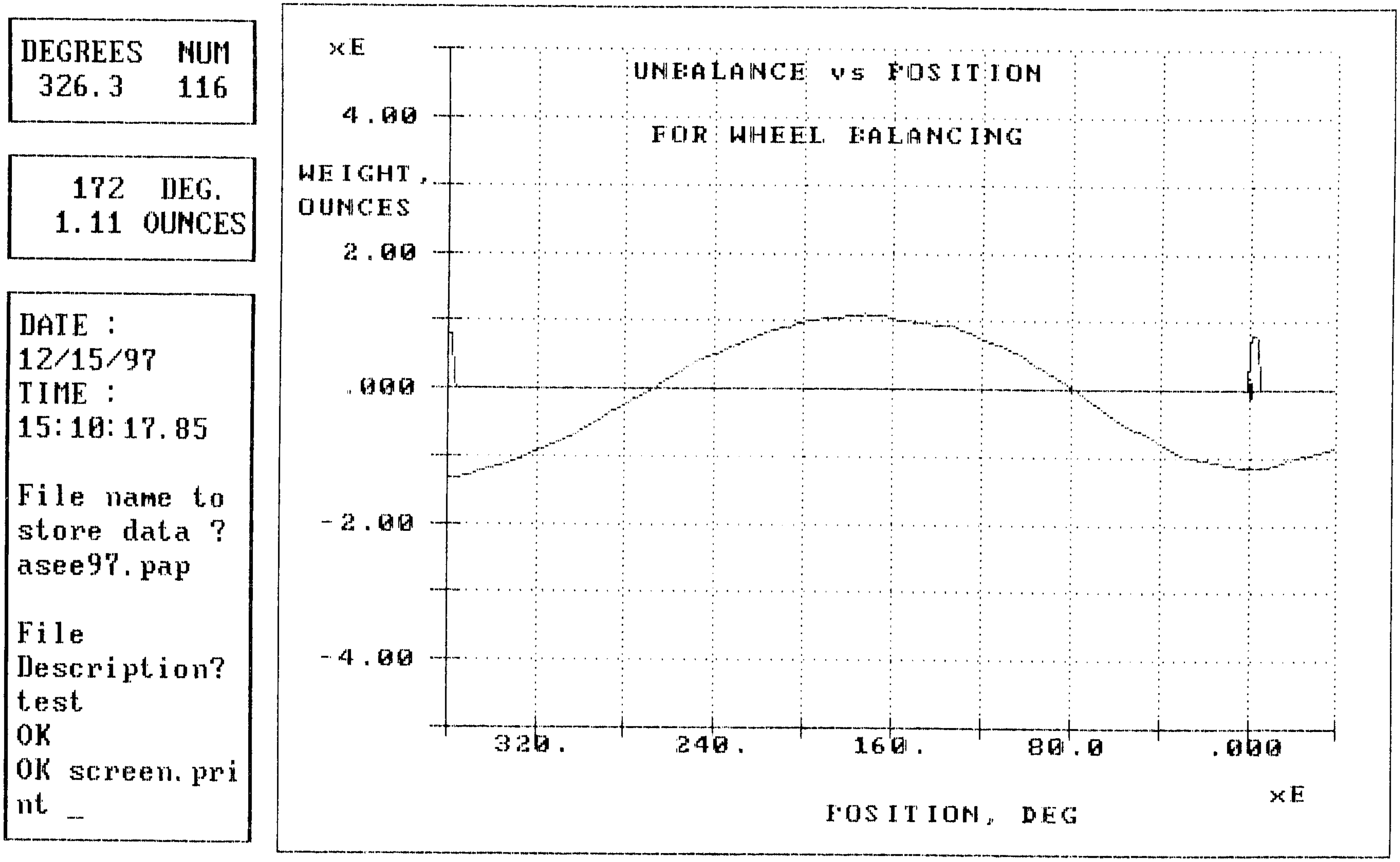

Figure 4. Screen Display of Wheel Balancing Machine ASYST Program

necessary voltage to the encoder is supplied by the data acquisition board screw terminal through an installed 5 volt voltage regulator. A small PC board was constructed and installed near the encoder to provide necessary pull down resistors for the data acquisition I/O inputs. Only 7 bits out of 8 bits of each I/O port is used for the encoder. The two remaining bits shall be utilized at a later date to switch off the electric motor and apply a magnetic brake to the shaft to stop the wheel.

Wheel Balancing Machine Data Acquisition and Programming

As mentioned above the ASYST software and DT2805 data acquisition board with DT707 screw terminal board are used for this project. The screw terminal board was previously placed in an aluminum box. The aluminum box provides two 25 pin computer connectors for portability. A female connector is used for digital I/O and a male 25 pin connector is used for rest of the board's functions. The 5 volt voltage from the voltage regulator is available on the digital I/O connector. A relay contact output is available from the analog 25-pin connector. Two analog signals and two seven bit digital signals are fed to the board from the wheel balancing machine. The 5 volts voltage is supplied to the machine from the box for the encoder as well as for the reference signal generator (photo interrupter).

ASYST software is used to acquire two analog voltages and two sets of 7-bit digital voltages. Calculations are done by the software and results are displayed. Information can be stored in a file and displayed at a later time. The computer program is not included with this paper due to space limitations. When the word "MENU" is typed, the program displays short instructions on how to set up the machine and start the acquisition.

Conclusions

The importance of laboratory experiences for students can not be overstated. Laboratory work provides them with direct experiences of testing various physical principles. It also provides experiences in handling equipment and training in experimental sciences which is necessary for them to ultimately carry out experiments and measurements themselves. Such experiences are provided by scheduled experiments in several courses and through design projects and Independent Study research projects. In four of the scheduled experiments, the data acquisition system is being used to give students additional hands on experience and information on modern ways of acquiring, analyzing and displaying the data. The student's understanding of the concepts and the theory is substantially enhanced by involving them in experiments and showing them the real equipment with all controls in operation. In general, use of the data acquisition system is always welcomed.

Although we had some technical problems with the wheel balancing machine, students liked dealing and solving these technical difficulties. I am hoping that next student working on it next spring semester shall be able to solve the remaining minor problems and improve the accuracy of measurements.

References

1. EMIN YILMAZ, "Upgrading of an Undergraduate Materials Testing Laboratory", ASEE Proceedings, 1990 Annual Conference, p.678.

2. EMIN YILMAZ, "Use of Data Acquisition System in Mechanical Engineering Technology", Computers in Education Journal, Vol.4, No. 2, April-June 1994, p.10-15.

3. EMIN YILMAZ, "Use of LabTech/Control in Microcomputer Based Instrumentation, 1997 ASEE Proceedings, CDROM, Session No: 1426.

4. EMIN YILMAZ, "How to Select Hardware and Software in Microcomputer Based Instrumentation", 1995 ASEE Proceedings, Session No: 2520.

5. Data Translation, 100 Locke Drive, Marlboro, MA 01752-8528.

6. Cyber Research, Inc., 25 Business Park Drive, Branford, CT 06405

7. ASYST, Data Acquisition, Analysis and Graphics Software. ASYST Software Technologies, Inc., Rochester, New York, 1988.

8. LabTech, 400 Research Drive, Wilmington, MA 01887.

9. PCB Piezotronics, Inc. 3425 Walden Avenue, Depew, NY 14043-2495

10. Locheed Martin Librascope, 811 Sonora Avenue, Glendale, CA 91201-2433.

EMIN YILMAZ

Emin Yilmaz is an Associate Professor of Engineering Technology at the University of Maryland Eastern Shore. He has M.S. and B.S. degrees in Mechanical Engineering and a Ph.D. degree from the University of Michigan in Nuclear Engineering. He is a heavy user of both micro and main frame computers in courses and in his research. He developed and taught several laboratory courses in engineering and engineering technology. You may contact him by telephone (410-651-6470) or by e-mail (eyilmaz@umes-bird.umd.edu) for further information. Web Page: http://tech.umes.umd.edu/eyilmaz.