Application of LabView for Undergraduate Lab Experiments On Vibrations Testing

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Abstract

This paper describes the implementation of LabVIEW, in an experiment in a mechanics laboratory in the mechanical engineering department at the University of New Haven, to allow the acquisition of real time data for display, analysis, control and storage. The data acquisition system is provided using the following products from National Instruments: AT-MIO-16L-9, data acquisition board; NI-DAQ, application programming interface; and LabVIEW, software development package. The goal is to carry out real-time measurements and display acquired waveforms on a PC screen and also store data associated with these waveforms for later use. The aim is to be able to control and apply voltage to a shaker driving a simple cantilever beam, and collect data from the resulting strain in the beam. In the vibration test, the response of the cantilever beam to a sinusoidal loading is determined by two strain gages mounted on the top and the bottom of the cantilever beam. The time domain signals are then analyzed using LabVIEW software to obtain a spectrum response.

This work will demonstrate that the capability to rapidly acquire, display and analyze data provides a valuable tool to students. It is also believed that the time students take to complete the experiments will be significantly reduced by using LabVIEW.

Introduction

The use of a computer to imitate an instrument or device is known as virtual instrumentation. One software development package used to create virtual instruments is LabVIEW (Laboratory Virtual Instrument Engineering Workbench). LabVIEW is a graphical programming language that, when used in conjunction with a data acquisition device and personal computer, allows the user to control devices, collect, manipulate and display data. Written code is not used in LabVIEW instead graphical representations of the circuits are constructed which are called virtual instruments (VI's). These VI's are manipulated so that they will perform the desired tasks at hand. The VIs (virtual instruments) in LabVIEW are run from their front panels. This is the panel with all of the controls and displays. Each front panel has an associated block diagram. This block diagram is built using the graphical programming language G. The components of the block diagram represent different structures, loops and functions. The wiring of the block diagram represents flow of data between these components. A VI becomes a sub VI when it is

placed inside the block diagram of another VI. These sub VIs are analogous to sub routines, and allow layering and modularity of the VIs.

 In this experiment, virtual instruments created with LabVIEW were used to investigate a cantilever beam subject to forced harmonic vibration. Two VIs and a number of subVIs were written. The Beam Data VI determines the harmonic nature of the beam, and the Frequency Data VI drives the beam specified frequencies, and at each frequency, determines the displacement at the end of the beam based on acquired data and harmonic data.

Theory

 A shaker is driven, with displacement y, to displace the fixed end of a cantilever beam and impart harmonic motion in the beam. Mounting two strain gages on the beam as shown in Figure 1 allows the measurement of maximum strain in the beam as the end of the beam oscillates in x direction. With virtual instrumentation, the computer operator can control the
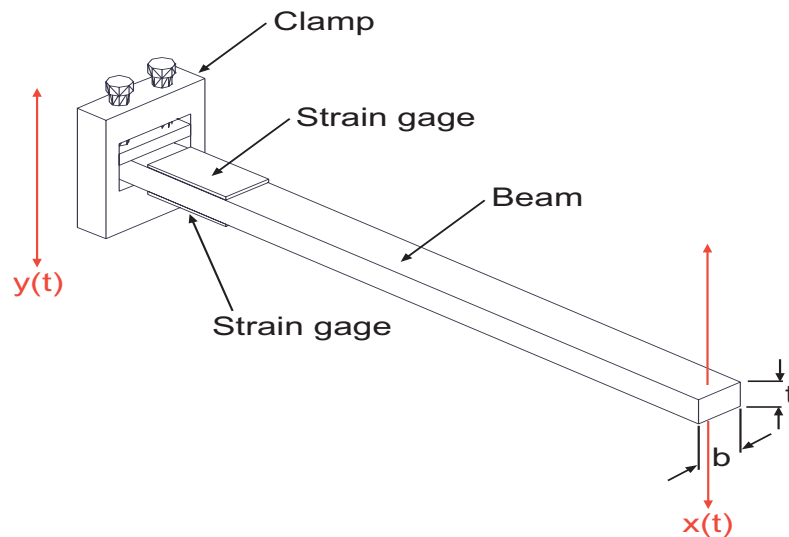

Figure 1. Cantilever Beam Setup. Strain gages are mounted on the top and bottom of the beam. The motion of the oscillator is y (t) and the deflection on the end of the beam is x (t). The width of the beam is b, and the thickness is t.

motion of the shaker and simultaneously record data from the strain gages. This data can be examined with two different approaches, through determination of the damping ratio and determination of the deflection of the end of the beam.

Two metallic resistance type strain gages were used in conjunction with a ½ Wheatstone bridge as shown in Figure 2. Briefly, the gages are mounted on a specimen and under pre-load conditions, the balance potentiometer is adjusted such that e_o is zero. Strain in the specimen elongates the strain gage, altering the electrical resistance in the gage. This change in the gage resistance unbalances the bridge, and results in a voltage at e_o. This voltage at e_o is proportional

to the strain. Using two gages in this configuration results in a doubled bridge output, as compared to using a single gage, and also compensates for temperature effects, and torsional and axial components. As the beam vibrates with harmonic motion, the output from the strain gages is a sine wave with amplitude proportional to the strain and a period inversely proportional to the frequency of the vibrations.
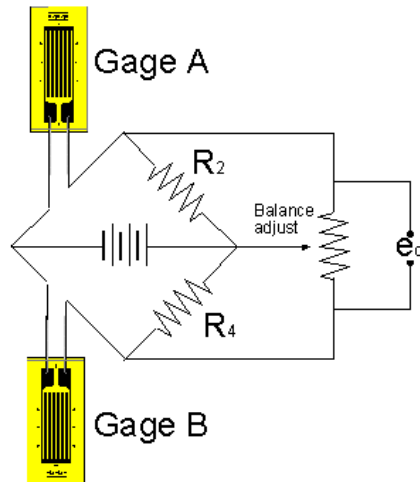
Figure 2 Wheatstone Bridge. A ½ bridge with two strain gages. After bridge is balanced such that voltage across e_o is zero, strain in gages results in voltage across e .

By driving the shaker with a sine wave, the aluminum beam vibrates with simple harmonic motion. Left to vibrate freely, without applied external forces, the beam will vibrate at its natural frequency, ω_n, and its amplitude of the response will decrease with time, as energy in the system is lost. The rate at which this amplitude decreases is known as the logarithmic decrement. The logarithmic decrement, δ, can be obtained by measuring two displacements separated by n number of complete cycles and applying: $\delta = \frac{1}{n} \ln\left(\frac{x_o}{x_n}\right)$ with x_o and x_n the amplitudes separated by n cycles. From δ, the damping ratio, ζ, can be found from: $\zeta = \frac{\delta}{2\pi}$. For our system with the displacement of the shaker, y, it can be shown that the deflection, x is approximated by:

$$\frac{x}{y} = \sqrt{\frac{1+(2\zeta r)^2}{(1-r^2)^2 + (2\zeta r)^2}}$$ with $r = \frac{\omega}{\omega_n}$ [1]. After impacting the beam, and allowing it to vibrate freely, the Beam Data virtual instrument will determine the natural frequency of the beam, logarithmic decrement and damping ratio of the beam. Along with the driving displacement, y, this data can be used to determine the deflection, x, at the end of the beam for a given frequency. The block diagram for the Beam Data VI is shown in Figure 3.
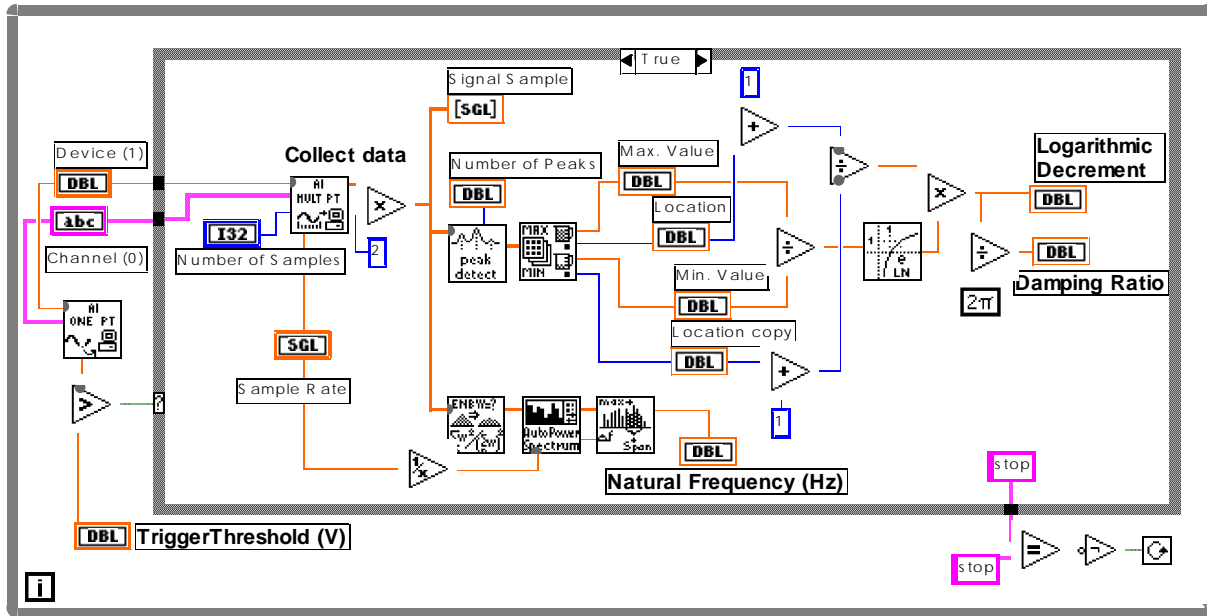
Figure 3. Block diagram for the Beam Data VI

The deflection in the beam can also be determined by measurements of strain, ε, in the beam. The maximum deflection of a cantilever beam with a point load on the end of the beam is: $y = \dfrac{PL^3}{3EI}$ with P, the load on the beam, L, the length of the beam, E, the modulus of elasticity for the material, and I, the second moment of area of the beam.[2] The maximum strain in a cantilever beam is: $\varepsilon = \dfrac{Mc}{EI}$, $(c = \dfrac{t}{2}$ with t the thickness of the beam).[2] From these two equations, and with $M = PL$ we can obtain the deflection, x, with: $x = \dfrac{\varepsilon L^2}{3c}$. The Frequency Data virtual instrument drives the oscillator at a series of determined frequencies and records the maximum strain at each frequency. With the user input of data from the Beam Data VI and measurements of the beam, along with the acquired driving displacement, the Frequency Data VI calculates the deflection at the end of the beam and the magnitude ratios, (x/y), for each frequency, based on the measured strain and based on the calculated damping ratio. The block diagram for the Frequency Data VI is shown in Figure 4. We now can compare the deflection of the end of the beam based on ω, ω_n, and ζ, with the deflection based on the measured strain in the beam.
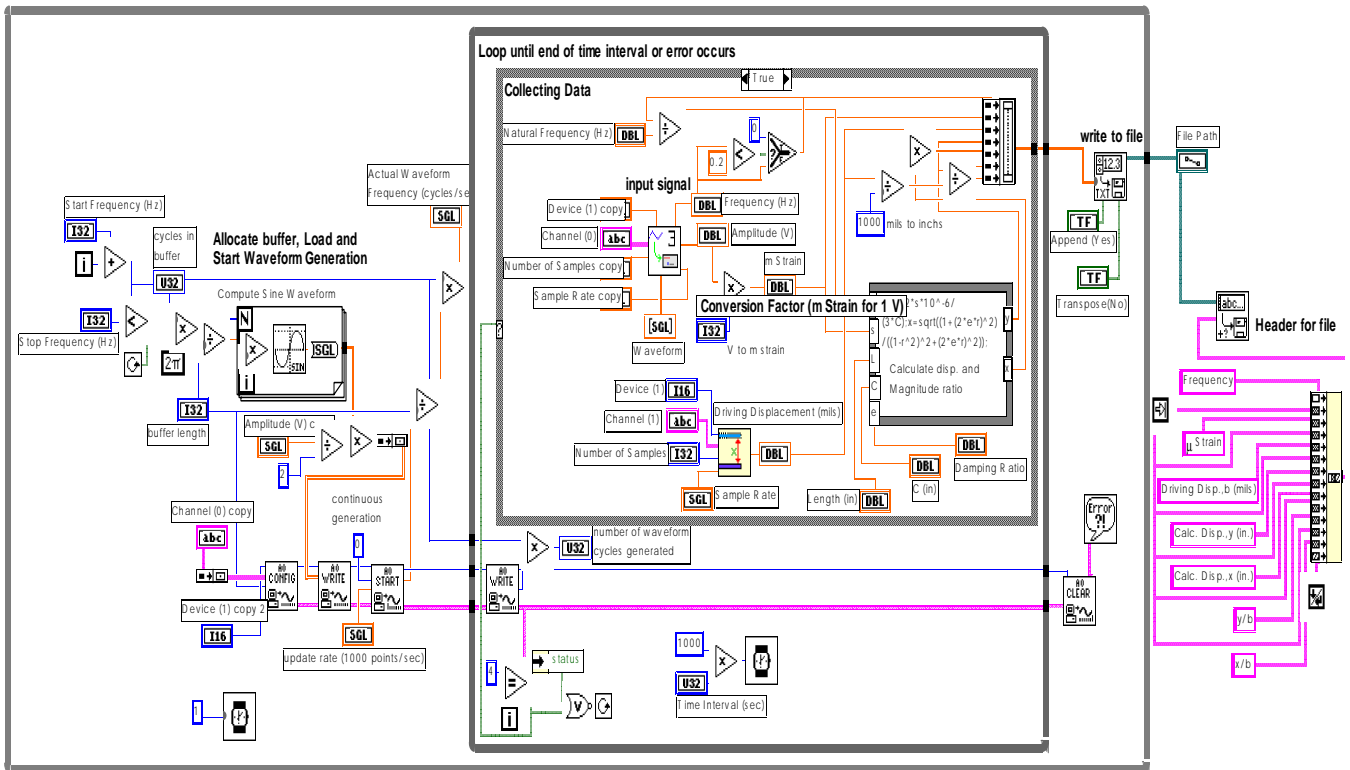
Figure 4. Block diagram for the Frequency Data VI

Procedure

The equipment was set up as shown in Figure 5. The VIs were written and run with LabVIEW 5.0 Student Edition, on a NEC 486 computer. Installed on the computer was a National Instruments AT-MIO-16L-9 multifunction input/output board driven by National Instruments NI-DAQ 6.1.2 software. Other equipment used included: Differential Floating Source Input Connector, which served as an interface between the AT-MIO-16L-9 and other equipment; Ling Dynamic Systems Power Oscillator Model PO300, a power amplifier; Ling Dynamic Systems Model 411 Shaker; Measurements Group Model 2120 Strain Gage Conditioner; Hitachi VC-6024 Digital Storage Oscilloscope; Vitec #461 accelerometer transducer; Vitec Model 654 Accelerometer. The Beam Data VI was used to determine ω_n, ζ, and δ. After setting the parameters on the front panel of the VI, shown in Figure 6, the beam was impacted lightly and the VI was run. After sampling the signal from the strain gage conditioner for a pre determined length of time the sampled signal is displayed along with the values for ω_n, ζ, and δ.The Frequency Data VI was used to determine the frequency response of the beam. On the front panel of the VI, shown in Figure 7, parameters are set for the input and output signals.
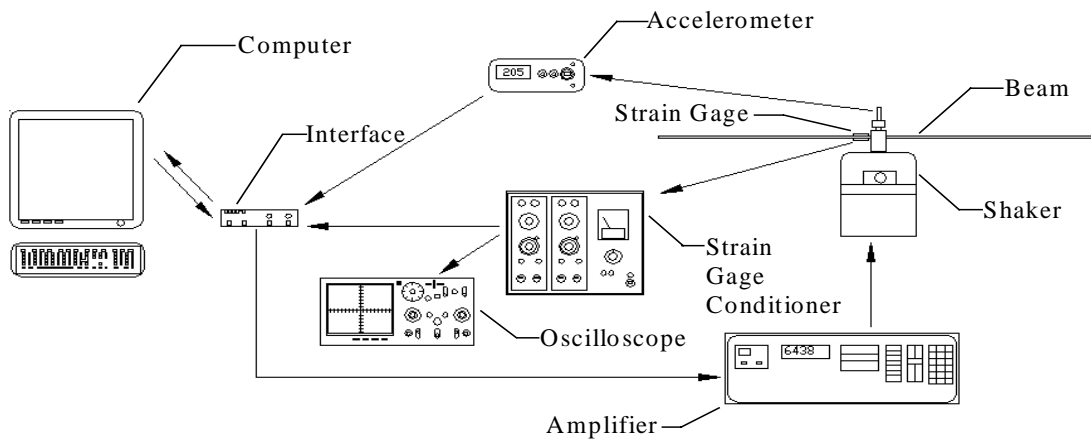
Figure 5. Equipment setup. Arrows indicate flow of data or signal.

The values found by the Beam Data VI for ω_n, and δ need to be entered along with the length and ½ the thickness (c) of the beam. A strain conversion factor needs to be entered. This factor depends on the strain gage(s) and bridge arrangement used. The VI will drive the beam at a series of frequencies and measure the maximum strain and driving displacement at each frequency. Values for the measured strain, driving displacement, calculated deflection based on strain and based on δ, and magnitude ratios, are written to a specified file. This file can later be opened with a spreadsheet program and examined.
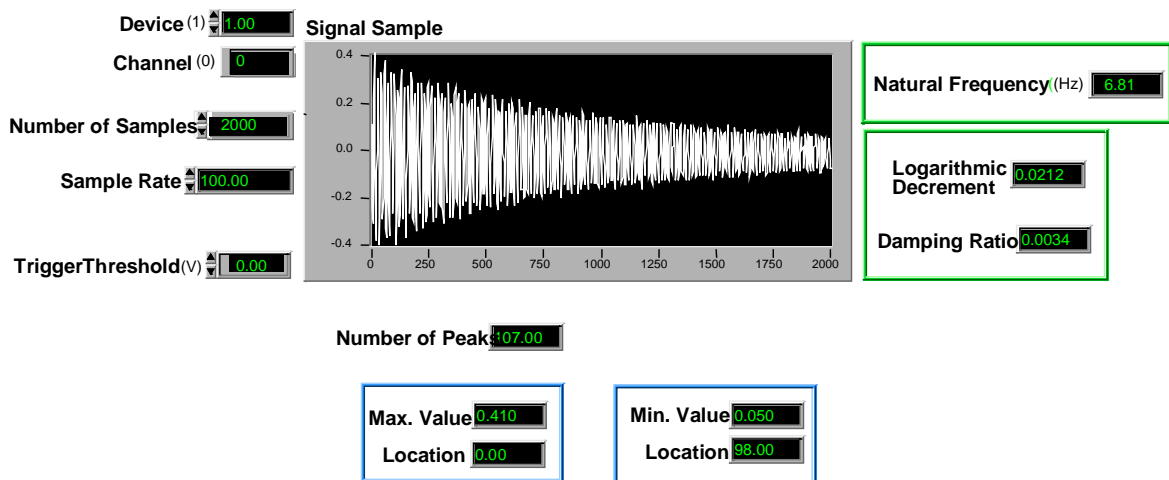

Figure 6. Front panel of Beam Data VI. Shown in the signal sample window is a typical acquired signal from an impacted beam.

Signal Out

Device (1) Channel (0)
1 0

Start Frequency (Hz) 3
Stop Frequency (Hz) 10
Time Interval (sec) 3
Amplitude (V) 0.15

Actual Waveform
Frequency (cycles/sec)
10.0

Gage Signal In

Device (1) Channel (0)
1 0

Sample Rate 100
Number of Samples 100
Conversion Factor (μ Strain for 1 V) 500

Waveform
0.1

0.0

Frequency (Hz) 10.0
Amplitude (V) 0.71
μ Strain 353.9

Beam Data

Length (in) 23.0
C (in) 0.006
Natural Frequency (Hz) 6.00
Damping Ratio 0.0060

Write to Spreadsheet

Append (Yes) YES
File Path c:\test
Transpose (No) NO

Driving Disp. (b) Number of Samples 100
Device (1) Channel (1)
1 1
Sample Rate 100
Driving Displacement (mils) 0.50

Figure 7. Front panel of the Frequency Data VI.

Results

The aluminum alloy beam used, measured 23.5 in. from the center of the strain gage to the end of the beam. The beam measured .123 in. in depth (c=0.0615) and 0.992 in. in width. The Beam Data VI was used to determine the natural frequency, ω_n, logarithmic decrement, δ, and damping ratio, ζ, of the beam. The VI was run eight times to yield the data found in Table 1.

Table 1 Data from Beam Data VI

Run	Natural Frequency (Hz)	Logarithmic Decrement	Damping Ratio
1	6.76	0.0450	0.0072
2	6.76	0.0159	0.0025
3	6.76	0.0595	0.0095
4	6.76	0.0333	0.0053
5	6.76	0.0612	0.0097
6	6.76	0.0180	0.0029
7	6.76	0.0249	0.0040
8	6.76	0.0858	0.0137

After discarding the highest and lowest values for δ and ζ, the average values for ω_n (6.76 Hz) and ζ (0.00643) were input along with the dimensional data, as parameters for the Frequency Data VI.

The Frequency Data VI was run three times. The average values for these three sets of data are given in Table 2. For comparison, the displacement at the end of the beam was also measured directly with a ruler, and these results are found on Table 3.

Table 2 Data from Frequency Data VI

Frequency	Strain	Driving Disp., y (mils)	Deflection (strain) x (in.)	Deflection (ω, ω_n, δ) x (in.)	x/y	x/y
3.04	7.65	15.56	0.023	0.020	1.508	1.254
4.01	20.77	66.83	0.064	0.103	0.953	1.542
5.00	41.75	109.83	0.128	0.243	1.166	2.209
6.00	148.31	136.26	0.455	0.641	3.339	4.706
7.00	600.30	82.32	1.842	1.120	22.374	13.610
8.00	143.60	124.36	0.441	0.312	3.543	2.506
9.00	91.50	129.55	0.281	0.168	2.166	1.294
10.00	69.88	131.09	0.214	0.110	1.635	0.842

Table 3 Measured deflection at end of beam.

Frequency (Hz)	Deflection (in.) Iteration			Avg. Deflection (in.)
	1	2	3	
3	0.03	0.03	0.02	0.03
4	0.09	0.09	0.03	0.07
5	0.16	0.16	0.16	0.16
6	0.41	0.47	0.47	0.45
7	1.66	1.59	1.53	1.59
8	0.28	0.28	0.28	0.28
9	0.22	0.22	0.22	0.22
10	0.09	0.09	0.09	0.09

Graph 1, comparing deflections, is constructed from the data on Table 2 and Table 3.

Graph 1 Deflection Amplitude vs. Frequency
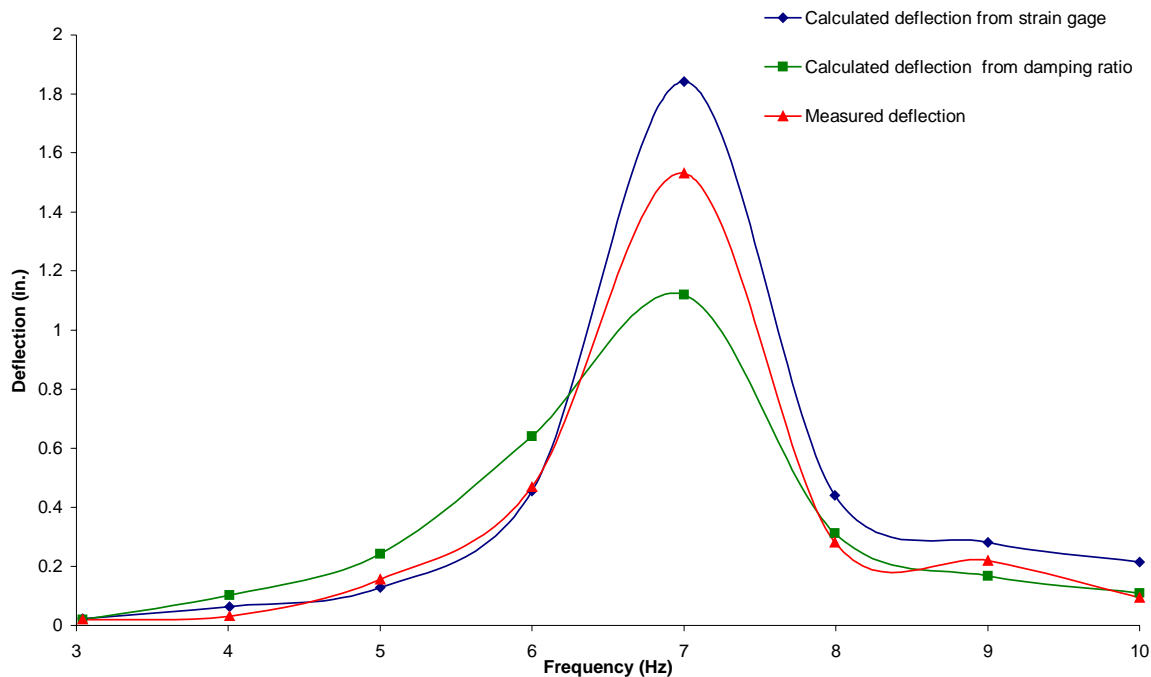
Discussion

Once the equipment was set up, the VIs were easy to use, and in a matter of minutes the experiment had been executed and the data recorded. The Beam Data VI was set to sample the signal from the strain gage for 20 sec. and after doing so, immediately displays the result. At this rate, the VI could be run almost three times in a minute. This saves considerable time over the method of using an oscilloscope to capture the signal, making the measurements of the data, and performing the calculations. The Frequency Data VI was even more of a time saver. With the interval between frequency changes set to three seconds, this VI gathered data and calculated results for a series of eight frequencies in just over 30 sec. This proves to be much quicker than the method of making a frequency adjustment, capturing the response on an oscilloscope, measuring the response, and performing calculations. For many students, these VIs also serve as an introduction to the rapidly expanding use of VIs.

The Beam Test VI worked as expected. The display of the signal sample clearly shows the decaying signal amplitude from the beam. Using an amplitude measurement from the start of this signal and a measurement from the end, ensures a reasonably accurate determination of the logarithmic decrement and damping ratio. These values, along with the determined natural frequency of the beam, allow the theoretical determination of the deflection at the end of the beam for a given driving frequency.

The Frequency Test VI fully automates the determination of deflection based on strain measurements in the beam, and allows for comparison of the results based on data from the Beam Data VI. The user needs only to set the parameters, and enter the data from the Beam Test VI. When the VI is run, the experiment proceeds, applying the harmonic excitations to the beam, collecting and analyzing the data, and then writing the results to a file which can be opened with a spreadsheet program. Contained in this file are the results based on the theoretical calculations and the results obtained by measurement of the strain in the beam.

A comparison of the results, as shown in Graph 1, indicates that data based on damping ratio and natural frequency are comparable to the data obtained from the measurements of strain. Many different factors could account for the difference in the magnitude of the results. The damping ratio value of 0.00643, as determined by the Beam Test VI, is an average value taken from values which range from 0.0040 to 0.0097. This is a fairly wide range of data considering that a change of only 0.00005 for the value of the damping ratio, results in an approximate change of 0.1 in the magnitude ratio, x/y. The range of values found for the damping ratio is most likely due to noise present in the strain gage signal. This noise could be reduced by use one of the many filters available in LabVIEW. Measurement of the beam deflection with a ruler was included only for gross comparison. It is very difficult to obtain accurate or precise measurements of the end of the beam as it oscillates.

Further refinement of these two VIs could lead to increased timesavings and perhaps, greater precision. Both VIs could be brought together as sub VIs in one VI that would perform the entire experiment. The Beam Data VI could be constructed to perform the experiment a number of times, average the data, and then export the result to the Frequency Data VI. This VI could also be configured to sweep through its frequency range a number of times, recording the data as it proceeds.

Conclusion

The use of virtual instruments created with LabVIEW allows the user to quickly investigate and gather data on the response of a cantilever beam subject to harmonic excitations, and also serves to introduce many students to the use of virtual instruments.

Bibliography
1. Rao, Singiresu S. Mechanical Vibrations. Addison-Wesley Publishing Company (1995).
2. Rieley, William F., Sturges, Leroy D., Morris, Don H. Statics and Mechanics of Materials. John Wiley and Sons (1995).
3. Craig, R.R., and McConnell, L., "Virtual Instruments Revitalize an Undergraduate Measurements and Instrumentation Course, 1999 annual ASEE Conference Proceedings, Charlotte, NC, June 20 - 23, 1999.
4. Neebel, D. J., Blandino, J. R., and Lawrence, D. J., " A Survey of Modern Computer-Based Experiments, Part No. 321884B-01, National Instruments, Austin, TX, March 1998.
5. Smith, C.C., Lund, E.K. and Dahl, J.F., "Instrumentation and Digital Data Acquisition in Mechanical Engineering," 1994 ASEE Annual Conference Proceedings, Vancouver, BC., 1994

6. Eibeck, P.A., " Multimedia Courseware Support for the Instruction of
    Engineering Experimentation," Proceedings of Frontiers in Education 23rd
    Annual conference, sponsored by ASEE and IEEE, Washington, D.C., Nov. 6-9,
    pp. 135-139, 1993.
7. Smith, C.C., Heaton, H.S., and Queiroz, M., "Integration of
    Computer-Based Data Acquisition Systems into Undergraduate Instrumentation
    Laboratories, 1992 ASEE Annual Conference Proceedings, Toledo, Ohio, 1992

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