A Freshman Module to Teach Instrumentation Methods

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Abstract

Evolution of modern electronic devices has reached a level where a black-box approach to designing and building systems is within the capabilities of beginning laboratory experiments. This facilitates the introduction of modern instrumentation methods to freshmen in an engineering curriculum. The paper describes a freshmen module designed to provide an exposure to transducers, signal conditioning, computer interfacing and signal processing. The module consists of a coordinated set of lectures and laboratory experiments.

The lectures begin with the concept of a transducer using the strain gage as a basic transducer. Introducing a differential amplifier using an op-amp as a basis follows this. Block diagram concepts are used throughout. In the first laboratory of the module, a cantilever with two strain gages connected to a differential (instrumentation) amplifier are used to measure loads and deflections. The output of the differential amplifier is read using a meter. Students build the circuits, calibrate them with known weights and then use them to measure an unknown weight and deflection.

The second part of the module introduces concepts of inputting signals into a computer, with the analog-to-digital converter being described as a functional block. In the laboratory, students connect the output of the differential amplifier to a commercial analog-to-digital converter unit and acquire data into the computer. Using a narrow-band digital filter to process the acquired data, students determine the natural frequency of the cantilever with applied weight loads.

Introduction

In recent years there have been many examples of engineering curriculum reform in the freshman year [1-4] . One of the primary motivations for change is to provide the beginning students with engineering experience so as to help them identify with engineering in the freshmen year. An important aspect of engineering education is the experimental verification of theoretical models developed in lectures and relating this to real engineering experience. Learning to make engineering measurements provides a fundamental basis for this process. This paper reports on an instrumentation module developed to teach freshmen students in the design of an instrumentation system, which is used to introduce students to engineering methods. The methods learned are used in design projects later in the year [5-7].

Union College is a private, undergraduate liberal arts and engineering college with approximately 2000 students. The engineering division offers programs in electrical, mechanical, civil and computer systems engineering as well as computer science. In 1995, the college was awarded a grant to revise the engineering curriculum. The freshman year was redesigned to include three 10-week trimester courses, illustrated in Table 1, that were common for all engineering and computer science students. This course sequence included the equivalent of one course in computer programming, and two courses in basic engineering science and design.

Freshman Sequence: Fundamentals of Engineering and Computer Science		
Fall Term - ESC-016	***Winter Term - ESC-017***	***Spring Term - ESC-018***
Introduction to Engineering Modules and Case Studies	Engineering Science Topics	Design Project
	Computer Programming	Computer Programming

Table 1. Union's 1996-1998 Freshman Year Engineering Curriculum

The fall term course was an introduction to engineering through a series of modules and case studies. In the winter term students began the computer programming section of the course and were introduced to specific engineering science topics such as energy, statics, instrumentation, digital logic and assembly language programming. The two-week instrumentation module is a part of a required winter term engineering course in the curriculum reform effort at Union College. The instrumentation module also permitted students to be inculcated into the different areas of engineering. It is hoped that this will facilitate communication between majors of the different disciplines and promote cross-departmental projects.

Overview of Lectures

The instrumentation module was implemented following those on statics and digital logic. At this point many of the students had not been exposed to Kirchoff laws and electrical circuit concepts. Most were concurrently taking mechanics in their physics classes and had been introduced to force, weight, mass, and Newton's laws. The statics module had introduced the students to the concept of stress and strain. As a result the lectures were designed to begin with the familiar concept of battery voltage and introduced voltage division equations in two resistor circuits as a starting point. Resistance was defined as a physical property. Many students had been exposed to Ohms law and to series and parallel resistive circuit combinations in their high school physics classes. Although Ohms law was defined in the first week's lectures, it was not used, except for deriving voltage division equations.

The lectures began with the concept of a transducer using the strain gage as a basic transducer. The stress strain relation was introduced as a material property. The strain gage was modeled as a resistor whose change in resistance was proportional to the strain.

Stress relations for a cantilever beam were described without deriving the resulting equations. The linear relationship between the applied force at the beam end and the resulting stresses, both compressive and tensile, at the base of the beam were emphasized. The relationship between the applied force and the deflection of the beam end was also described. In doing so, it was demonstrated to the students that the cantilever beam, with an ability to measure stress using strain gages, was capable of being used to measure weights and deflections. Practical applications of this in building weighing mechanisms were discussed.

The last part of this week's lecture consisted of deriving the output relations of balanced and unbalanced bridges with strain gages. Only voltage division and algebra were used in the analysis. Care was taken to treat the two gages as having different unloaded resistances R_1 and R_2 respectively. The balance condition was defined with unequal completion resistances, which are respectively a factor a times R_1 and R_2. Multiplying the resistance of one gage with a factor $(1+\gamma)$ while multiplying the other with the factor $(1-\gamma)$, was used as a means of unbalancing the bridge. Figure 1 shows the schematic of the unbalanced bridge.

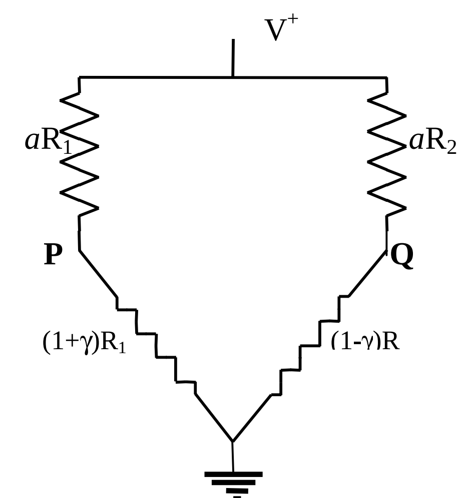

Fig. 1: Unbalanced Bridge Circuit

The factor a was demonstrated to be larger than 1, and with $\gamma \ll 1$, γ^2 could be neglected in comparison with $(1+a)^2$, leading to the following approximation:

$$V_0 = V_{P'} - V_{Q'} = \left[\frac{1+\gamma}{1+a+\gamma} - \frac{1-\gamma}{1+a-\gamma}\right]V^+ = \frac{2a\gamma}{(1+a)^2-\gamma^2}V^+ \cong \frac{2a}{(1+a)^2}V^+\gamma \qquad (1)$$

The output voltage of the unbalanced bridge was proportional to strain represented by γ. Numerical calculation was used to show that the error in the approximation is negligible and that for a value of even 1500 micro-strains, the output voltage with a + 15V drive was only a few milli-volts, leading to the need for amplification.

An ideal op-amp was defined as an operational element and was used as a basis for introducing inverting and non-inverting amplifiers followed by the introduction of a difference amplifier. The analysis emphasized voltage division based equations only. An instrumentation amplifier was next defined as a special type of difference amplifier capable of precise large difference gains. All through the lectures a building block approach was emphasized.

The lectures for the second week, described the process of acquiring data into a computer. In this case, the concepts of analog and digital signals, sample and hold functions and successive approximation analog-to-digital conversion, including formatting of the resulting digital data were introduced. Graphical descriptions of signals, the sampling process and successive approximation together with numerical examples were used to describe the procedure of acquiring data into a computer. A block diagram approach was used throughout. The need to require a buffer voltage follower to protect the input to the data acquisition circuitry was also emphasized.

Laboratory Experiments

Two sets laboratory experiments, each of two three-hour durations were designed to complement the lectures. Each experiment was preceded by a lecture wherein the related theory was reviewed and procedures were explained. In the first set of experiment, students learned to use a digital voltmeter to measure voltages and then verified voltage division with resistors and the voltage relations of op-amp based inverting, non-inverting and difference amplifiers. Strain gages in the cantilever transducer were completed to form a bridge circuit. The output of the bridge was connected to an instrumentation amplifier. A part of Figure 2 represents a schematic of the arrangement.

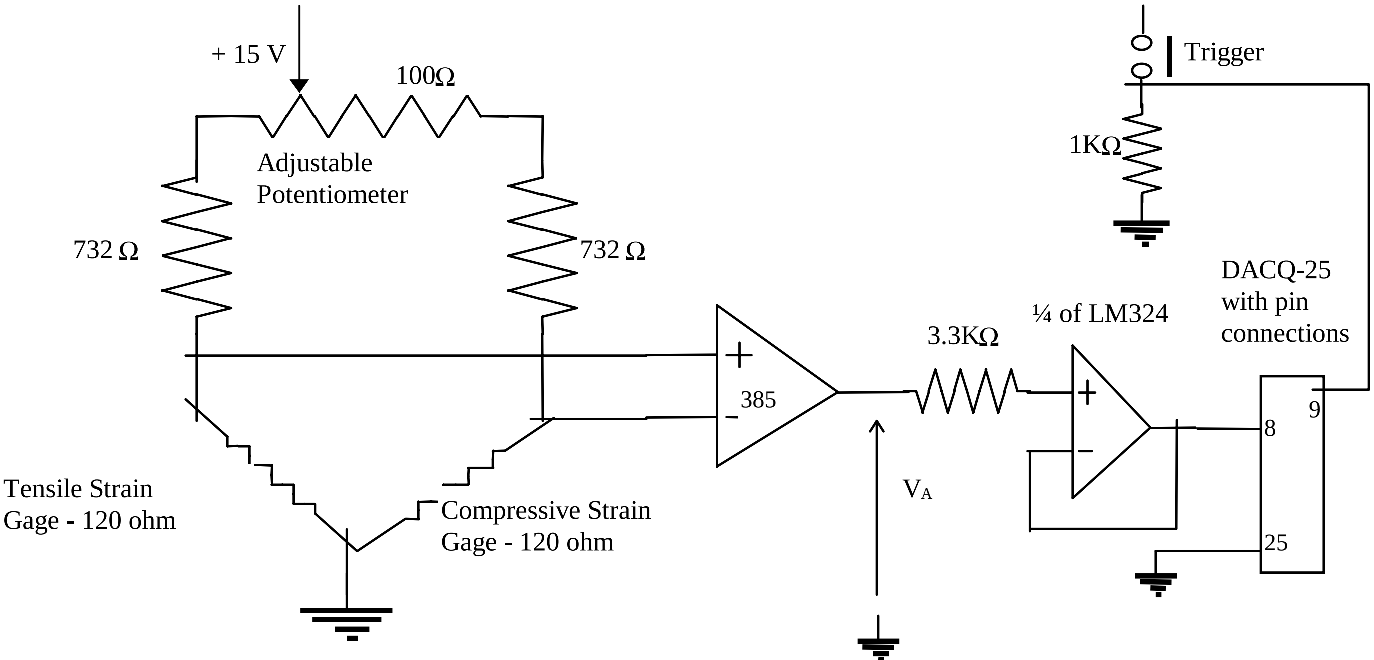

Fig. 2: Strain Gage circuit with Instrumentation Amplifier, Protection and DAQ-25 Input

The students connected the part of the arrangement shown in Figure 3, including the 1NA118 instrumentation amplifier. The output voltage was taken from pin 6 of this amplifier. This corresponds to V_A in the schematic of Figure 2. The cantilever with the strain gages bonded and electrical connection to the gauges were provided to the students. It may be noted that with modern integrated electronic circuits the construction of the setup becomes very simple and could be done in a few minutes on a protoboard.

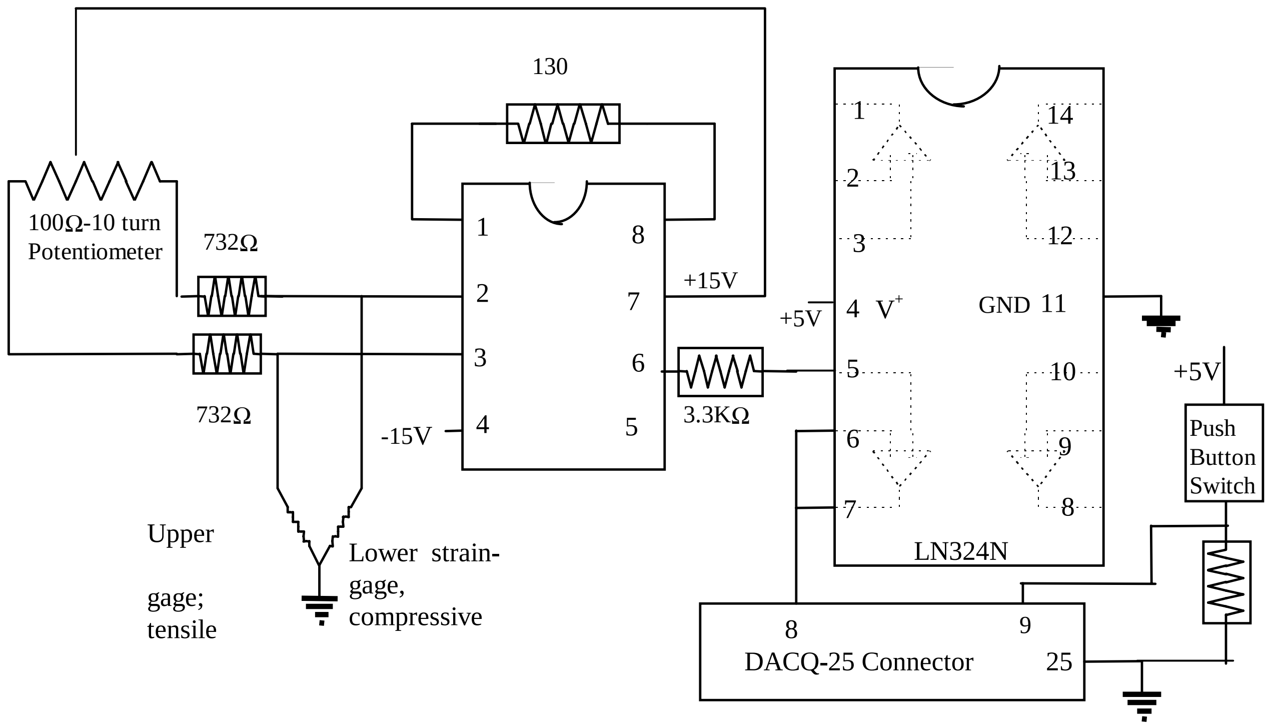

Fig. 3 : Physical Layout of Strain Gage Circuit and Protective Amplifier with Connections to DACQ-25 Connector

Figure 4 shows the physical arrangement of the cantilever beam and the position of the strain gages. The gages were prestressed to measure both tensile and compressive strains.

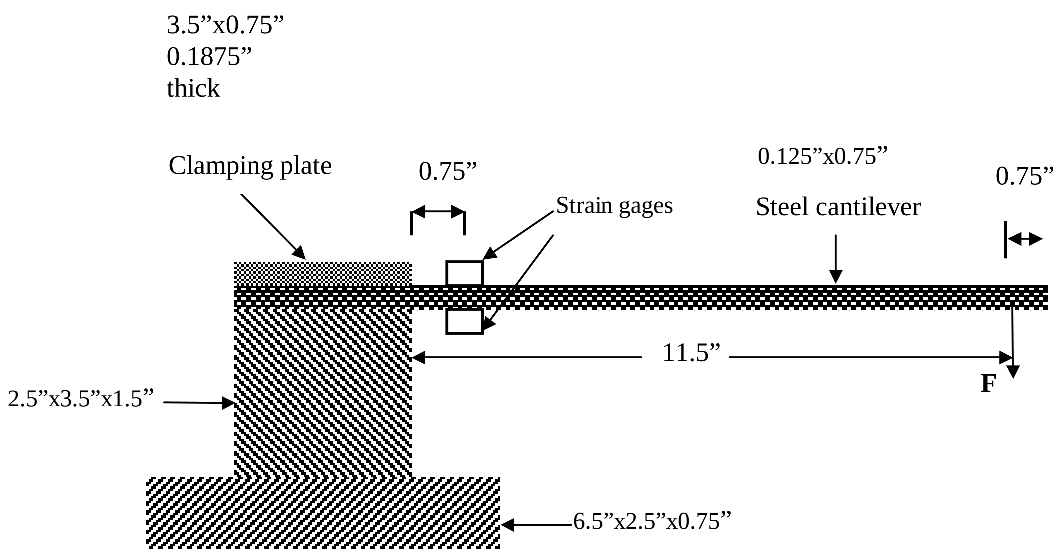

Fig. 4- Actual arrangement of Cantilever beam test setup

The students measured the output of the instrumentation amplifier using a digital voltmeter that was used in the first part of the experiment. Using the ten-turn, 100-ohm potentiometer they first balanced the bridge with an unloaded cantilever. Following this, they applied several known weights to the end of the cantilever and for each load they recorded the output of the instrumentation amplifier as well as the deflection of the end of the beam using a dial gauge. They learned that, in effect, they had constructed two transducers, one to measure weights and the other to measure deflections. This part concluded with the students guessing the weights of a bag of apples supplied to each group that they measured using the weighing system that they had built. After they had measured the weight, they were informed of the true value and competed at which team was able to come closest to the actual values.

A second part of the first week's experiments consisted of using a non-linear transducer, a thermistor to measure temperature. The negative coefficient thermistor was connected in series with a resistor and the series combination was powered by a 5V supply. The output voltage across the thermistor was measured using the digital voltmeter at various temperatures. Students learned the use of various standard temperature including phase change points for calibration of the arrangement. The points used were ice-water phase change, melting of paraffin, and other compounds and body temperature, and boiling water as test points. They then estimated the room temperature as measured by their thermistor.

During the second week a low-cost data acquisition system the DAQ-25, which connects with the parallel port of IBM compatible personal computers was used to acquire the data. The students also implemented the buffer voltage follower to protect the input to the acquisition system from overload. They connected the full schematic as shown in Figure 2. The physical connections of the circuitry are shown in Figure 3. They now acquired the calibration voltages and the unknown weight values in the computer and measured the voltages using the PC. They used signal averaging to reduce noise in the acquired data.

The final portion of the experiment consisted of acquiring the sampled values of the transient waveform obtained by causing the weight at the end of the cantilever to oscillate. They did this for a few weights and stored the results on diskettes together with calibration values for static deflection of the cantilever end point. The data, after signal averaging, was stored on diskettes. It was later used in the C++ programming section wherein he students implemented low-pass and band-pass digital filters to measure the natural frequency of the oscillation.

Assessment and Conclusions

The cantilever strain gage part of the module was quite successful. It provided an understanding of use of modern electronic circuitry in the implementation of electronic measurement systems, which prepared them for building instrumentation for the weather station project [7] undertaken by some of them in the next term. The students were exposed to various facets of engineering and learned how the different engineering disciplines complemented each other. The civil and mechanical engineering students learned the basic concepts of electrical circuits and the use of modern day electronics. They learned how simple it was to connect the electronics to create useful applications, and the use of electrical circuits in making engineering measurements. The electrical engineering students reinforced their concepts of stress, strain, force and other mechanics terms and learned about the need to understand these in building useful applications. Students enjoyed competing for measuring the unknown weights using their own calibrated transducers and the apples, which they ate after opening the bags.

All the students were introduced to computer based data acquisition and the processing of acquired data using a computer. They learned about signal averaging to reduce noise, programmed simple data filtering algorithms in C++, and obtained an understanding of how computer processing could be used to extract information from acquired data. This was also their first use of the PC in a laboratory, which they seemed to like. Students commented on the advantage of not having to write down data.

The temperature measurement phase of the module was not very successful. The students had difficulty with equipment getting wet and this part of the laboratory experiment turned out to be messy and frustrating. The phase change reference points were not very stable and showed some hysteresis. This led to overall frustration with the experimental part of the laboratory.

The instrumentation module required a considerable amount of planning effort. The low cost data acquisition modules were limited in scope and required a considerable amount of experimentation. The software supplied was limited to slow computers and would not work at first with higher speed processors. The manufacturers developed a software patch that helped somewhat. Automatic triggering of the data acquisition would not work and we had to implement hardware triggers to initiate data acquisition. All in al the effort was very useful and while not all students grasped most of the material, many learned the methodology of making engineering measurements. The concepts and skills learned in the module were useful in the spring term, especially for the students who chose to weather station project [7]. Students did believe that they had to put in a considerable amount of effort in this module. Some students who had difficulty handling algebra struggled with the homework assignments and needed help, which was provided in a problem help session.

Unfortunately, the instrumentation module could not be continued in the following year due to a reduction in the engineering science and design content of the freshmen year implemented for students entering in the fall term of 1998 and thereafter. Since there was to be no design project in the third term, it was felt that the concepts learned in this module could also be developed in the upper level course experiments of the curriculum. The experiment itself was used in the upper level microprocessor course where students programmed a microprocessor in assembly language to acquire data after prototyping the above circuits.

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