# MODERNIZATION OF A MECHANICAL ENGINEERING LABORATORY USING DATA ACQUISITION WITH LABVIEW

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## Abstract

Computers using modern electronic instrumentation and data acquisition have revolutionized the experimental laboratory. With very limited funding available, universities face a major challenge in upgrading their older laboratories with state-of-art systems common to modern industry. The University of Tennessee at Chattanooga College of Engineering and Computer Science has just completed this process for the Mechanical Engineering Laboratory. The previous lab (a thermal science lab with 1 credit hour) used no computer data acquisition while the new lab (having both mechanics and thermal science components with 1 hour lecture and 1 hour lab) has the electronic instrumentation and data acquisition integrated throughout. No new laboratory systems were purchased as on-hand systems were retrofitted with new instrumentation and data acquisition using LabVIEW (Laboratory Virtual Instrument Engineering Workbench) [1]. The development of the new lab provided a challenge and comprehensive learning experience for the responsible faculty member while saving the university money. The paper describes many aspects of university related activities that were considered during the development of the laboratory along with the specific content of each laboratory.

## Introduction

Engineering laboratories have historically been underfunded and neglected at most universities. This has resulted from the university not giving adequate workload credit for development and teaching of labs as compared to that given for research [2]. This has promoted laboratory obsolescence as faculty interest and support for providing on-going development of new labs and supportive skills have declined. Yet, today our industry advisors tell us they expect our graduates to have skills that can only be learned in a laboratory setting where modern instrumentation and computers interface in performing data acquisition, analysis, and presentation [3]. In general, engineering faculties have a problem, as many faculty members do not possess the modern skills required to support such laboratory teaching and development [4]. The process of overcoming these constraints can only be done with faculty development and curriculum revisions.

## Curriculum Considerations

The curriculum revisions required for supporting the new laboratory concept at The University of Tennessee at Chattanooga were not accepted as imperative by some of the faculty even though our experienced graduates and industry representatives insisted that we move ahead with haste in bringing about the changes. Our making the revisions to the mechanical engineering curriculum was made easier as our Dean of Engineering and Computer Science and mechanical engineering area director fully supported the changes.

The credit hours for the new two hour lab was obtained by combining one credit hour from a Heat Transfer Lab (Engineering 406) required of all mechanical students with one hour of elective lab required of all thermal science mechanical engineering students. The elective lab contained experiments that supported fundamentals related to combustion and mass/energy balances.

## Laboratory Development Alternatives

A new experimental laboratory can be developed by purchasing new equipment that incorporates modern data acquisition features [5]. Therefore, the total package is purchased from a single supplier who is responsible for its design and operation. This is generally the fastest way to expand an older lab as well as develop a totally new lab. But, it does generate many problems that must be faced with the operation and maintenance of the system. An alternate way to develop a new lab is to take older, proven systems and retrofit them with modern electronic measurement and computer data acquisition systems with a faculty member responsible for the development.

Both approaches for developing a laboratory offer several comparisons. The purchase of a totally new system is typically more expensive than an older model that had no data acquisition, analysis, or presentation capabilities. The large increase in costs is primarily associated with instrumentation and computer software and hardware. A major portion of the increased cost is related to developmental expenses required to produce small volume systems typical of laboratory equipment. The development of a new lab through retrofitting older equipment is less expensive than the full purchase as the developmental costs are reduced. The newer instrumentation and computer data acquisition costs are incorporated in both. But, the university's costs for such equipment are normally reduced over that for commercial vendors. The new mechanical engineering laboratory would have cost about $350,000 to purchase while UTC has spent less than $120,000 in developing the lab, with only about $60,000 being new money spent solely for computer software-hardware and various other types of instrumentation and sensors. The most important advantage to retrofitting is that the faculty member is involved in developing and operating the new system. The commitment to developing the specifications for selecting the new instrumentation and writing the computer data acquisition applications offers a rewarding learning experience. The faculty members have a greater understanding of the complexities and day-to-day problems that will be faced during the operation of the lab if they have been responsible for developing each component.

The faculty members who were responsible for developing the new laboratory have attended a five-day workshop taught by National Instruments. Three days were used in teaching basic LabVIEW (Laboratory Virtual Instrument Engineering Workbench) programming [6], and two days were used for teaching data acquisition fundamentals [7]. Attending the LabVIEW workshop was most helpful as it provided a jump-start that could not have been obtained readily through use of National Instruments' publications. A university faculty developmental grant was used to support travel and workshop expenses.

## New Laboratory Scope and Objectives

The new laboratory was designed with the following objectives [8]:

1. To give the student an opportunity to apply the theory presented in mechanics and thermal science options of mechanical engineering.

2. To familiarize the student with measurement techniques using many “state-of-art” instruments that are encountered in industry.

3. To give the student experience in computer data acquisition, data analysis and oral and written presentations.

4. To expand the student’s computer application skills through use of word-processing, spreadsheets, and graphics.

5. To develop the student’s oral and written communication skills through oral presentations and technical report writing.

6. To develop student team coordination skills.

The laboratory experiments consists of three modules (common, thermal, and mechanics) with the common labs being related to thermodynamics, fluid mechanics, and heat transfer that are taken by all mechanical engineering students. The thermal labs cover thermal science curriculum content while the mechanics labs contain experiments that are related to the mechanics (machine design) curriculum. All mechanical engineering graduates are expected to have a general understanding of both mechanics and thermal science areas. It is anticipated that students having completed the new lab will have obtained experiences that will enhance their opportunity to be a more successful engineer.

The content of each of the lab areas was established to stress the basic fundamentals taught in the curriculum while demonstrating the unique potential of experimental measurements using computer data acquisition. These considerations provide the opportunity for integration of many forms of instrumentation into a single experiment. It is important to understand that thermal science experiments represent about two-thirds of the new laboratory content. This emphasis will be reduced as more mechanics experiments are developed. The development of these additional experiments represents a challenge, as thermal science systems with extensive electronic instrumentation and data acquisition capabilities are common while mechanics (machine design) systems are less common.

Two three semester hour courses, Heat Transfer (Engineering 405) and Mechanical Vibrations (Engineering 445), are corequisite with the new Mechanical Engineering Laboratory course. The lecture portion of the new Mechanical Engineering Laboratory covers the general characteristics of instrumentation, electrical measurement systems, statistical analysis, and computerized data acquisition systems.  Homework is assigned, and tests are administered in the lecture portion of the new lab.

A new text entitled “Introduction to Engineering Experimentation” by Anthony J. Wheeler and Ahmad R. Ganji [9] provides the best coverage of measurement systems with electrical signals, computerized data acquisition systems, and statistics. Most other texts that were considered were revised editions of texts that contained less information related to these important areas of modern experimental measurements.

## Administration of the New Laboratory

The laboratory was developed for fifteen students per class.  Five experiments are conducted *concurrently* each week at five different workstations.  Three students are responsible for conducting each experiment.  A manager is assigned the role of over-all responsibility for conducting the experiment and submitting the final report for the group.  A second student is responsible for theory and procedures, and the third student is responsible for data acquisition, presentation, and analysis.  The roles of the students are rotated for each experiment. The development of the final report is done jointly by group members with the manager coordinating the effort.  The roles of each student will be assigned at least one week prior to the experiment. The lab instructor and group members will meet individually and/or separately to discuss the role each is to play in conducting the assigned experiment.  These details must be completed prior to the group arriving to conduct the experiment.  This provides for an informed discussion of the details of the experiment by the work station group during the first phase of the three hour lab period without the instructor being responsible for *total* learning during this period.  The latter portion of the lab period is used to complete the experimental objectives.   *Two* instructors divide their time between the five-workstation groups as the different experiments are being completed. The new lab was first offered during the Fall 1996 with nine students (three work station groups). This enabled the team-teaching instructors to deal with many unknown problems that developed during the initial operation of the new lab.

Formal reports are submitted for about half of the experiments while informal reports are submitted for the others.  The reports are due two weeks after the experiment is completed.  The student grade is evaluated with the lecture portion counting 30% (10% for homework and 10% each for the midterm and final exam), the laboratory portion counting 55% (42% for reports, 5% for oral presentation(s), and 8% instructor’s evaluation), and design project 15%.

## Recognition for the New Laboratory

The faculty responsible for developing the mechanical engineering laboratory were recently selected by National Instruments to develop “MODEL” courseware that will be used nationwide in promoting utilization of computer data acquisition, data analysis, and oral and written presentations in the university engineering laboratory.  National Instruments developed the LabVIEW data acquisition software and hardware boards used in our senior laboratory.  New external funding by the University of Chattanooga Foundation and the UTC Center of Excellence for Computer Applications has been provided. This will provide for the new laboratory to be fully developed and put on the Internet - World Wide Web where UTC distance learning students as well as any Internet user will be able to complete the laboratory course without having to come on campus.

## Student Impressions of the New Laboratory

All students taking the lab have expressed appreciation for having been able to take the new course. Some of their comments are as follows:

1. “Being exposed to LabVIEW while getting to learn about this new form of data acquisition is the most important positive impression from the class.”

2. “Being given the chance to not only understand the lab itself but also how it is setup and how it works is important.”

3. “Exposure to a wide variety of topics not within my specialty is important.”

4. “Having the computer acquire experimental data is much more convenient and efficient than taking it by hand.”

5. “It is interesting to see how fundamental theory learned in class is supported by experimental study.”

6. “I can see an immediate application in my work area.”

## Contents of each Experiment

### Common Experiments

1. Refrigeration Trainer

The objectives of the lab are (1) to complete overall energy and mass balances for the heat pump-air conditioning system, (2) to utilize many forms of electronic instrumentation, (3) to introduce LabVIEW data acquisition, analysis, and presentation, and (4) to develop spreadsheet analysis skills.

A Model 900 Heat Pump-Air Conditioning Trainer manufactured by Lab Science is used in the experiment. The system as purchased had six Bourdon pressure gages and six type K thermocouples that obtained pressures and temperatures at the discharge of the compressor, the inlet to the condenser, the exit of the condenser, inlet to the evaporator, the exit of the evaporator, and the inlet to the compressor. Various other instrumentation/controls required to operate the system in both cooling and heating modes as a heat pump are included. The Trainer was retrofitted with (1) two electronic pressure sensors to establish the high and low side pressures, (2) electronic dry bulb-relative humidity sensors on both sides of the condenser coil, (3) a hot wire anemometer on the discharge side of the condenser coil, and (4) a turbine flow meter at the exit of the condenser to measure the Freon-12 flow rate. In addition six thermocouples were connected to signal conditioning devices to support data acquisition. A LabVIEW application was developed for the modified Trainer using the experimental data for analysis and presentation. A listing of all new instrumentation added to the Refrigeration Trainer system to support data acquisition is presented at the end of the paper.

A Pentium 133 desktop computer using Windows 3.1 is used at each of the five workstations. Experimental setups as they are needed are brought out of storage and used to replace those having been operated with all wiring and signal conditioning instrumentation being retained on each experimental apparatus. This provides for convenient storage and setup of each experiment.

An *extensive* spreadsheet is completed for the experiment with energy balances being performed on the evaporator and condenser using the Freon-12 refrigerant properties and flow rate. An air side energy balance is conducted for the condenser using psychometric conditions. Traditional coefficient of performances and energy efficiency values are computed for each test. Compressor efficiency values are computed by LabVIEW assuming the Freon-12 refrigerant to be an ideal gas while real fluid properties are used in the spreadsheet program *developed by the student* to perform a similar computation. Nine tests are run for the system as the air flow rates are set at low, medium, and high for both coils. The results demonstrate how the Trainer's performance is related to airflow capacity over the condenser and evaporator coils.

The Trainer had been used some over the years in a Heat Transfer Lab (Engineering 406) with temperatures, pressures, and Freon flow rate being read from indicators located on the system. No extensive use had been made of it to support a student's retention of fundamental thermodynamics, fluid mechanics, and heat transfer principles as an integrated system.

## 2. Heat Conduction

The objectives of the lab are (1) to introduce basic graphical programming and data flow management used for LabVIEW data acquisition, analysis, and presentation and (2) to determine the thermal conductivity of two metals and thermal contact resistance between two metals in contact.

A Thermal Conduction System (Model 9051) manufactured by Technovate of Pompano Beach, Florida is used in the experiment. The system was modified so that all temperatures were obtained by computer data acquisition. A LabVIEW application was developed that computed average temperatures that were used for computing thermal conductivity, heat flux, and contact resistance values for the experiment. *Front panels, block diagrams and extensive details for this lab and all other labs developed are available from the authors.*

Before these modifications were made to the Thermal Conduction System, all temperature results were recorded by hand with all computations being completed using a calculator and/or spreadsheet techniques.

3. Heat Exchangers

The objectives of the lab are to determine (1) effectiveness of the heat exchanger an (2) the over-all heat transfer coefficient for a concentric tube type heat exchanger for parallel and counterflow operation. A Turbulent Flow Heat Exchanger Apparatus (H 950) sold by P.A. Hilton is used in the lab. Rotameter flow meters are used to measure water flow rates passing through each part of the concentric flow tube arrangement. Thermocouples with a running average display device are use in obtaining water and surface temperatures. No additional instrumentation has been added to this system. All of the other labs have included data acquisition in various forms through retrofitting of older systems generally.

Thermal Experiments

4. Internal Combustion Engine Mass and Energy Balances

The objectives of the lab are (1) to perform mass and energy balances on the internal combustion engine and (2) to develop basic programming and user skills for LabVIEW computer data acquisition, analysis, and presentation.

A Ford 1.1 liter (67 cubic inch) engine coupled to a Megatech Model DG100 electric dynamometer, a Meriam Laminar Flow air meter, a MicroMotion gasoline flow meter, and a Hedland Ez-view radiator flow meter are used in the lab. Type K thermocouples are located in the exhaust pipe of the engine, the inlet to the radiator, and the exit to the radiator. A listing of all new instrumentation added to support data acquisition is presented at the end of this section of the paper.

Testing is completed for idle operation of the engine with the exhaust gas composition for the engine conditions being provided to the student. The actual measurement of the idle exhaust composition is performed in Experiment #5.

A steady-state First Law of Thermodynamics analysis was completed on the engine with the convective and radiation heat losses from the engine being determined. The basic combustion equation was balanced with the air-to-fuel ratio being computed. The percentages of available energy lost through the radiator, off-engine, and through the hot exhaust gases were then determined for the energy conversion process.

5. Combustion Products and Emission Controls

The objectives of the lab are (1) to investigate the products of combustion associated with burning of gasoline in an internal combustion engine, (2) to compare the emissions being produced by a basic carburated engine at idle and at loaded operation, (3) to investigate the emission reduction performance of a catalytic converter for idle and loaded engine operation, and (4) to compare the tail pipe emissions of student’s automobiles at idle operation.

The instrumentation used in Experiment #4 is used in Experiment #5. In addition, The TESSCOM Exhaust Gas Analysis Console is used in performing exhaust analysis. ASYST software is used in performing data acquisition. The ASYST data acquisition system has been used in performing engine testing for eight years while LabVIEW data acquisition has only been added this past year to some engine testing activities.

The exhaust gas concentrations for the engine are measured for idle and loaded operation. During testing, combustion emissions leaving the catalytic converter are also monitored. Comparisons are made between the emissions leaving the engine and that leaving the catalytic converter. The efficiency of the catalytic converter in removing carbon monoxide and hydrocarbons is determined for each test. The exhaust gas concentrations are converted into emission factors (mass of emission per unit time) for each exhaust pollutant.

Exhaust gas analysis is completed for alternating periods of time at the inlet and exit of the catalytic converter. This provides for detail analysis of steady state emissions reduction performance of the converter.

6. Natural Gas Boiler Study

The objectives of the lab are (1) to perform energy and mass balances, (2) to consider alternate ways to analyze the performance of a natural gas fired boiler, (3) to analyze the performance of a gas fired boiler, and (4) to be exposed to large scale industrial systems.

A natural gas fired boiler at the UTC Central Energy Facility along with a Teledyne Max 5 Combustion Gas Monitor is used in the lab. The probe for the combustion monitor is placed in the boiler stack with exhaust gas temperature, carbon dioxide, carbon monoxide, hydrocarbons, and oxygen concentrations being measured. The boiler efficiency is also determined by the Max 5 instrument. The students use these results in determining the air to fuel ratio and excess air level being used for each test. The testing is repeated over several days in order to obtain results associated with varying boiler loads. Experimental results for testing by each group is compiled and used by all groups for use in report writing. No LabVIEW application exists for this experiment.

## Mechanics Experiments

7. Stress-Strain-Deflection of Beam

The objectives of the lab are (1) to compare the bending stress and strain, deflection, and stiffness of a beam determined using strain gages with that using applied load and traditional strength of materials fundamental equations and (2) to determine the damped natural frequency characteristics of the beam.

A 60-inch long steel beam 0.5 inches thick by 1 inch wide is placed on simple supports. A load is applied at the middle of the beam with the deflection being measured at 24 inches from one end, the same location for strain gages being located on top and bottom of the beam. The two strain gages represent two elements of a half bridge arrangement commonly used in strain gage measurements. The output from the strain gages is used to compute the strain and bending stress at the surface of the beam. The beam is then loaded in the middle incrementally with additional strain, stress, and deflection being determined for the beam using strain gage output. A LVDT sensor, located at the strain gages, measures beamdeflection. Fundamental strength of materials equations are used to predict stress, strain, and deflection resulting as additional load is added. Calculated deflections based on strain gage output and mechanics of material equations are compared to the deflections resulting from the LVDT sensor. A listing of instrumentation used to support data acquisition for the beam is presented at the end of the paper.

8. Linear Vibrations

The objectives of the lab are (1) to obtain linear displacement, velocity, and acceleration results for damped, forced linear vibration using a linear voltage differential transformer (LVDT) sensor and an accelerometer.

A Sanderson Free and Forced Vibrations Apparatus (Model 4.13a) sold by Feedback Incorporated of Hillsborough, North Carolina is used in the lab. The apparatus used a pen on drum paper chart for recording the displacement of the vibrating mass. A frequency meter displays the operating frequency for the vibrating mass. The degree of dampening being used in the viscous dashpot is determined by the angular position of the oil plate. A Sensotec LVDT sensor was installed on the vibrating mass apparatus along with a Sensotec accelerometer. The LVDT displacement is differentiated to obtain the velocity. Then the velocity output is differentiated to obtain acceleration. LabVIEW performs both differentiations. The acceleration results obtained by differentiation are compared with acceleration results obtained directly from the Sensotec accelerometer. A listing of all new instrumentation added to support data acquisition is presented at the end of this section of the paper.

The retrofitted Sanderson Vibrations Apparatus is a much better teaching aid as it provides for studying the fundamentals of free and forced underdamped vibrations while also introducing the student to new analysis techniques and new forms of instrumentation that were not used in earlier laboratory studies or the original Sanderson Apparatus.

9. Rotational Balancing

The objectives of the lab are (1) to investigate static balancing and (2) to show how a rotating system of masses can be dynamically as well as statically balanced.

A Static and Dynamic Balancing Apparatus (TM 102) sold by TecQuipment is used in the experiment. No instrumentation was included with the system or is required to produce a dynamically balanced system as location, angle position, and mass properties are only needed. But, to demonstrate a measure of the degree of unbalance, a Sensotec accelerometer was mounted on the platform containing the rotating system. This provided a visual feel for frequency and magnitude of unbalance along one axis.

Two masses are placed on the shaft and statically balanced. Then three masses are placed on the shaft with static and dynamic balancing being obtained. On rotating the shaft, vibration is induced due to dynamic unbalance. A four mass system is then dynamically balanced using a graphical technique to determine the angular position of each mass and mathematics to determine the axial location along the shaft for each mass. The relative magnitude of unbalance is determined using the accelerometer.

10. Kinematics of a Piston/Crank & Cam Follower of a Briggs & Stratton Engine

A new experiment has been developed that is based upon the material presented in our kinematics and dynamics of machinery and machine design class. This experiment uses a 3.5 horsepower Briggs and Stratton (B & S) lawnmower engine to study the piston, connecting rod, and crankshaft mechanism and the cam-follower mechanism.

The B & S engine was modified by removing the cylinder head, carburetor, and ignition system. A pulley was put onto the output of the crankshaft of the B & S engine with a belt connecting the pulley to an electric motor. An LVDT (linear variable displacement transformer) was used to measure the displacement of the piston, and another LVDT was used to measure the displacement of the intake valve. Two LabVIEW virtual instruments (VI's) were written: one for the piston and the other for the valve motion. In both VI's, the measured displacement is plotted versus time. Then using the differentiation sub-VI in LabVIEW, the velocity versus time and acceleration versus time diagrams are produced. Also, the maximum and minimum values for displacement, velocity, and acceleration are shown on each LabVIEW front panel.

A second B & S engine identical to the instrumented engine has cut-away sections which show all functional internal parts of the engine. A crank handle was attached to the crankshaft of the cut-away engine so the motion of all internal parts can be viewed as the crankshaft is rotated. A third B & S engine was totally disassembled and used for display and study of each engine component.

Once the experimental results are produced by data acquisition for a crankshaft speed, the students prepare a TK Solver or Maple V model of the piston displacement, velocity, and acceleration versus time using the equations for an inline slider crank mechanism. The model results are compared with experimental results for the piston motion.

Also, the students prepare a TK Solver or Maple V model for the cam-follower mechanism. By observing the cam shape and the experimental output for the cam motion, the students choose an appropriate cam shape for rise and return from the following follower motion types: cycloidal, parabolic, simple harmonic or combinations of these motion types. The model displacement, velocity, and acceleration results are compared to the experimental results obtained for the cam motion.

This laboratory tries to show the practical applications to the many kinematic and dynamic models taught in a traditional machine analysis and design class.

## Design Projects in the Laboratory

Since the first section of this new laboratory was taught, a three to four week design project has been a part of the laboratory. It represents 15% of the student's grade and is performed in-groups assigned by the instructors. To give the student an experience in the development process of an experiment, the design project was introduced. These projects use either existing laboratory devices or new apparatuses to develop an experimental program to bring these devices to data acquisition. In the laboratory, the student see the end results of endless trials to get an experiment debugged using the various electronic sensors, signal conditioners, and DAQ boards with an error-free LabVIEW virtual instrument being the product.

Two different projects have been completed during the past year. The first project was related to renovating an old, blow-down supersonic wind tunnel with electronic pressure sensors and thermocouples being added to support data acquisition. A LabVIEW application that computed test section Mach number and speed using compressible flow fundamentals and test pressures and temperatures was developed. The renovated tunnel system worked well with steady-state test section flow being shown to exist for about five seconds during the total testing period of about fifteen seconds. Using the Bourbon pressure gages and temperature dials used in the older system, the period of steady-state operation was very difficult to determine due to the transient nature of the system.

The second project was related to the design and construction of an aluminum planar truss that was cantilever supported in a frame. The truss used roll-pins to attach the aluminum members to aluminum plates forming the classic gusset joints. Each member has a strain gage bonded to both sides to measure tension or compression due to the applied load. In the first semester, the truss was designed and fabricated in the engineering shop and analyzed using basic statics. The strain gages were added and wired. In the second semester, another group obtained the appropriate data acquisition devices and generated a LabVIEW virtual instrument for the truss project. This group also tested the truss using a conventional strain gage indicator to record strain gage output before connecting the gages to the strain gage data acquisition system. The data acquisition system was then used in obtaining the loading in each member of the truss, with the loading values being compared using basic statics. This year's projects being planned will retrofit existing fluid mechanics and mechanics of materials experiments with modern electronic sensors that will support data acquisition.

## Instrumentation Listing for each Experiment

The following instrumentation is used in each experiment to support National Instrument's Windows 3.1.1 LabVIEW software. A Pentium 133 computer is used to run the software. A National Instrument's AT-MI0-16E-10 data acquisition board is used in each computer. A National Instruments SH6850 Cable is used for connecting the board to each 2050 Adapter Board. The 5B Backplane is connected to the 2050 Adapter Board using a SC1, 26-position ribbon. If a CB-50 Connector Block is used, it also connects to the 2050 board using a NB1, 50 position ribbon.

*Experiment 1*: Heat Conduction; one NI 5B Backplane, twelve type “k” thermocouple 5B47-K-05 Signal Conditioning Modules (0-500C for 0-5 volts output), one RTD temperature sensor 5B34-Custom Signal Conditioning Module (-35 to 115 F for 0-5 volts output), one 2050 Adapter Board.

*Experiment 2*: Refrigeration Trainer; one NI 5B Backplane, eight type “k” thermocouple 5B47-K-05 Signal Conditioning Modules (0-500 C for 0-5 volts output), two Omega PX304-200AV pressure sensors (0-200 psia for 0-100 mV output) with two 5B30-03 Signal Conditioning Modules (+100 mV in for +5 volts out), one Omega FTB-503-5VD turbine meter (0-0.5 gpm for 0-5 volts out) with a 5B31-02 Signal Conditioning Module (+5 v for + 5 volts out), one Omega FMA-604-V hot wire anemometer (0-10 v in for 0-5 v out) with a 5B31 Signal Conditioning Module (0-10 v in for 0-5 v out), one 2050 Adapter Board.

*Experiment 3*: LabVIEW software is not used.

*Experiment 4*: IC Engine Mass and Energy Balances; one 5B Backplane, one MicroMotion 5D flow meter (0-0.4 lbm/min for 1-5 volts output), one Meriam Laminar Flow Element (0-1 in. water for 0-51 CFM) with a Modus T20-01005 pressure transmitter (0-1 in water for 0-5 volts out) with one 5B31-05 Signal Conditioning Module (+5v for +/- 5 v out). four type “k” thermocouple 5B47-K-05 Signal Conditioning Modules (0-500 C for 0-5 v out), one 2050 Adapter Board, one CB-50 Connector Block..

*Experiment 5*: LabVIEW is not used as earlier installed ASYST data acquisition software is used.

*Experiment 6*: Teledyne Max 5 data acquisition is used.

*Experiment 7*: Stress-Strain-Deflection of Beam; one 5B Backplane, one Trans-Tek Model 244 LVDT displacement transducer (0-1 inch for 0-4 v out) without signal conditioning, two SR-4 strain gages with one 5B38-04 half bridge Signal Conditioning Module, one CB-50 Connector Block and one 2050 Adapter Board.

*Experiment 8*: Linear Vibrations; one 5B Backplane, one Sensotec MDL-3000 (+/- 3 in) LVDT displacement sensor without signal conditioning, one Sensotec JFT-3630-01 (+/-3g) accelerometer with a 5B30-05 Signal Conditioning Module (+/-100 mV in for +/-5 v out), one 2050 Adapter Board, one CB-50 Connector Block..

*Experiment 9:* Rotational Balancing; one 5B Backplane, one Sensotec JFT-3630-01 accelerometer with 5B30-05 Signal Conditioning Module (+/-100 mV in for +/-5 v out), one 2050 Adapter Board.

*Experiment 10*: Piston/Crank & Cam-Follower motion; one 5B Backplane, two Sensotec MDL-3000 (+/-0.25 in and +/- 1 in) LVDT displacement sensors without signal conditioning, one CB-50 Connector Block.

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