DESIGN OF MODERN, INTEGRAGTED LABORATORY-STATION (ILS) FOR ENGINEERING EXPERIMENTAL COURSES

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ABSTRACT

The objectives were to design modern, Integrated Laboratory Stations (ILS) including well balanced blend of fluids/thermal and structural/mechanical, electronic and computer technology, with a goal to teach engineering students the most important experimental skills and expose them to modern instrumentation and experimental methods, expected by their future employers. The new design of ILS apparatus incorporates modern sensors and computerized data acquisition (DAQ) with signal conditioning, including data analysis and presentations, as well as improvement in efficiency of presenting ever increasing context in limited number of contact and lab hours. Within a single bench with shelves, a number of apparatus with different typical sensors and instruments are integrated with computerized DAQ system. More apparatus could be added if needed and variety of experiments could be developed using designed apparatus, instrumentations and sensors.

1. INTRODUCTION

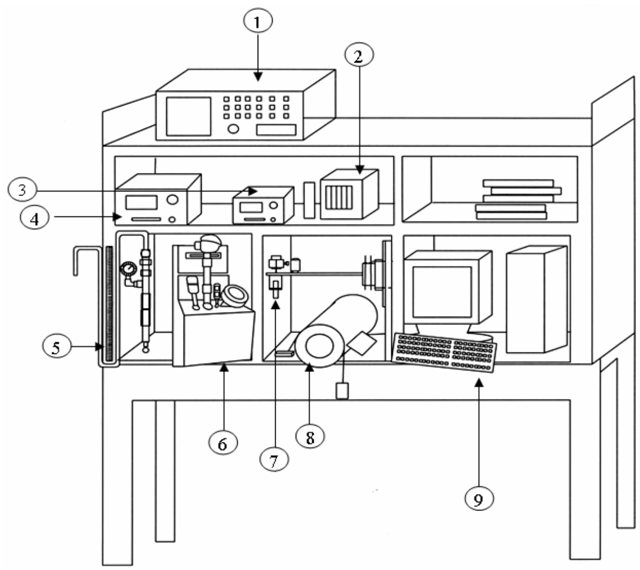
Experimental methods are very important in engineering education and even more so in engineering practice. A modern Integrated Laboratory Stations (ILS) has been developed, fabricated and assembled to support objectives of experimental courses and related activities at the Department of Mechanical Engineering (ME) at Northern Illinois University (NIU). Using the ILS apparatus the ME students will be exposed to modern sensors, instrumentations and computerized data acquisition (DAQ) components and systems, and perform basic calibration and comparative measurements, as well as investigate properties and control basic mechanical sensors, components and apparatus. Furthermore, the students will analyze measured data using modern computerized DAQ system (NI Data Acquisition-DAQ Hardware, 2005) and LabVIEW® application software (NI LabVIEW® Application Software, 2005), as well as use obtained results for comparison with known reference and/or theoretical data, feedback for apparatus control, and finally for effective technical analysis and presentation of their experimental work. Last but not least, the integrated design with vertical shelves and back to back and next to each other layout of multiple lab stations will save on lab space and make the teamwork more convenient.

The PC-based data acquisition, which emerged in the 1980's, is revolutionizing the way engineers and scientists are taking measurements now and especially in the future (Kostic, 1998). Rather than using a set of specialized instruments that sometimes require transcribing measurements to paper for data logging, the PC-based data acquisition helps harness the existing computational power to efficiently develop the measurements and control engineering components and systems (Kostic, 1997). A typical DAQ system contains sensors and transducers to sense the measured signals, cabling and signal conditioning hardware, plug-in DAQ PC-board, and finally PC and application software to support the data acquisition, storage and processing, including what-if analysis, graphing, and data presentation and publishing. A widely used LabVIEW® **(L**aboratory **V**irtual **I**nstrument **E**ngineering **W**orkbench**)**, a graphical programming application software, developed by National Instruments, is integrated with ILS apparatus. It is suitable for developing automated instrumentation systems using the plug-in DAQ boards and other inexpensive off-shelf components.

2. INTERGRATED LABORATORY STATION (ILS)

The Integrated Laboratory Station (ILS), as described next, is a typical DAQ system with modern sensors (some are robust industrial components for demonstration purposes), signal conditioning components (SCXI), a plug-in DAQ PC-board, and application software to support the DAQ hardware. Basic demonstration, comparison and calibration of different sensors and instruments are provided. The objective is to use the off-shelf computerized data acquisition components for experimentation and calibration of different sensors common in real life measurements, as well as to gain the valuable experience by working with modern technology, expected from contemporary engineering graduates. The ILS apparatus is designed to provide versatility, flexibility and visibility, see Fig. 1, in order to facilitate effective execution of typical engineering measurements, analysis and presentation using LabVIEW® and other engineering software applications. The ILS apparatus has standard industrial input/output connections and interfaces, thus providing capability for expansion of add-on and/or mobile components. Since all different sensors/instrumentations are integrated at the same bench-station, all measured data will be acquired using the same DAQ system and other standard instruments. Students will have an effective learning curve and after proper introduction, they should be comfortable with experimentation and other lab projects.

The ILS apparatus, schematically presented in Fig. 1, consists of a 6 *ft* long × 3 *ft* wide × 6 *ft* tall bench with add-on shelving, which houses four units: (***i***) Temperature Sensors Unit, for calibration of and measurements with different temperature sensors, see Section 2.1, (***ii***) Pressure Sensors Unit, for calibration of and measurements with different pressure sensors, see Section 2.2, (***iii***) Cantilever Beam and Sensors Unit, for calibration of and measurements with strain gage, accelerometer sensors and non contact linear displacement transducers, see Section 2.3, and (***iv***) Motor Investigation and Sensors Unit, for calibration of and measurements with tachometer and load sensors, torques, start-up characteristics, and computerized motor control, see Section 2.4. The ILS apparatus also houses basic bench-top instrumentation and computerized data acquisition (DAQ) with signal conditioning components (SCXI), see Section 3. Different calibration and measurements could be set-up and performed using the standard, stand-alone instrumentations and also using computerized DAQ system, with interactive and follow-up analysis and graphing, comparisons with reference data, and technical presentations.

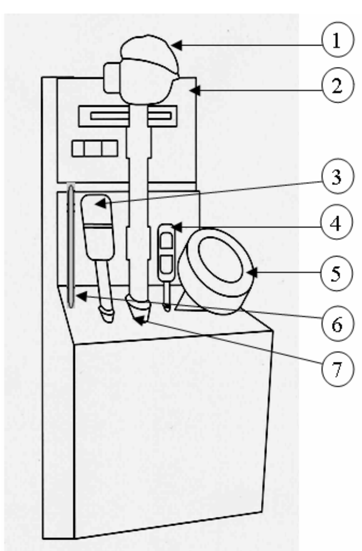


Pos.No.	Component
1	Oscilloscope
2	SCXI & DAQ Equipment
3	Multimeter and Function generator
4	Power Supply
5	Pressure Sensors Unit
6	Constant-temperature Bath with Temperature Sensors Unit
7	Cantilever Beam and Sensors Unit
8	Motor Apparatus and Sensors Unit
9	Computer with Monitor

Figure 1: ILS Apparatus with sensors units and instrumentation components.

2.1. Temperature Sensors Unit

The Temperature Sensors Unit, see Fig. 2, consists of a constant temperature bath and a specially designed temperature sensors holder-plate with five temperature sensors, as described below.



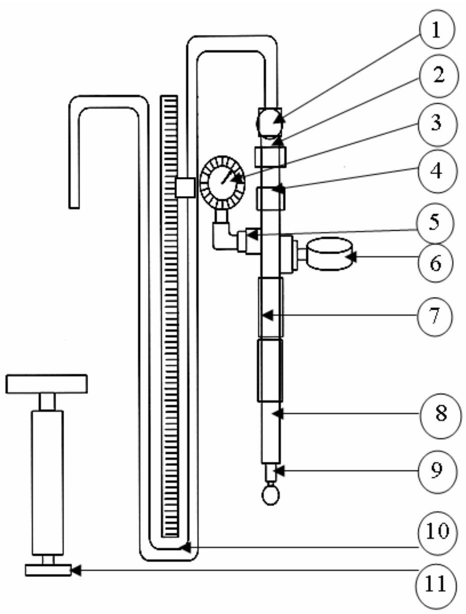
Pos. No.	Description	Brand/Vendor and Part No.
1	Spring-Loaded thermocouple probe with cast iron head, type J calibration, inconel sheath, 1/16" O.D., grounded junction, 12" length	Omega NB1-ICIN-116G-12-TBSL
2	Constant Temperature Bath with Temperature Sensors Fixture Plate: Max temperature 180° C, precision 0.1° C	Haake A81
3	RTD probe: Quick disconnect type PR-13 RTD probe with mating connector, style 2 wiring (3 leads), 100 ohm @ 0°C, 1/4" diameter, 6" long, European curve (alpha = 0.0385)	Omega PR-13-2-100-1/4-6-E
4	Quick-disconnect thermocouple probe: Subminiature quick-disconnect thermocouple probe, type-K, 0.125" O.D. stainless steel sheath, grounded junction, 6" length	Omega KMQSS-125G-6
5	Dial Thermometer with 3 inch head, 6 inch stem length, 0 to 100°C range, ¾ inch NPT thread and reset screw	Omega A-0-100C-6-3/4
6	Red Safety Liquid-filled-in-glass Laboratory Thermometers 5 to 105 C range, 1° division	Omega GT-6410RL
7	Solid black Rubber stoppers: Made of high quality rubber with resiliency and pliability over a long period. Top ϕ=24mm, bottom ϕ=18mm, height=25mm	Voigt Item Group Code STP07 Size 3

Figure 2: Temperature sensors unit.

Calibration and comparative measurements using different temperature sensors could be performed at different temperature levels provided by the constant temperature bath. The temperature sensors' characteristics, like accuracy, precision and dynamic characteristic could be analyzed and estimated along with the uncertainty in measurements of each of the sensors.

2.2. Pressure Sensors Unit

The Pressure Sensors Unit consists of a specially designed pressure sensors manifold made of appropriate piping and fittings, see Fig. 3. It houses common pressure gage, a pressure sensor, and a U-tube manometer, all attached to the same pipe-manifold. Calibration and comparative measurements using different pressure sensors could be performed at different pressure levels provided by pressurizing the pipe-manifold with hand air-pump. The pressure sensors characteristics, like accuracy, precision and dynamic characteristic could be analyzed and estimated along with the uncertainty in measurements of each of the sensors.

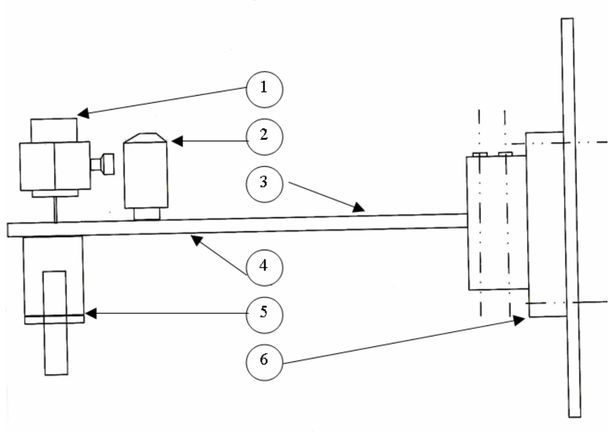


Pos. No.	Name or Description	Make/Vendor and Part number
1	Brass Air Tank Valve	McMaster 8063k37
2	Quick Opening Worm-Drive Hose Clamps	McMaster 5322K14
3	Pressure gage	Omega PGC-25L-15
4	Pipe Union	McMaster 4881K69
5	Reducing Hex Bushing	McMaster 4881K611
6	Pressure sensor	Omega PX139-030A4V
7	Pipe Fitting	McMaster 4880K109
8	Pipe manifold	
9	Brass Shut-Off Plug Valve	McMaster 7910k13
10	U-tube manometer (Teflon PTFE Tubing)	McMaster 5239K18
11	Hand Pump	RecSupply.com OO-9341-50

Figure 3: Pressure sensors unit.

2.3. Cantilever Beam and Sensors Unit

A simple cantilever beam apparatus is designed to provide measurements of deflection (displacement), strain, and acceleration using typical transducers and sensors, depicted on Fig. 4. The cantilever beam is attached to the bench shelf using specially designed holder. Using measured displacement and strain, it is possible to determine the stress under load or material properties of the beam, like modulus of elasticity. Measuring the change of displacement, stress or acceleration in time, by using the oscilloscope or DAQ system, it is possible to determine vibration of the beam and its natural frequency.

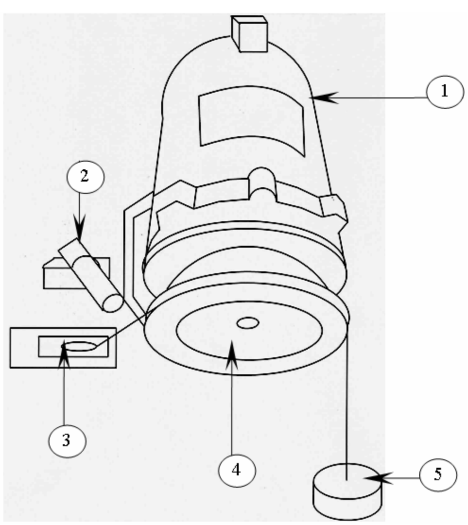


Pos. No.	Name or Description	Part No.
1	Miniature DC Displacement Transducers with +/- 5 mm linear stroke	LD400-5
2	Accelerometer with 10 foot cable	ACC101
3	General Purpose Foil Strain Gages 120 Ohm for Aluminum	SG-3/120-LY43
4	Cantilever Beam	-
5	Non-contact linear displacement sensor with 2-5 mm range	LD701-2/5
6	Cantilever Beam Holder	-

Figure 4: Cantilever beam and sensors unit.

2.4. Motor Investigation and Sensors Unit

The Motor Investigation and Sensors Unit, see Fig. 5, consists of a flywheel mounted on the shaft of a variable-speed electric motor, which characteristics are to be investigated. The motor-flywheel system's rotational speed may be varied by changing the power using the motor drive and control unit, see Fig. 6. Different torque load may be applied on the motor by friction of winded rope around the flywheel on which a hanger with the standard weights is attached at one side, while the other side is fixed to a load cell, which measures the holding force. First, the tachometer is to be calibrated, then torque load vs. rpm characteristic could be investigated, and finally, motor-flywheel start-up dynamic characteristic is to be measured with an oscilloscope and DAQ system. Lastly, the mass-moment of inertia of the flywheel is determined using the start-up dynamic characteristic results and compared with independent results obtained by using known geometrical and material properties of the rotating system.



Position No	Description	Part No
1	DC Electric Motor: 1/3hp 1800RPM 56C Frame 24volts DC TENV, 13.5 A, 22 lb	Electric Motor Warehouse 108050
2	Speed Sensors: Non-Contact Speed Sensors with Pulse Output from 0 to 20 kHz	Omega SPR101-12N
3	Load cell: Half bridge, tension/compression load cell +/- 20 lb capacity	Omega LCLB-20
4	Flat Idler Pulley: 5 3/4" OD overall, 5" running dia., inside flat width 1 1/8", 17 mm bore bushed to 5/8", heavy duty, painted	Phoenix Pulleys 37500113
5	Standard Weights	-

Figure 5: Motor investigation and sensors unit.

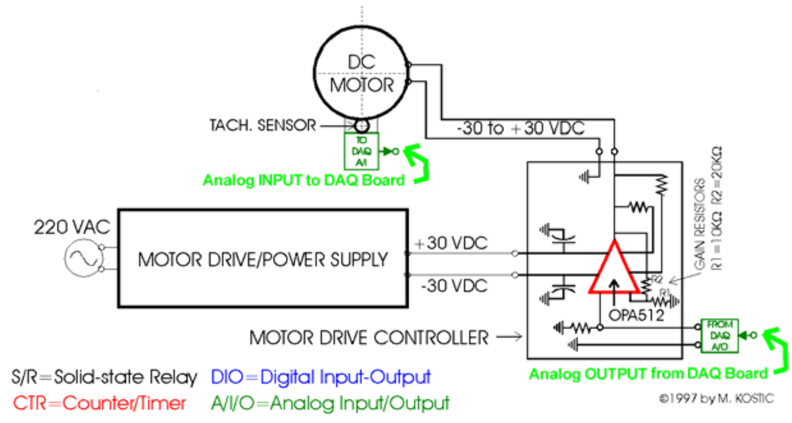


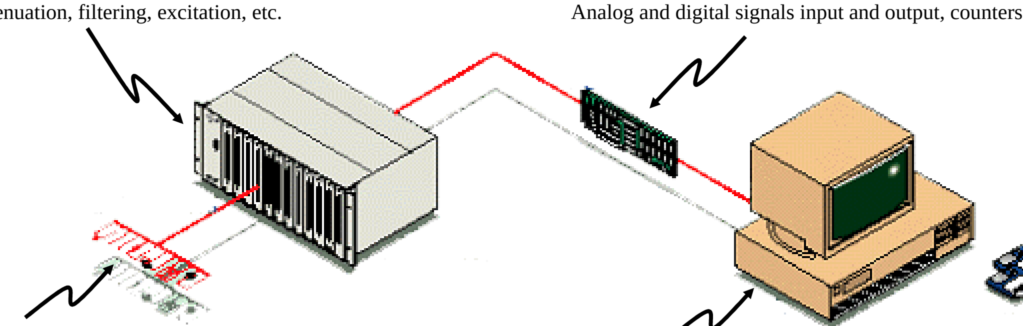
Figure 6: Motor power supply with control drive and tachometer.

3. BENCH-TOP INSTRUMENTATION AND COMPUTERIZED DATA ACQUISITION

The measurements of different physical quantities could be performed in three different ways: (1) directly with those sensors or instruments which have built-in output scale or display; (2) using sensors and standard bench-top instrumentation, like multimeter or oscilloscope; and (3) using sensors and computerized signal-conditioning (SCXI) and data acquisition system (DAQ), see Figs. 1 to 7, and for more details see Table 1. In addition, LabVIEW® application software is used for automatic measurements and control, like motor drive and control, see Fig. 6. The LabVIEW application program could be developed for automatic measurements and control, data acquisition, data analysis and feedback control, including data presentation and publishing. Furthermore LabVIEW features allow for convenient remote and on-line (over Internet) data measurements and automation, as well as online data acquisition and sharing (Kostic, 2001 & 2003). Important part of data acquisition is cabling and signal conditioning or SCXI components, see Table 1. The incorporated SCXI Bundle is a flexible signal conditioning system for many different types of sensors and transducers. The SCXI is also beneficial for high channel count systems. Included in the bundle is LabVIEW, SCXI-1000 chassis, PCI-6024E DAQ board,

SIGNAL CONDITIONING: Modify transducer signals to match DAQ board specs/ranges. *Examples*: amplification or attenuation, filtering, excitation, etc.

PLUG-IN DAQ BOARD: Measures (acquires), processes, stores, and generates signals, as instructed by software program. *Examples*: Analog and digital signals input and output, counters, timers, etc.



TRANSDUCERS: Sense the measured quantities and change their properties or generate corresponding electrical signals. *Examples*: strain gage, thermocouple, accelerometer, potentiometer, etc.

COMPUTER with SOFTWARE: Control the DAQ board, process, store, and display data, as instructed by software program. *Examples*: LabVIEW application programs to acquire data, simulate instruments, and generate results, etc.

Figure 7: A Typical data acquisition (DAQ) system.

SCXI-1349 1-meter cable, SCXI-1180 feed through panel, and an SCXI-1302 terminal block (NI SCXI Academic Bundle, 2005). Additional SCXI components are described in Table 1.

Table 1: Bench-Top Instrumentation and Computerized Data Acquisition

S. No	Description	Part No	Vendor	Qty.
1	Agilent Technologies Digital Multimeter, 6.5 digit precision	34401A	Newark Electronics	1
2	Tektronix Digital Storage Oscilloscope	TDS1012	Newark Electronics	1
3	Tektronix Oscilloscope Communications Extension Module	TDS2CMA	Newark Electronics	1
4	Agilent Technologies Power Supply	E3644A	Newark Electronics	1
5	SCXI Bundle for 120 VAC: SCXI-1000 Chassis, PCI-6024 DAQ Board, SCXI-1349 Cable, SCXI-1302 Terminal Block, and LabVIEW Professional	777448-37	National Instruments	1
6	SCXI-1102 32-Channel Thermocouple Amplifier	776572-02	National Instruments	1
7	SCXI-1303 32-Channel Isothermal Terminal Block	777687-03	National Instruments	1
8	SCXI-1322 Temperature Sensor Terminal Block	777687-22	National Instruments	1
9	SCXI-1122 16-Channel Isolated Transducer Multiplexer	776572-22	National Instruments	1

4. CONCLUSION

All of the lab demonstrations for MEE 390, Experimental Methods in ME course at NIU, are to be developed around the Integrated Laboratory Stations (ILS) and could easily be replicated in as many units as needed depending on the class sizes and future enrolment. The ILS apparatus is like an automated *"Mechatronics Bench"* with typical mechanical and electronic instruments used by engineers in industry and research laboratories today. Since the ILS apparatus incorporates standard industrial input/output connections and interfaces, thus providing capability for expansion of add-on and/or mobile components, which further facilitates research experience in other science, engineering, and design courses, including students' competitions. Restructuring lab courses based on ILS apparatus could result in significant curriculum impact.

In addition to basic calibration and measurement experiments, additional experiments could be designed by students and faculty for special and individual projects. It is expecting that other faculty contribute to further development and utilization of newly designed ILS apparatus.

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NI LabVIEW® Application Software (2005): www.ni.com/labview

NI SCXI Academic Bundle (2005): http://sine.ni.com/apps/we/nioc.vp?cid=13144&lang=US

NI Signal Conditioning (SCXI) Hardware (2005): www.ni.com/signalconditioning