2006 LabVIEW in the Curriculum Paper Contest

- National Instruments LabVIEW in the Curriculum Academic Conference is for those interested in teaching, researching and learning with NI LabVIEW.

- This booklet collects together the best submissions, including our three winners from the 2006 LabVIEW in the Curriculum Paper Contest, which celebrates innovative uses of virtual instrumentation in teaching or research.

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2006 LabVIEW IN THE CURRICULUM PAPER CONTEST

The 2006 LabVIEW in the Curriculum Paper Contest celebrates innovative uses of virtual instrumentation in teaching or research.

JUDGING AND CRITERIA

A panel of NI technical experts and executives judged the technical papers according to the following criteria:
1. Is the application an excellent example of virtual instrumentation in teaching or research?
2. Is the application innovative, timesaving and cost-effective?
3. Are the benefits and solution clearly articulated?

CONTEST WINNER AND RUNNERS UP

1ST PRIZE – Virtual Underwater Lab: Efficient Tool for System Integration & UUV Control Development, Edin Omerdic, University of Limerick (Page 56-79)

2ND PRIZE – LabVIEW as a tool for measurements, batch data manipulations and artificial neural network predictions, Dr Stan Zurek, Dr Philip Marketos and Prof. Tony Moses, Cardiff University (Page 112-119)

3RD PRIZE - Development of an Active Damping System for a Racing Car using cRIO Hardware and LabVIEW Software, Richard Elliott MEng, Cardiff University (Page 21-26)

A SELECTION OF OTHER ENTRIES TO THE CONTEST

Developing a software for real time monitoring of thermal limitation in High Efficiency Deep Grinding (HEDG), Andre Batako, Siva Koppal, Liverpool John Moores University (Page 1-9)

Application of Virtual Instruments (VIs) for an enhanced learning environment, Dermot Brabazon, Philip Smyth, Eilish McLaughlin, Dublin City University (Page 10-17)

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Remote access and monitoring of two phase flow rig using Web/WAP protocol, Nadeem Qazi, Cranfield University (Page 80-85)

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Overview of the Instrumentation System Developed for a VW 1.9 TDI Diesel Engine Installed in Loughborough University’s Powertrains Laboratory, Edward Winward Meng AMImechE, Loughborough University (Page 96-111)
Developing a software for real time monitoring of thermal limitation in High Efficiency Deep Grinding (HEDG)

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Products used:
LabVIEW 7.1

The Challenge:
The challenge of this research work is to develop a new control system for temperature monitoring in grinding process, with an easy-to-use front end, to assist the operator in decision-making on the quality of the process in order to improve production efficiency by avoiding burn of workpiece.

The Solution:
The developed software is integrated in the grinding operations in Laboratory conditions to ensure that, the ground workpiece does not reach the critical damaging temperature and ensure good surface integrity and improved workpiece quality.

ABSTRACT
High Efficiency Deep Grinding (HEDG) unlike the normal surface grinding is known to operate under a new grinding regime. Grinding under this new regime offers a positive outlook for the grinding industry. Direct benefit associated to this operation is a high removal rate with reduced thermal damages during grinding. Thermal damages are continuously monitored through the employment of a single pole grindable thermocouple. The thermocouple is inserted into the workpiece and provides real time temperature reading. Signals obtained from the thermocouples are then fed into the Data Acquisition (DAQ) system that operates with LabVIEW. The combination of LabVIEW and MatLab produces the data processing system software, which analyses the temperature profiles. The benefits of the developed software include the ability to control the maximum grinding temperature and to predict grinding temperature based on actual spindle power. Any measured temperature exceeding the critical temperature activates the alarm. This allows for the avoidance of defect and burn and reduces the amount of rejected workpieces.

1.0 INTRODUCTION
Grinding is an important operation engaged in production engineering to remove unwanted material and to introduce desired geometry and surface properties. Once considered as a secondary operation, grinding is now more widely known as ‘abrasive machining’. Many processes associated with grinding can be extremely complex such as the high efficiency deep grinding. HEDG operation works under a new grinding regime, achieving low specific grinding energy with high material removal rate. The success of HEDG is dependent on the improvements made towards monitoring the quality of the workpiece by means of accurate temperature measurements. There are numerous developments in temperature measurement, ranging from the most sophisticated equipment such as the acoustic emission to a simple thermocouple. Some temperature measuring equipments proved to be advantageous however, with reference to practical application, cost and reliability; thermocouple emerges as the most dominant temperature measuring technique in laboratory testing environment. The measured temperatures are used to monitor thermal limitations in the grinding zone in order to control excessive heat concentration in the grinding zone which burn and tensile stress hence, low quality workpiece. The removal of intense heat from the grinding zone is dealt with the coolant application and extremely fast wheel speed. Thermal modelling is used to predict the temperature rise in the grinding zone. The
distribution of total heat flux generated in the grinding zone varies depending on the system configuration.

Understanding the heat flow help to minimise the damage to the workpiece and to the grinding wheel. This highlights the importance of heat partitioning ratio between the wheel, the workpiece, the chip, the coolant and the environment. The prediction of maximum dry and wet temperatures is based on the measured power. The predicted value is compared with measured temperature from the workpiece. It is essential to maintain an agreement between both the theoretical and experimental values. Accurate temperature measurement is an essential factor when monitoring thermal damages in ground workpieces. Inserting single pole grindable thermocouples into a workpiece secures most accurate temperature measurements. The temperature signal from the grinding operation through the thermocouples is fed into a data acquisition system. The objective of the data acquisition system in a grinding process system is to capture, process, analyse and present the data in a format that advise the operator to tame immediate decision to avoid damage.

2.0 DATA ACQUISITION SYSTEM

A National Instrument DAQ NI 6100 data acquisition board was used with the NI BNC-2120 kit to facilitate the connection between the source of the signal and the DAQ itself. Figure 1 shows the actual grinding machine under investigation. This us a unique high speed, high stiffness grinding machine developed at Liverpool John Moores University. This machine can take deep cut 1-5 mm (tested) up to 25 mm (planned). The wheel speed can reach 145 m/s with a work speed up to 3.3 m/s. The drive is a 63 kW motor and the spindle unit has a high stiff hydrostatic bearings. In order to predict the temperature in the grinding zone, the power is measured. The measured temperature for the thermocouple is used to validate the prediction model. In this experimental set up the grinding wheel speed was 4000 rpm on average with a feed rate of 250-500 mm/s.

Figure 1: picture of the actual grinding machine

Figure 2 illustrates the schematics of the data flow through the system. More than five parameters including acoustic emission are monitored. However, in the frame of this investigation four parameters were monitored because the NI-6100 has only four inputs. These parameters are: temperature, power, table speed and feed force. It is possible to calculate the grinding power from the feed force as well as from the differential pressure of the hydrostatic bearings.
3. Temperature modelling

Temperature modelling [1-6] has been used to predict the temperatures in the grinding zone in order to achieve damage free grinding process. Figure 3 illustrates the schematics of a circular arc of contact used for temperature prediction in grinding. The contact surface is assumed to lie around a circular arc. The heat source is the summation of infinite moving line sources disposed around the contact arc. The contact length $l_c$, is arc AFB. A line source at $F(x_i, z_i)$ moves at speed $v_w$ parallel to the x-axis at angle $\phi_i$ to the finish surface BC. The varying angle $\phi_i$ is the angle FBC, the maximum value of it along the arc AFB is the contact angle $\phi$. The length of the arc, BF is $l_i = d_e \phi_i$ where $d_e$ is the effective wheel diameter. The temperature rise at any point $M(x, z)$, due to the whole heat source AB, is

$$T = \frac{1}{\pi \cdot k} \int_0^{l_c} q \cdot e \cdot \frac{v_w \cdot (x - l_i \cos \phi_i)}{2 \cdot \alpha} K_0 \left[ \frac{v_w \cdot r_i}{2 \cdot \alpha} \right] dl_i$$  (1)

$$r_i = \sqrt{(x - l_i \cos \phi_i)^2 + (z - l_i \sin \phi_i)^2}$$  (2)

$K_0$ is the order zero Bessel function of the second kind. $\alpha$ is thermal diffusivity and $k$ is thermal conductivity. For a rigid wheel and workpiece the contact length for deep cuts is given by,

$$l_c \approx \sqrt{a_e \cdot d_e}$$

The contact angle may be estimated from the contact length and the effective wheel diameter: $\phi = l_c / d_e$ and $q$ is heat flux (power per unit contact area)

Figure 2: Sketch of data acquisition system for HEDG
3.1 Simplified model

The total machining power is converted into heat. The total heat flux $q_t$ is obtained by dividing the measured power by the contact area. The total heat flux is ten portioned between major heat sinks i.e. workpiece, wheel, fluid and chips.

Figure 4 shows the major heat sinks used in the

\[
q_t = \frac{q_w + q_s + q_{ch} + q_f}{A} \tag{3}
\]

Where: $q_w$ is Heat flux entering the workpiece; $q_s$ is Heat flux entering the grinding wheel; $q_{ch} =$ Heat flux carried away by the chips; $q_f$ is Heat flux carried away by the fluid.

Heat fluxes are derived as a product of the respective heat convection factors ($h$) and maximum contact temperature ($T_{max}$).

\[
q_w = h_w \cdot T_{max} \tag{4}
\]

\[
q_s = h_s \cdot T_{max} \tag{5}
\]

\[
q_f = h_f \cdot T_{max} \tag{6}
\]

\[
q_{ch} = h_{ch} \cdot T_{mp} \tag{7}
\]

Where $h_w$ is heat conduction factor for the workpiece, $h_s$ is the heat conduction factor for the grinding wheel, $h_f$ is the heat convection factor for the fluid, $h_{ch}$ is the heat conduction factor for the chips and $T_{mp}$ is the melting point temperature of the chip. The total grinding heat flux $q_t$ is calculated from the following equation for known specific grinding energy $e_c$.

\[
q_t = \frac{e_c \cdot a_e \cdot v_w}{l_c} \tag{8}
\]

Where $a_e$ is the actual depth of grinding cut, $e_c$ is the specific energy, $v_w$ is the workpiece feed rate and $l_c$ is the contact length between the grinding wheel and the workpiece. The total heat flux $q_t$ can also be derived from the power supplied to the spindle from the equation below.
\[ q_i = \frac{P}{b \cdot l_c} = \frac{F_t \cdot v_s}{b \cdot l_c} \tag{9} \]

Where \( P \) is the spindle power, \( b \) is the grinding material width, \( l_c \) is the contact length; \( F_t \) is the tangential grinding force and \( v_s \) is the wheel linear speed. The heat transferred into the chip can raise its temperature up to the melting point; thus using \( T_{\text{max}} \) as melting point temperature (\( T_{\text{mp}} \approx 1250 \, ^\circ\text{C} \)), the heat flux carried out by the chip is calculated as follows

\[ q_{ch} = \rho \cdot c \cdot T_{\text{mp}} \cdot \frac{a_e v_w}{l_c} \tag{10} \]

Where \( \rho \) is the density of the workpiece material, \( c \) is the specific heat capacity, \( T_{\text{mp}} \) is the melting temperature, \( a_e \) is the real depth of cut, \( v_w \) is the workpiece speed and \( l_c \) is the contact length.

Alternatively \( q_{ch} \) can also be derived as

\[ q_{ch} = e_{ch} a v_w \frac{v_w}{l_c} \tag{11} \]

where \( e_{ch} \), is the specific energy per unit volume for the chip. The heat flux into the workpiece can be expressed as

\[ q_w = \frac{\beta_w}{C} \sqrt{l_c} v_w T_{\text{max}} \tag{12} \]

This allows in determining \( T_{\text{max}} \) as in Eq. (2) by computing the workpiece conduction factor as

\[ h_w = \frac{\beta_w}{C} \sqrt{\frac{v_w}{l_c}} \tag{13} \]

The maximum heat flux convected away by the grinding fluid can be estimated by

\[ q_f = (T_b - T_o) \cdot h_f \tag{14} \]

Where \( T_b \) is the film boiling temperature of the grinding fluid, \( T_o \) is the ambient temperature, which is assumed to be 20°C and \( h_f \) is the heat convection factor for the cooling fluid.

4. DEVELOPING A GRINDING PROCESS SOFTWARE

The software can be entirely developed using either LabVIEW or MatLab however, a combination of both is used for this research work. The primary role of MatLab in this software development is for data manipulation and temperature prediction model, which uses some integration (eq.1-2). LabVIEW acquires the data, processes using the simplified model and produces a graphical presentation.

The development of the grinding process software was divided into three stages, which are data logging (data storage), analysing and data presentation. A piece of software for data logging was initially developed for general purpose. The next stage of this development was the analysis and presentation of the data, which are the main objectives. The use of circular buffer approach embedded in LabVIEW software enables to stream the data into a hard disc at high sampling rate (up to 1.5 MS/s). Figure 5 shows the basic front end of the software initially developed in LabVIEW 6.
The data logging software was developed and tested for a variety of sampling rates. The sampling rates range from 1 Hz up to as high as 1.5 MHz. However for this investigation a sampling rate of 150 kHz to 250 kHz was found to be adequate for this process. Figure 6 shows a MatLab script embedded into LabVIEW to deal with data manipulation and temperature modelling.

The data recorded for the sensors are highly noisy hence need filtering. These data splits into filtered and unfiltered signals to form temperature waveform graphs. The maximum filtered temperature is obtained from the array of max and min sub-VI, which also provide a numerical indicator on the front panel. Signal sampling is the most difficult task in a grinding process. This is...
because of the fast response needed to record the signals over a short period of time due very short contact time (few milliseconds). An increase in the sampling rate, result in high frequency noise being captured during this process. This high frequency noise distorts the readings from the measurements taken. Noise filters are introduced to filter the high frequency noise.

Maximum predicted temperatures are determined through successive computation of the simplified thermal model in eq.3-13. The newly developed software was validated against the values obtained from the experiments and predicted wet and dry maximum temperatures. The results obtained were in good agreement with each other.

*Figure 7: Block diagram for determination of Peclet number and C-factor.*

The greatest challenge in designing the software is determining the value of C factor. This is because C-factor remains constant for shallow grinding after a Peclet number of 10, however the scenario changes for deep grinding where the angle of contact varies drastically. Figure 7 shows the block diagram for determination of Peclet number and C-factor. Peclet number is a dimensionless parameter proportional to the work speed. It is also proportional to the contact length of the sliding heat source and inversely proportional to the thermal diffusivity of the material under the heat source [7].

\[
P_e = \frac{v_w \cdot l_c}{4 \cdot \alpha_w} \tag{15}
\]

Where \( P_e \) is the Peclet Number, \( l_c \) is the contact length, \( v_w \) is the workpiece speed and \( \alpha_w \) is the thermal diffusivity of the workpiece. The contact length \( l_c \) can be expressed as \( l_c = 2l \).

The workpiece thermal diffusivity is

\[
\alpha_w = \frac{k_w}{\rho_w \cdot c_w} \tag{16}
\]

where \( k_w \) is the workpiece conductivity, \( \rho_w \) is the workpiece density and \( c_w \) is the workpiece specific heat. Due to time dependent and two-dimensional heat flow, the precise value of C depends on the value of the Peclet number. As an example for values of \( P_e=10 \), the value of C is 1.06 for shallow grinding. This value is constant even for \( P_e \) exceeding 10.
For deep grinding, the values of C can be selected to reflect temperatures on the plane of the finished workpiece surface. Higher Peclet numbers couple with higher contact angle and the value of C will decrease. For an example, the angle of contact for shallow grinding is 0 degrees however, for deep grinding the angle of contact could go as deep as 40 degree with an increasing Peclet number which will eventually reduce C factor as shown in Figure 9.

![Figure 8: Factor C determination graph [1, 5, 7]](image)

In Figure 9, it is seen that the front panel provides a graphical presentation of the grinding process. Process parameters are defined on the left hand side of the panel. The operator sets the workpiece material, work speed, wheel material, wheel speed, wheel diameter, depth and width of cut and the type of coolant as well as the critical grinding temperature. After grinding the predicted dry and wet temperatures are displayed and an alarm alerts the operator if the process does not meet the required criteria in terms of critical temperature. The actual recorded signal of power and temperature is also displayed in form of raw and filtered signal.

![Figure 9: Front panel of a fully developed software with operating parameters](image)

6. CONCLUSION

This research work proves that it is possible to combine both MatLab and LabVIEW software to develop an open loop control system for grinding operations. The operating parameters are easily changed and the results can be viewed with the advancement in the virtual instrumentation. The
developed grinding process monitoring provides a great assistance to the operator. However it is an open loop control that includes the operator who takes the decision depending on the warning information provided by the system. The developed software provides a real time monitoring of thermal limitation in high efficiency deep grinding in laboratory conditions. Efforts are being made towards the improvement of the system to develop a close loop control of grinding processes. It is intended to build a process database with historical trend to support the system. Further work includes the fusion of all the above-mentioned work to develop a neural network to provide optimal process parameters in HEDG.

Reference:
Application of Virtual Instruments (VIs) for an enhanced learning environment

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Products Used:
6024E series with connector block SCB68 and USB DAQ 6009
LabVIEW 7.1
DAQ MX 8.1

The Challenge:
Unless laboratory classes are sufficiently explicit, students can find it difficult to visualise the concepts being taught. Laboratories should also be engaging to help develop student’s interest in the subject matter. The challenge in this work was to develop laboratories that meet these goals by evaluating their effectiveness.

The Solution:
Develop and implement pedagogically sound virtual instruments to aid the learning process. Compare the student’s laboratory results for a control group that took the non-instrumented version with those who took the instrumented laboratory and examine the statistical significance of these.

Abstract
Over the past two years, seven Virtual Instruments (VIs) have been developed using LabVIEW software and associated instrumentation. These have been piloted with over 200 undergraduate and postgraduate engineering and science students at Dublin City University (DCU). VIs developed for:

- Moment of inertia laboratory
- Simple harmonic motion evaluation
- Load cell examination and application
- Linear variable differential transformer (LVDT) and accelerometer examination
- Centrifugal force investigation
- Determination of beam shear centre position
- Control and measurement from an automated capillary viscometer

This implementation phase was coupled with evaluation of traditional teaching methods versus the new instrumented laboratory methodology. Quantitative evaluation of student performance in both continuous and final assessments has shown a statistically significant improvement in student learning for those who took the new instrumented laboratories. Qualitative analysis of videotaped laboratories and questionnaires also show an increased level of student interaction with the instrumented experiments. The methodology developed, which is applicable to all discipline areas, and evaluation of the results is presented in this paper. VIs provide cost effectiveness by allowing the virtual instrumentation of conventional teaching and research equipment, as well as a more interactive experience for distance learning students who can interact with the VI and control experiments remotely.

1. Introduction and Rationale

Effective and appropriate experimentation is often seen as a highly significant component of an undergraduate engineering or science based curriculum. Third level institutions are under pressure to keep up to date with commercial advances and technology; so that students graduating from their courses have the necessary skills to operate in a competitive business
environment [1]. However indications are that due to the high cost involved in upgrade and maintenance of equipment, that there has been a decline in the emphasis placed on experimentation in engineering courses in recent decades [2]. Institutions attract new students to their courses by making them interesting, comprehensive and relevant to industrial applications and the majority of graduates either continue within academia or take up employment in their chosen discipline. In both, research and industrial applications, it is commonplace to use a computer for data acquisition. Students that have not gained experience in automated systems during their course work are disadvantaged both in acquiring and performing the duties required. Virtual instrumentation can help not only the students but the faculties themselves by recreating the equivalent of very expensive conventional laboratory equipment quite cheaply [3]. Through the use of a Data Acquisition (DAQ) tools, students can record relevant data from the experiments in real time. This allows students to concentrate on the concepts and details of experiment itself and not get distracted by the process of data recording. Animations, images and video clips can also be embedded within the virtual instrument which engage students and give them real world examples that relate to their coursework. Students can thereby gain not only a better understanding of what they are doing but why they are doing it [3].

This departure from more traditional labs can benefit the faculty in terms of reduced monetary cost as the throughput of students can be increased and the number of laboratory demonstrators can be reduced. The implementation and use of virtual instrumentation and Computer Based Learning (CBL) techniques also provides a more user friendly environment for the demonstrators to work in. The VIs can be readily turned into web pages allowing students to remotely access and control the experiments via the web. This provides a useful resource for students who took the laboratory session. However, this is especially beneficial in cases where distance, personal disability or lack of resources once meant that students would not previously have had an opportunity to perform the experiment. The use of VIs can also be combined with other methodologies, such as problem based learning or guided inquiry, to allow the design of an interactive environment at a minimal cost.

2. Details of Work

In the conventional laboratory, the students were given a lab manual which they had to read prior to starting the laboratory. From survey results, students often found it difficult with this method to understand what they had to do or how to find the result. The introduction of a virtual instrument for the laboratory experiments allowed the possibility of guiding the student through the operation of the experimental apparatus and the collection of the required data. The first five experiments for which virtual instruments were developed were picked from already existing laboratories that were used to aid the learning process. This section presents these five experiments, listed below, and the evaluation of the effectiveness of these experiments.

1. The moment of inertia laboratory (first year undergraduate)
2. Simple harmonic motion evaluation (first year undergraduate)
3. Load cell application (third and fourth year undergraduate)
4. LVDT and accelerometer (third and fourth year undergraduate)
5. Centrifugal force investigation (first year undergraduate)

The first experiment was developed to teach students the concept of moment of inertia and the law of conservation of energy. To do this students apply a well defined amount of potential energy to rotate a flywheel. By using theoretical relations equating this potential energy to the kinetic energy of the flywheel and the friction losses in the bearings the students calculate the moment of inertia. Two variables they need to do this is the maximum speed of the flywheel and the number of rotations that the flywheel makes. These parameters were difficult to measure without instrumentation.

The second experiment was designed to introduce students to principles of simple harmonic motion and to teach them how to investigate the effect of making small changes in amplitude. Students were also asked to determine the radius of gyration of a compound pendulum about its
centre of gravity and compare their measured values with that of a simple pendulum. This experiment requires students to record the period of oscillation for both the simple and compound pendulums. A simple manual electronic stopwatch had been used prior to instrumentation and had proved to be inaccurate depending on the reactions of the person using it. When instrumented, an optical sensor was used to more accurately calculate the time taken for each oscillation.

In the load cell application experiment students were asked to calibrate a load cell and determine some of its static performance characteristics. During the calibration students apply a load to the cell using a mechanical press. Two outputs are given to the students, a voltage output from the load cell being calibrated and an actual load reading given from an already calibrated cell in series within the press. The two data sets are recorded by the virtual instrument and graphed in order to show students the characteristic curve of the cell. Students must have wired the driving and measurement circuits and powered the load cell. In order to do this they must have a basic knowledge of electronics. Later in the experiment students also build an amplifier circuit for the load cell. Previously, this proved difficult for the majority of students to do and they needed help from the demonstrator. However with the aid of clear and concise explanations in the virtual instrument, students were able to attempt and complete the section un-aided.

The fourth experiment was developed to use the linear variable displacement transducer (LVDT) and an accelerometer to determine material and dynamic properties of a vibrating beam. In this experiment a cantilevered beam was allowed to vibrate in particular modes which are related to the beam geometry and material properties. Students previously found it difficult to visualise what is happening in real time and how to relate their results to the experiment. With the outputs from the LVDT and accelerometer being shown on a graph simultaneously as the experiment was being performed the students found it easier to understand the theory of harmonics as well as the difference between theoretical and experimental plots of mode shape.

The centrifugal force experiment was designed to allow students to visualise the relationship between the magnitude of centrifugal force acting on a body and its rotational speed and radius of rotation. The apparatus consisted of speed control unit, a tachometer and a rotating arm. The rotating arm had bell cranks at each end to which variable weights could be attached. When a sufficient speed was reached the bell cranks were flung out with an audible ‘click’. Students found it difficult to note the speed at which this happened. A microphone was added along with a virtual instrument to gather the data required for the experiment and also to give the students some real world examples of were such effect may be seen.

The VIs for the above experiments were developed using LabVIEW software and associated instrumentation, have been piloted with over 200 undergraduate engineering and science students at Dublin City University (DCU). The design of the virtual instruments for each of these experiments was divided along pedagogical lines into three sections which are presented consecutively to the students:

1. **Introduction**
   In this section, the students were given an overview of the experiment to be undertaken, an animation showing how it worked, what was being measured and how it related to real applications.

2. **Procedure and Data logging**
   In this part of the experiment students perform the experiment and see the data logged and graphed on the PC as they progress though the experiment.

3. **Theory and Calculations**
   In this section, the students work through their calculations manually and calculate the result being sought from the experiment. They then enter their own values into the computer and receive immediate feedback of how these compare to the automatically calculated values from the VI.
Figure 1 shows the datalog screen of the flywheel and load cell experiments. It is within this section, figure 1 (a), that students record the data required to calculate the experimental value for the moment of inertia. The total number of rotations of the flywheel is shown in the top left along with its rotational speed. Students are also shown a real time animation of the flywheel and a real time plotted graph of its speed against time. This makes it much easier for students to visualize what is going on in the experiment. When conducting the load cell experiment, students have to collect several groups of data sets from calibrated and uncalibrated load cells. Clear instructions and tips were included within the VI in order to guide the students through the experiment. In this experiment students apply a varied load to the load cell and the uncalibrated load cell the output of which was read into the PC with the aid of a NI USB DAQ 6009. The values from the already calibrated load cell were entered manually by the student. The resulting calibration plots were automatically plotted by the Virtual Instrument.
Figures 1 Front panel data capture screens from (a) the flywheel and (b) load cell experiments.

3. Results and Conclusions

The effectiveness of the new laboratory implementations was analysed using students from the same class some who took the instrumented and some the traditional non-instrumented versions of the same experiments. After completing the laboratory, the students’ were also given multiple choice questions (MCQs) based on the topics that they had just investigated. The effectiveness of student understanding was examined from the students' results for both the MCQs and the laboratory report grade. Students where also given questionnaires, which they completed anonymously, at the end of their laboratory course to determine which form of laboratory they preferred and which they felt to be the most enjoyable and effective.
Figure 2 presents the graphs of the average laboratory report results for the students. The effectiveness of each of the developed laboratories is presented along with the confidence interval on these results. This confidence interval was calculated on the basis of a 95% confidence level for a t-distribution. The results of the students for all of the experiments is also presented in figure 2 (f). Figure 2 (a) represents the results for the flywheel experiment. The flywheel was one of the first virtual instruments to be developed in this work and therefore has the largest number of students results for analysis (234 students). The average mark attained by students attempting the instrumented version was 65.34% in comparison to 56.15% on the uninstrumented. This represents an average student improvement of about one grade by students who took the instrumented experiment as opposed to non-instrumented. It is also important to note that after the first year of implementation, this virtual instrument was redesigned and improved. There was a clearer difference between instrumented and non-instrumented in the second year showing that it is not enough to just put experiments in virtual form but that their design is important for improved quality and effectiveness. The main difference between the two years, that can be attributed to this improvement, was that clearer instructions were given in the virtual instrument in the second year as to what the students had to do.

Figure 2 (b) – (e) also show an improvement in student learning for those that took the instrumented version over the non-instrumented version for the compound pendulum, load cell, LVDT and centrifugal force experiments respectively. The results for the load cell experiment did not show the benefit for the virtual instrument. The reason for this was that the students were not brought through the experiment by the virtual instrument but rather by the demonstrator. This was true for the non-instrumented and the instrumented experiments. The demonstrator also used the virtual instrument to aid both the instrumented and supposedly non-instrumented students. In figure 2 (e), the centrifugal force experiment also does not show as significant a difference as some of the other experiments. This was due to the fact that only approximately 65 students in total have to date been analysed with this experiment.

The last figure 2 (f) presents the average grades taking all the results for the instrumented and non-instrumented experiments. Across the whole range of instrumented experiments an average of 71.7% was achieved and for the non-instrumented an average of 62.1%. Students who took the instrumented experiments had on average a grade higher result compared to those who took the non-instrumented experiments. In addition, the confidence intervals for these results do not overlap showing a clear benefit from the new teaching methodology.

It has been shown, that the implementation of virtual laboratories can provide both cost effective and pedagogical benefits. VIs allow students to gain a better understanding of what they are doing and why they are doing it. There has been enough positive feedback to merit continued implementation, development and research with this type of instruction. Further work to develop the virtual instruments may involve incorporating an answer sheet within the VI so that the students can perform the experiment though the VI and also submit their report though it. As the students readily self engage with the VIs, demonstrator work loads have decreased.
Figure 2 Total average student report results for the instrumented and non-instrumented (a) flywheel, (b) compound pendulum, (c) load cell, (d) LVDT, (e) centrifugal force, and (f) the total for all experiments.
4. Acknowledgements

The authors would like to thank DCU Teaching and Learning and National Instruments fellowships for supporting this work.

5. References

LabVIEW Interface Controls a Newly-Developed Bioreactor for Tissue Testing

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Products used:

NI LabVIEW 7.1
NI Measurement & Automation Explorer
NI PCI-6221 DAQ
NI 68-LP Cable Connector Block
NI RC 68-68 Cable

The Challenge

The aim of this research project was to design and develop a small pneumatic testing machine (called a bioreactor) to carry out force-controlled dynamic compression tests on engineered biological tissues. The newly-developed bioreactor is capable of applying different regimes of static and dynamic loads to individual samples, while continuously monitoring the variation in sample deformation. This allows for real-time changes in the mechanical properties of the tissue to be determined. Critical to reliable test data is the need for precise and repeatable sample loading, as well as accurate measurement of sample deformation and energy absorption.

The Solution

To meet the aforementioned requirements, a fully computer-controlled pneumatic system has been developed based on a NI PCI-6221 DAQ device. Using LabVIEW 7.1 a simple, user-friendly front panel was created to control two pneumatic valves, as well as display signals from a load cell and a linear displacement transducer. Data are signal processed in real-time before being saved to a user-specified filename. The use of LabVIEW allowed precision transducer calibration to be easily achieved, and has resulted in an easy-to-use research instrument.

Introduction

The objective of the project was to design and develop a laboratory testing machine (or ‘bioreactor’) to investigate the response of metabolic activity of chondrocytes (cartilage cells responsible for extracellular matrix production) when stimulated under dynamic compression. It has been shown that dynamic compression can positively influence chondrocyte metabolic activity, and subsequently regulate the mechanical properties of the tissue or artificial scaffold in which they are cultured [1].

The bioreactor should be capable of mimicking the physiological loading conditions to which chondrocytes are subjected to during joint articulation due to normal activity such as walking or running.

Bioreactor’s requirements

The bioreactor had to be capable of loading both relatively high stiffness cartilage explants (~1MPa) and relatively low stiffness artificial scaffolds (10-50 kPa). To maintain the same level of stress at the cellular level, the bioreactor had to be able to adapt the level of compression depending on the material tested.

It also had to be possible to regulate the frequency with which the dynamic compression is applied, in order to mimic the loading conditions experienced during the above-mentioned activities.

Furthermore it was necessary to understand how the loading effects mechanical properties of the sample. To this end the bioreactor had to able to monitor real-time variation in the stress-strain characteristic of the material.
As the device is used for research purposes, accuracy and repeatability of the settings and of the readings are very important, as well as a good resolution and a good data storage system. Finally, the device had to be user-friendly and easy to use as it is an instrument to be used by people not necessarily expert in computer programming or electronics.

**Bioreactor Design**

To meet the loading specifications required for the bioreactor, a pneumatically actuated bellows system has been developed. The force is generated by the extension of the bellows due to the increasing internal chamber pressure, and the loading frequency is obtained by switching on and off the air supply. To control the compression force generated by the bellows a proportional pressure control valve has been used; this valve controls the pressure in the circuit in proportion to an input analog voltage signal. A solenoid valve is placed to open and close the circuit, giving the load the desired application frequency. Furthermore, an LVDT and a load cell are used for measurement of sample deformation and applied load respectively. With this information we are able to monitor the real-time variation in the mechanical properties of the construct and adapt the loading conditions as necessary (Fig. 1).

![Fig. 1: The compression rig into the incubator](image1)

**Bioreactor control**

Using a NI PCI-6221 DAQ card and the 7.1 LabVIEW Software, it has been possible to control the pneumatic valves and acquire the signals from the transducers (LVDT and Load Cell). Using the 16 bit NI PCI-6221 DAQ, in fact, it could be possible to acquire the analogue voltages given by the two transducers and to control the two pneumatic valves, respectively with an analogue and a digital voltage output signal. LabVIEW also allowed an easy implementation of Low-Pass filters, and reduced programming time through the DAQ assistant. Finally a user-friendly front panel has been made, in order to allow an easy and simple control of the testing machine and a direct visual understanding of the testing process (Fig. 2).

![Fig. 2: Screen shot of the personalized LabVIEW 7.1 Front Panel](image2)
By using this system it was also possible to easily and quickly calibrate all the electronic devices connected.

**Conclusions**

Through the combination of LabVIEW and the DAQ system it has been possible to design and fabricate a relatively simple, efficient, reliable and low-cost testing device (Fig. 3). Furthermore, LabVIEW offers flexibility and allows us to quickly modify or implement functionalities when needed. Other advantages of this PC-based system include transportability and easy data saving.

![Fig. 3: The bioreactor](image)

**Potential Applications**

It should be possible to scale-up the device in order to develop a system capable of controlling a multiple-chamber testing machine. The flexibility of LABVIEW will simplify this process.

**Acknowledgments**

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**References**

Development of an Active Damping System for a Racing Car using cRIO Hardware and LabVIEW Software

Author(s):
Richard Elliott MEng, Cardiff University.

Products Used:
- NI cRIO-9004 Real time controller
- NI cRIO-9103 4 slot FPGA chassis
- NI cRIO-9201 8ch 12bit +/- 10V Analogue input module (3 used)
- NI cRIO-9263 4ch 16bit +/- 10V Analogue output module
- NI LabVIEW 7.1/ FPGA/ Real-Time

The Challenge
To develop a system to analyse a racing vehicle's performance in real time and control the active magneto rheological dampers of the suspension. The system must be able to log 50 channels of data at 100Hz, and the damper control algorithm must run faster than 500Hz. The system is to be used by students for the research and development of active damping and vehicle dynamics. The hardware has to be reconfigurable, small, light and rugged so that it can be integrated into the vehicle.

The Solution
A small and robust 4 slot NI CompactRIO controller has been programmed by students with no previous experience using the intuitive dataflow language of LabVIEW to perform damper control and data logging.

Abstract
This paper presents the development and use of National Instruments CompactRIO hardware for active damping control on a Formula Student race car. The key features of the system are presented, along with details of how LabVIEW was used to create code specifically for this application.

The successful implementation of the system by the students of Cardiff University for vehicle development and active damping research is then demonstrated.

The paper concludes with details of planned future developments for the system to further enhance track performance and research.

Introduction
The Formula Student competition is for engineering students to conceive, design, fabricate and compete with small formula-style racing cars. The technical restrictions are limited so that the knowledge, creativity, and imagination of the students are challenged. The cars are built with a team effort over a period of about one year and are taken to the annual competition for judging and racing with approximately 80 other vehicles from universities throughout the world. The end result is a great experience for young engineers in a meaningful engineering project as well as the opportunity of working in a dedicated team effort.