Instrumented Stake Test

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Instrumented Stake Test

Professional Project

Prepared by Louis Berei III

July 31, 2005
Executive Summary

The information technology solution offered by this project provides a client with a measured accurate product for the purpose of new product and warranty design verification. A developing product, just off the drawing table or CAD computer will have no previous history of testing. Procedures and test equipment must be designed and developed in a time sensitive period due to production deadlines that will affect profitability. The ability to reuse the resulting test stands, computer hardware, data acquisition equipment, and software is a key element to a test laboratories bottom line.

The goal of this project assigned to is to provide a product to a customer, in the form of data, which will be collected as a result of a predefined scenario. The Instrumented Stake Test Project was designed and constructed by the writer for the purpose of collecting force data from a rotating lawnmower blade impacting a metal stake. Important to the client’s requests is an insurance the resulting test data will be presented in a useable format compatible with their analysis software. Test Laboratory management has mandated the data acquisition software will be written using National Instruments Corporation’s LabVIEW Graphical Development Software. Utilization of Microsoft Windows XP operating system in conjunction with LabVIEW is also required.
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Chapter 1

Introduction

Model based computer simulations are important to reducing product development time and cost [1]. Designers using this technology must meet critical criteria important to a product's quality and reliability. Until the process of designing and analysis becomes truly autonomous, verification of new designs is needed for validation purposes [2]. Verification may involve physical prototypes and data acquisition methods that are easily configurable for reuse. Rapid prototyping tools have enhanced venues for acquiring information and automatic controls related to the verification process [3]. LabVIEW is one of the tools available that will operate in a PC-based environment to provide data acquisition and interactive control interfaces for physical prototypes [4].

1.1 Business Problem Statement

A customer contacted the test laboratory requesting a test called the Instrumented Stake Test. The test laboratory’s customer manufactures and designs walk behind lawnmowers but lacks high speed data acquisition testing capabilities. The manufacturer contracted the test laboratory because it has facility and equipment needed to run the test. The manufacturer’s design engineers created the need for a recorded electronic measurement based on the premise that the load applied to the lawnmowers cutting blade at impact is not known. The measurement, which is to be obtained from a real life event, will be used in calculations to determine the correct design of the lawnmower’s cutting blade.
blade. If the design of the cutting blade is too stiff objects, such as rocks in the blades path, will damage the lawnmowers engine. Warranty claims resulting from this event may affect the manufacturer’s profits. If the blade is designed correctly cost savings could be realized because it is less costly to replace the lawnmower blade than the engine.

The test laboratory where the Instrumented Stake Test was conducted offers its facilities and component level testing services to manufacturers of motor-driven vehicles. Instrumentation and electronic test equipment are used by the test lab to verify the accuracy of computer-aided designs created by their customers. The laboratories business strategy is based on the concept that most components designed by manufacturers cannot be put into production unless thorough testing is completed. The electronic testing services offered by the test lab are broken down into two testing formats: mobile units under test (UUT) and automated test stands (ATS).

Although both test formats make use of electronic data acquisition devices, the UUT is an on/off road format while ATS is usually a custom built fixture bolted to the facility’s floor. Reusability is an important factor leading to the financial success of the test lab because costs prohibit using most test equipment for a one-time/one-format test application. Other factors impacting the test labs profitability include pre-test research to ensure the correct test equipment is purchased for a planned test project and placing test equipment in storage until it is needed for a similar test application.
This project will address and provide a solution for a customer using research, analysis, and designs based on a LabVIEW software application. The project will provide the requested test data to the customer in a usable format that will be compatible with their analysis software. The strategic goal is to apply the overall design, using LabVIEW software applications, to several test applications in the same test lab.

1.2 Project Relevance

The relevance of this project is to reorientate the format used for data acquisition in the test laboratory while maintaining a positive bottom line. The test laboratory currently utilizes over 12 different electronic data acquisition hardware devices, each with its own pre-packaged software platform. Test lab employees, who use the equipment to collect data for customers, have limited access to the pre-packaged software. Reconfiguration to some devices requires major code changes limiting reusability and adding to equipment post purchase costs because of extra technical support needed from the manufacturer. The project goals are defined as:

- Create a profit for the business by providing a customer with data from a predefined test.
- Implement graphical programming into the test lab.
- Standardize data acquisition hardware for reuse.

Advancements to data acquisition technologies have created a form of “technological determinism” [5] influencing the test labs decision to pursue
different methods. As a result of this philosophy, project costs were approved two years prior to the selection of this project. Management concluded instituting technical advancements were deemed necessary to the test labs future data acquisition and testing plans. Over the two years, components of the National Instruments hardware were put in place to run small tests until software development efforts could be started. Outsourcing of projects has been used in the past but cost overruns and vendor expertise in the data acquisition field were detrimental to the projects successes.

1.3 Scope of the Project

This project was targeted toward updating an existing test laboratory’s data acquisition methodology. The evaluation of data acquisition system coincided with a customer test request called the Instrumented Stake Test Project. The Instrumented Stake Test Project was designed and built for the purpose of collecting force data from a rotating lawnmower blade impacting a metal stake. All resulting test data was presented in a useable format compatible with the customer’s analysis software. The data acquisition software was written using National Instruments Corporation’s LabVIEW Graphical Development Software utilizing the Microsoft Windows XP operating system. Designing and documenting the solution will enhance opportunities for reuse with similar equipment in future test projects. The conclusions extracted from this test related to reuse and more efficient methods of configuring data acquisition equipment provided management with documented decision characteristics.
1.4 Limitations

Due to the different configurations of data acquisition equipment, occasional delays would occur when scheduling test applications incurring prolonged development times.

While most of the data acquisition devices accommodate formats that will be compatible with analysis software, there have been occasions where data had to be massaged or reformatted for use by the customers design engineers.

1.5 Project Objectives

Test laboratory management generated a mandate to standardize the test labs data acquisition equipment and control cost. As a result of this mandate National Instruments Corporation’s LabVIEW Graphical Development Software was selected as the best fit for future test projects. The Instrumented Stake Test Project is targeted at evaluating means and methods necessary to incorporate LabVIEW into the test labs environment for the collection of data. The topics mentioned during this report are related to supporting the project and the data acquisition process using LabVIEW.

1.6 Summary

Standardizing the hardware and software data acquisition platforms used for different test scenarios would be ideal because of potential cost savings. National Instruments data acquisition hardware is adaptable to different types of test applications. Computer equipment supporting National Instruments LabVIEW
graphical programming environment is off the shelf and supports the data
collection hardware with a variety of interfaces. LabVIEW's hardware platform
versatility allows it to be used with other vendors test equipment. The
Instrumented Stake Test will serve as a pilot project as to the feasibility of using
graphical programming software in the test lab for data acquisition. A successful
project will represent a stepping stone aimed at utilizing motion control,
instrument control, image acquisition, and other features aligned with graphical
programming.
Chapter 2

Measurement Research

The chapter will present an overview of the determining factors required to produce the test data requested from the customer. Data acquisition covers a broad range of test equipment, sensors, signal conditioning, and interfaces [6]. The information gathered from the test requestor or customer concerning a potential test scenario is vital to the selection of proper data acquisition equipment [7]. Efforts put forth to appropriate the different data acquisition elements range from equipment that is currently in storage to special ordering custom made components. A data acquisition component producing good return on investment would be equipment that is constantly being used for tests and versatile. Computers have become the backbone of data acquisition technology in recent years because of portability, increased memory size, processing speeds, and driver improvements replacing analog based methods. Not all sensors used in collecting data are compatible with the computers architecture of ones and zeroes.

Analog to digital components are used to convert the small electrical analog signal some sensors produce so the data is useable by the computer. Electrical signals sensors generate range from small currents to various voltage levels dependent upon their design. Analog to digital (A/D) converters are used to multiplex, synchronize, convert, and sample the sensors analog signals. The converted signals are processed by the computers microprocessor(s) for use as
meaningful data [8]. The data is used by software programs, collected, and/or monitored real time for decision making purposes.

2.1 Information Gathering

The projects direction toward the use of LabVIEW influenced the initial information gathering process away from software to hardware compatibility. Prior to accepting a potential customers request for test, hardware must be evaluated to ensure memory capacity, acquisition speed, and sensor compatibility. Elements of this criteria were specified when the existing equipment in the test lab was purchased and may not be reconfigured without additional cost. Customer satisfaction would be better served if the test laboratory had the capability to manipulate data in multiple formats. The management based decision to use LabVIEW was based on strategies aimed at standardizing the test labs data acquisition equipment and controlling cost. Technology improvements to driver software by National Instruments enable quicker development times and expanded application options. The availability of drivers offered the lab capabilities to interface with existing data acquisition test equipment through their USB, FireWire, and PCMCIA platforms [9]. Acquiring electronic data using personal computers or laptops requires software interfaces for the user to understand different states of the test procedure. In addition to interfacing measurement devices, LabVIEW provides graphical software that a programmer can use to custom design user interfaces. LabVIEW uses virtual instruments or VIs, consisting of front panels and diagrams to create data flow
programming models. VI’s can be programmed to represent objects such as test lab equipment in a research and development environment. The objects can be created, tested, and used as small programs or embedded into larger VIs. The LabVIEW application builder allows the programmer to create stand-alone executables with execution speeds similar to programs compiled in C language.

2.2 Requirements and Methods

The requirements meetings determined one strain gage transducer would be used for a stress measurement. A strain gage applied to the stationary steel stake will generate very small electronic signal when the rotating mower blade strikes the stake. The stress generated from the resistance produced by the stake as a result of the collision creates displacement and deformation called strain. The critical data needed for the project to be successful would be to capture the initial deformation of the steel stake caused by the mower blades impact. The impact produces a sharp peak in the resulting waveform which is collected by the National Instruments data acquisition equipment [10]. The data is displayed on a LabVIEW chart with one axis expressed in microstrain and the other representing seconds.

2.2.1 Measurements

R.B. Hawood states “A premise association between theory and practice has generally eluded a solution, and until this is achieved both fields of research must necessarily be pursued” [11]. The method of practical measurement
selected was a detection transducer in the form of a strain gage feeding into a National Instruments signal conditioning module. The signal conditioning module is connected to a laptop computer which acts as the decision point for instrumentation set up, GUI interface programming, compiler, file storage, and control center for the actual collection of data. Construction of the modules needed to form the data acquisition system was completed on a work bench and moved to the test cell for the final connections, system confirmation, and calibration tests. The transducers signal was recorded to a .txt file in a format specified by the customer. The transducers signal was also used on the test technician's graphical user interface operating on a laptop computer. The signal from the transducer was received by the signal conditioner in a continuous analog form and converted into a digital representation for use by the laptops logic circuits [12].

2.2.2 Acquisition Speed

The analog to digital converters logic circuits used to control the transfer of data to memory or internal registers are affected by the application. Performance factors such as accuracy, signal frequency content, and signal level were matched to the strain gage transducer. The customer requested to have the data representing the moment of impact which is when the mower blade strikes the stake. Recording this moment of the event required a high resolution analog to digital converter to capture the maximum number of bits representing the analog signal in the short time span. The requested number of samples requires a data
acquisition speed at least of 100,000 samples per second. Duration needed to capture the event has been determined to be one and one half seconds. This determination was based on the test stand technician’s previous experience about the moment of impact. After the data acquisition button was pressed the laptop chart showed one and one half seconds of data collected at 200,000 samples per second.

2.2.3 Reusability

Reusability of the strain gage was not possible once impacted by the lawnmower blade. The data acquisition equipment is available for reuse once the data has been confirmed and the customer approves. The interface software was designed for reuse with the data acquisition equipment. The design allows virtual instruments to be replaced within the main menu offering the same look with different functionality.

2.3 Instrumentation

Strain Gage

Strain gage sensors measure mechanical strains for the purpose of monitoring deflections involving structures and their components [13]. Examples of structures measured would include load arms of tractors, bridges, or parachute cords. The size of a strain gage is a major advantage that leads to this flexibility of use. The strain gage used for the Instrumented Stake Test will be smaller than a postage stamp in area and close to the same size in thickness. Strain gages
are also used as part of completed sensors, examples would include load cells used in scales and pressure transducers used in flow measurements or atmospheric conditions. Manufacturers of sensors use strain gages to take advantage of its small size thus eliminating mechanical mass needed to develop the same sensor in the past. The selection process for the strain gage required knowing the type steel used for the stake that will be contacting the mower blade. The type of test, accuracy of measurement, and required gage length were other factors considered during the process [14]. Once the information was analyzed it was determined the Vishay Micro-Measurements CEA-06-125UN-350 strain gage would be selected. The 350 ohm gage with an open faced constantan-alloy pattern was applied to the 1 inch diameter steel stake with M-Bond 200 adhesive. The strain gage installation involved thoroughly cleaning a surface of the stake near the projected impact zone with sandpaper and uncontaminated solvents. The gage is then aligned and attached to the stake with the adhesive. Wires that carry the electrical signal to the termination module are then soldered to the gage. After removing the solder flux the gage is covered with a protective coating. The electrical signal the gage sends out when in a relaxed state is defined as a voltage and referred to as a zero reference. A calibration was performed before the actual test is conducted to re-zero the gage.

**Tachometer**

A blade speed 3200 revolutions per minute measurement blade was requested by the customer to match the CAD model. The information was not
required as collected data because the lawnmower motor was able to idle at a constant speed without intervention. The throttle on the lawnmower was adjusted and verified using a calibrated [15] Shrimpo DT-207L handheld laser tachometer before the test began. The tachometer was adjusted to non-contact RPM and reflective tape placed on the motors crankshaft. The reading was taken at an opening between the lawnmowers deck and motor. In addition, a Tiny Tach model digital tachometer was attached to the spark plug wire and the readings corresponded to the data from the Shrimpo tachometer.

2.4 Data Acquisition Options

Commercially produced data acquisition systems have many options available to users creating the need for careful consideration. Matching applications related to the needs of the user, requestor, environment, sensors, and accuracy were some of the characteristics evaluated for the Instrumented Stake Test. A factor that led to the selection of National Instruments LabVIEW software was the graphical software could be compiled as an executable program and run on different PCs and laptops in the test lab. In addition to the LabVIEW software National Instruments supports different hardware versions of data acquisition equipment connect to PC’s which include USB and FireWire interfaces. In the case of the Instrumented Stake Test the National Instruments PCMCIA DAQCard-6036E with a maximum sample rate of 200 ks/s was selected for use with a Compaq nw8000 laptop computer. The customer requirement of at least 100 ks/s acquisition rate was exceeded to provide better quality data.
Between the PCMCIA DAQCard-6036E and the strain gage a signal conditioner was required to complete the circuit. The National Instruments SCXI-1000 chassis was selected to use as a vessel for National Instruments SCXI-1520 8 Channel Universal Strain Gage Module. A SCXI-1314 Universal Strain Gage Block provided a hardware interface by utilizing terminal blocks to provide wires from the strain gage connection points.

The strain gage module offered a programmable excitation source for the strain gage used in the Instrumented Stake Test. It also offered completion circuitry of the Wheatstone Bridge (fig. 2.2) and options to use 120 or 350 ohms resistors. In addition to the 8 Channel Universal Strain Gage Module the SCXI-1000 chassis was fitted with a SCXI-1180 Feedthrough Panel. The Feedthrough Panel allowed a push button switch to be hardwired to correct channel on the PCMCIA DAQCard-6036E for triggering of the data acquisition event. A SCXI-1302 Terminal Block provided a hardware interface between the Feedthrough
panel and push button switch by utilizing terminal blocks. The selection of data acquisition equipment for the Instrumented Stake Test allows flexibility and reuse capabilities for future use in the test lab. The SCXI-1000 chassis has four slots that can be configured for numerous types of data acquisition requests because modules are available to interface with the test lab's variety of transducers. The SCXI-1000 chassis is also compatible with the test lab's desktop computers by replacing the PCMCIA DAQCard-6036E with other DAQ devices offering USB or PCI bus compatibility.

2.5 Mechanical Test Fixture

The mechanism for releasing the spring loaded stake into the lawnmowers' turning blade was a simple cam latch attached to a pull cord. A circular hole in the concrete floor with a spring attached to the bottom acted as the pre-launch container. Into the hole a steel pipe acted as a sleeve to hold the stake. A

![Figure 2.2 Wheatstone Bridge Western Regional Strain Gage Bridge Standard/ISA Standard 37.8](image-url)
threaded steel flange with a hole large enough for the stake to pass through
cover the top. The stake was inserted and the pre-load was applied when the
stake was pushed down far enough to set the cam latch in place. The
lawnmower was placed on top of the hole without tie downs.

2.5.1 Layout

The room used to run the test (test cell) is used for other test involving
planned collisions and the resulting thrown debris. Since it is possible flying
debris may occur, equipment wires and cable must be protected from damage.
The laptop computer was placed on a table outside the test cell with the SCXI-
1000 chassis containing the SCXI-1520 8 Channel Universal Strain Gage Module,
SCXI-1314, Universal Strain Gage Block, SCXI-1180 Feedthrough Panel, and
SCXI-1302 Terminal Block. The strain gage instrumented stake's 10' wire,
supplying the analog signal, was aligned through the housing of the of the spring
mechanism out of the test cell to the SCXI-1314 Universal Strain Gage Block.
The push button switch wired to trigger data collection was connected to the
SCXI-1302 Terminal Block use outside the test cell.

2.5.2 Spring Loaded Actuation

The mechanical test set up was based on customer feedback and the test cell
technician's previous operational experience using the launch mechanism. The
lawnmower was placed over the launch zone so the expected impact would be
approximately one inch from the outside edge of the blade. Wheels were
chocked, exhaust fans were turned on and the lawnmowers blade was verified to be operating at to 3200 rpm. The test technician pulled the cord attached to the cam latch releasing the stake from its spring loaded position vertically into the revolving lawn mower blade.

Figure 2.3 Stake Launching Trigger Diagram
Chapter 3

Project Methodology

Integrating the waterfall and rapid prototyping life cycle models was necessary to keep the project on track. Although major changes were not anticipated it was necessary to insure the customer requests were specifically met. The project was broken down into three major tasks which led to the fully developed system. Each task of development had a related rapid prototype model developed because of potential customer, user, and hardware concerns on an ongoing basis. The three major tasks were defined as:

- Sensors had to be configured to the compatible hardware and drivers.
- Data was to be collected and presented in an acceptable format.
- Graphical user interface represent all aspects of the test format.

Another factor considered for using the rapid prototype model was the short time allowed to develop the project and the projects overall size. Having the project broken down into three tasks allowed development to continue on another part when working through bottlenecks [16]. Changes to the requirements of the three rapid prototype models were reflected in the waterfall model as development progressed. Partial functionality established during rapid prototype development led to the use of LabVIEW's DAQ assistants during programming of the three tasks. Partial functionality was also used for hardware verification to establish the best signal conditioner interaction between the sensors and software.
3.1 Problem Analysis

“Man begins testing things in his earliest childhood and continues throughout his life. While an infant will test an object by putting into his mouth, adults have developed better tests to learn about objects.” [17] Problems presented as a result of the customer’s test request and the configuration of data acquisition test equipment must be married to form an acceptable plan to follow. Timing affecting the collection of data influenced the design because if the sequence of events is off by seconds the data will not be collected. The design of a user interface must be made easy to use and reliable.

3.1.1 Test Hardware

One strain gage connected to the interface board of the NI SCXI-1000 chassis will be wired to collect the electrical signals representing a raw form of data. The strain gage is attached with bonding methods to the stake essentially turning the stake into a transducer. The stake is a one time use expendable item and if more than one test is required another stake is used after it is instrumented. The lawn mower blade should be considered part of the test and is also expendable because of the damage incurred by the impact. The non instrumented lawn mower blade model is predetermined by the customers CAD model. The lawn mower motor is also determined by the customers CAD model and should not be expected to be reused for future test purposes as a result of forces created by the sudden impact. The analog signal runs through 16 feet of 26 AWG stranded three conductor copper wire. Two of the conductors are
connected to one of the two solder tabs on the strain gage. The remaining conductor is soldered to the second solder tab. The wire runs to the SCXI-1314 Universal Strain Gage Block where the three wires are connected by way of a terminal screw block. The Strain Gage Block is a connection point between transducers and the SCXI-1520 Strain Gage Module that handles signal conditioning. The SCXI-1000 Chassis houses the Strain Gage Module and the SCXI-1180 Feedthrough Module and is capable of handling two more modules in the two remaining open slots. The Feedthrough module allows a direct feed to the DAQCard located in the laptop computer to the normally closed push button switch used to trigger the data acquisition process. The laptop computer is a Compaq nw8000 with Windows XP SP2 installed. All communication between the laptop computer and SCXI-1000 Chassis is handled through one shielded cable to keep noise to a minimum. The laptop computer contains the software needed to run the test and communicate with the SCXI-1000 chassis. The software used to communicate with the SCXI-1000 sensors is a National Instruments configuration utility called Measurement & Automation Explorer (MAX). MAX was installed when the LabVIEW application was loaded onto the laptop to enable parameters for devices and data acquisition channels [18]. The method of communication to the user is a graphical user interface custom developed in the test lab using the LabVIEW application software.
3.1.1.1 I/O

Interface of the instruments will be handled by LabVIEW’s MAX configuration utility software. The physical analog input channel SC1Mod1/ai0 is used to collect the strain gage signal. A push button switch connected to input channel PFI0 through the Feedthrough Module will enable the data collection process. The Measurement and Automation Explorer (MAX) saves the logical device numbers and parameters used in configurations. MAX also provided system diagnostics for troubleshooting during systems hardware testing.
3.1.1.2 DAQ Channels

The data acquisition analog input channel for the strain gage must provide accessibility to several screens on the user interface. Therefore a global channel configured with the MAX configuration utility is used.

3.1.1.3 Triggering

The test used two forms of triggering actuated by a mechanical action initiated by the operator of the test:

1) Triggering of the data acquisition unit with a push button switch to start collecting data.

2) The mechanical trigger used to launch the stake into the mowers moving blade.

The data acquisition trigger was activated using a Normally Open push button switch. Three seconds after the data acquisition switch was pressed the pull cord for the mechanical switch was pulled and the stake launched into the moving mower blade. The data was displayed immediately onto the computers graph. Triggering was very important to the test because a failure by the data acquisition trigger would result in a loss of data and lawnmower motor would have to be replaced. Extensive testing was performed in the test cell without the mower the day before the test to verify the trigger timing.
3.1.2 User Interface

The functionality of VIs within the user interface is important to the Instrumented Stake Test. The test is designed to make use of the VIs packaged with the application by implementing them with VIs created specifically for the project. The user interface was written specifically for the Instrumented Blade Stake Project using LabVIEW’s graphical programming software. The main menu portion of the program and its options to select four separate actions can be reused for future tests by the programmer and test lab. Placing new or existing VIs into the program will change the functions of the overall program while utilizing the reuse functionality of the main menu screen [19]. All screens begin with the menu screen which offers the user access to the variety of options needed to complete the test. The menu screen is generated by double-clicking an icon located on the Microsoft Windows desktop screen. The buttons, indicators, graphics and pictures on the menu screen can be moved or changed easily but the functionality will remain the current. The charts and graphs representing the data are interactive allowing adjustments to X and Y axis values. The user interface provides a logical solution to collecting sensor information from a strain gage for the purpose of viewing data in real time, saving the test data to a file, and verifying the file location.
3.1.2.1 Requirements

The operator taking data needed information to insure the instrumentation is providing a usable signal, a method of collecting data, and verification the data is in the pre-selected directory. This created a need for developing a graphical user interface.

3.1.2.2 Screen Layout

The layout of the screen has a main window with buttons activated by clicking in them with a mouse. Four selections at the main window are available. Within each selection information is be provided to the user showing graphs, file locations, buttons to start a process, and a button to return to the main menu.
3.1.2.3 File Designation

The customer requested data in a .txt file but during the development stage data collection to Excel files were tested for future use. After taking data the user is given the option of saving the data in several formats:

- ASCII text file
- Excel file
- LabVIEW measurement file

The Take Data VI opens a pop up window allowing the user choose the file name, type of file, and the location where the data file is to be saved.
3.1.2.4 Data Verification

It is not unusual for a test involving data acquisition to take weeks to develop and two seconds to run. If the collected data is not verified immediately after it is taken some part of the cost of the test would be lost affecting the bottom line [20]. Since the test lab’s business plan is based on data, it was necessary to insure the data was properly collected in a safe location and ready for distribution. Related cost factors were considered when developing the graphical user interface by implementing a VI for verification. The Verify Data Location selection on the Main Menu screen displays data from the file where it is located to the screen, as opposed to having data collected directly from the transducer.

3.1.2.5 Instrumentation Global

To use the same transducer channel for different virtual instruments in the data acquisition process global channels were created using National Instruments MAX software.

3.2 Design Phase

Before the test began information was acquired from the customer to determine what sensors, data acquisition equipment, test cells, and procedures are to be used. Additional information was required from the test technician to determine the operator guidelines.
3.2.1 User Interface Plan

While the main focus of the Instrumented Stake Test is to collect data for a customer so it may be analyzed for design purposes this does not happen without a reliable, reusable user interface. LabVIEW provides the capability to develop and use transducer signals through the user interface. Development of the user interface for the Instrumented Stake Test involved interfaces, controls, front panels, and indicators for the purpose of reuse with another stake test scenario or other future tests.

3.2.2 System Plan

Test equipment was pulled from storage, other test set ups, or purchased. When the equipment is gathered the hardware consisting of sensors, computers, interfaces are checked for communication and calibrations. Once the equipment functions, the interface software that the test technician uses to control and monitor test conditions is written and tested. After the set up is moved from the prototype bench to the test cell the equipment is tested and verified again before the actual test is performed. The main data acquisition system consisted of the following equipment that was necessary to complete the Instrumented Stake Test:

- National Instruments data acquisition hardware components
  - NI SCXI-1000 Chassis
    - NI SCXI-1314 Universal Strain Gage Block
    - NI SCXI-1520 Strain Gage Module
    - NI SCXI-1180 Feedthrough Module
    - NI SCXI-1302 Terminal Block
- Laptop computer
  - Compaq nw8000
- Windows XP/SP2 installed
- NI DAQCard
- NI Shielded cable
- NI LabVIEW Graphical Development Software
- NI Measurement & Automation Explorer (MAX) software

- Instrumentation and miscellaneous hardware
  - push button switch
  - Strain Gage
  - Strain Gage Cable
  - One diameter round steel stake

### 3.2.3 Sensor Layout

The strain gage sensor was placed four inches from the top edge of the one inch diameter steel stake. Part of the length of wire leading from the strain gage sensor to the SCXI-1314 Universal Strain Gage Block was attached to the stake using liquid latex to prevent fraying during the stakes launching.

![Instrumented Stake Test
Strain Gage Sensor Application
Drawing](image)

Figure 3.4 Instrumented Stake
3.2.4 Test Cell Plan

The location in the test lab where the Instrumented Stake Test was conducted is called the Thrown Object Test Cell. The room is specially constructed to prevent impacted items from leaving the room. The existing stake test physical structure located in the Thrown Object Test Cell required rework to create clearance to run the transducer wire through the cap and well holding the instrumented stake. The electronic data acquisition method used in this test was developed for the Thrown Object Test Cell to take advantage of the existing test fixture.

![Instrumented Stake Test Test Stand Drawings](image)

Figure 3.5 Instrumented Stake Test Cell Layout
3.2.5 Test Procedure

A. Starting the Test Executable

At the log on window find an icon called **Shortcut to StakeTest1006.exe**.

![Shortcut Executable Icon](image)

**Figure 3.6 Shortcut Executable Icon**

**Double clicking on the icon** will show the Main Menu screen listed below. The name of the test and test number are listed above the diagram of a strain gage. On the left hand side of the screen buttons representing test options are shown.

![Main Menu Screen](image)

**Figure 3.7 Main Menu Screen**
B. Start the Data Acquisition Procedure

Select the Xducer Set Up Screen. This allows streaming of live data from the strain gage channel. This is used for set up and verification the channel is functioning properly. It can also be used as a quick and dirty way to check calibration by using a C-clamp to position the base of the stake to a table and hanging a weight at a defined location. The screen is also useable as a troubleshooting tool. The microstrain should match pre test calibration checks. The screen as shown below superimposes over the main menu screen. To go back to the main menu screen select Return. To start viewing real time data select Start View.

![Figure 3.8 Xducer Set Up Screen (Inactive)](image)
C. Evaluate the Signal

Select Start View the Data Viewer On indicator will light and data will start streaming from left to right across the chart. Pressure to the strain gage transducer will result in fluctuations. The data appears jittery because of the low level of voltage being produced by the transducer. If a slight impact is made to the stake it will be seen as a spike shown in the picture below.

![Figure 3.9 Xducer Set Up Screen (Active)](image)

When finished with this screen select Stop View and the displayed data will stop moving on the screen. Select Return button closes the screen and returns to the main menu.
D. Acquire the Signal

The Next step to completing this test is to take the data the customer will receive representing the final product. After selecting the **Take Data** Button on the display panel another screen is displayed showing a large chart, indicators, and push buttons. This screen is where the triggering process begins by selecting the start button which lights the Processing Data indicator. Once the start is selected the operator will have approximately twenty seconds to begin the data acquisition process. If not completed an error screen will be displayed directing the user to end the process.

![Take Data Screen (Inactive)](image-url)

Figure 3.10 Take Data Screen (Inactive)
E. Triggering the Process

Select the Start Button which turns on the processing indicator and data is ready to be collected. The Start Button will put the data acquisition process in a wait state until the wire connection is separated by the action of the push button switch. The data acquisition **push button switch is pressed then three seconds after the pull the cord** to release the spring loaded stake is activated. One and one half seconds later the screen will change signaling the next step in the data acquisition process is ready to be completed.

![Figure 3.11 Take Data Screen (Processing Data)](image)
F. Save the Data

After data is collected the screen becomes very busy showing the data as it was collected directly from input channel of the transducer and a required response from the user to save the information before the process is allowed to resume. The required response pop-up screen offers the user the option of putting the data in any directory associated to the computers network. Selecting cancel will indicate to the user the data will not be saved if the option is not selected. If the user decides not to save the data the pop screen will disappear and data will be lost. The Processing Data light will stay illuminated until the user elects to save to a file or the cancel the save process.

![Figure 3.12 Take Data Screen (Save to File Pop-Up)](image-url)
G. View the Data Location

If the data is saved the Processing Data indicator will stay illuminated until the data is processed into the designated file. After the data is saved the indicator will turn off and the File and Path Data Saved In: indicator will show the path chosen by the operator. Additionally the pop up screen disappears and the collected data will be in full view and available for zooming by changing the x and y axis limits. This completes the data acquisition process.

![Figure 3.13 Take Data Screen (Transducer Data)](image)

When finished with the screen select the Return button and the program will return the user to the Menu Screen.
H. Verify Data is in the File

From the Main Menu Screen select the **Verify Data Location** in File Button. This step is very important because it verifies the data is actually in the file chosen in the Take Data step. The screen below will appear. **Press the start button** and the computer program will automatically find the file used to save the data in the last step and return it to the screen for verification.

![Figure 3.14 Verify Data Location Screen (Inactive)](image)

Figure 3.14 Verify Data Location Screen (Inactive)
I. Retrieve the Data

After selecting the Start Button the processing Data Indicator will illuminate for several seconds as the data is retrieved and presented to the screen from the stored location.

Figure 3.15 Verify Data Location Screen (Retrieving Data)
J. View the Information

When all the data is retrieved the Processing Data Indicator turns off and the Viewing Data Stored at: Indicator shows the file path origination. The graph and file path should be the same as in the previous step. The difference is the data in the last step was accumulated from the sensor in real time and this step accumulated the data from a file. This step completes the data acquisition process for the Instrumented Stake Test. To return to the Main Menu Screen push the Return Button. At the Main Menu Screen the test could be repeated when another transducer or lawnmower is ready for test.

![Verify Data Location Screen (Data from File)](image)

When back to the Main Menu to end the data acquisition process select the End Test Program. This closes the program and returns to the desktop window.
3.2.6 Safety Procedure

A mushroom style push-pull/twist emergency stop switch was installed to turn the lawn mower off in the test cell if the impact with the stake does not halt the motor. All user interfaces and controls were located outside the test cell in anticipation of flying debris. The lawn mower was a gas given model and the test cells exhaust fans were turned on to clear the room of fumes. Upon completion of the test the test technician cleared the test cell before entry by test personnel [21].

3.3 Construction Phase

Reusing existing components of the test labs data acquisition equipment and improved software features cuts costs and saved development time. Construction consisted of:

- Assembling and wiring the data acquisition system.
- Programming the sensors into the MAX software.
- Programming the user interface.
- Reworking the stake launch apparatus.
- Building the instrumented stake.

LabVIEW 7 Express was used by the Instrumented Stake Test to take advantage of DAQ Assistant VIs which automatically generates code used to streamline I/O configurations. This process saved time and kept the projects completion date within the timeframe for completion [22].
3.3.1 Developing VI’s

LabVIEW’s polymorphic ability to combine different read and analog input functions into one Virtual Instrument (VI) provides a one source method to the test lab for writing the code needed for its different operations. A VI is capable of giving the appearance and operating the same as physical test equipment such as an oscilloscope [23]. VI programs are well suited for research and development labs because of its capability to represent test instrumentation, acquire data, and control automated equipment. The Instrumented Stake Test utilizes LabVIEW’s extensive library of VIs to save development time associated with presenting and manipulating the acquired data. The VIs specifically written for the Instrumented Stake Test Project are used to display data to the users screen, store data, and indicate the location of the data.

Processes and communication with other VIs needed to run the test were reviewed and essential features defined [24]. The self contained characteristics of a VI were extracted in the analysis phase leading to the VIs development in the design phase. The design of the Instrumented Stake Test applications was broken down into three parts:

- A start up phase.
- The main programs.
- Shutdown options.

After coding in the implementation phase the VI was bench tested before insertion into the main program. Each VI was developed using this object oriented paradigm which included single step mode testing, custom probes, error
feedback, and highlighted execution debugging tools in the maintenance phase to verify functionality [25]. A virtual signal generator VI, available through LabVIEW’s graphical programming environment was used to imitate a strain gage signal from the SCXI-1000 chassis during bench testing. The virtual signal generator was replaced with the SCXI-1000 chassis for calibration testing and stayed with the system when moved in place to the test cell. There were four virtual instruments developed for the Instrumented stake test to incorporate the user’s needs from a case study initiated during the design stage.

![Main Menu Screen (StakeMeasure.vi)](image)

The resulting hierarchy was formulated to present a main menu screen VI with three tests action VIs available to the user: Upon selecting the executable StakeTest1006.exe (fig 3.6), the user will be presented with a main menu screen (fig 3.7) with switches to open new screens for the different functions required to complete the test. The main menu screen VI was created using a cluster shell to house the switches used for operator controls. The Xducer Set Up Screen, Take
Data, and Verify Data Location switches call a VI program corresponding to part of the Instrumented Stake Tests functionality.

<table>
<thead>
<tr>
<th>Switch Selection</th>
<th>VI Program Name</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Menu Screen</td>
<td>StakeMeasure.vi</td>
<td>User Options</td>
</tr>
<tr>
<td>Xducer Set Up Screen</td>
<td>LData.vi</td>
<td>View Transducer Signal</td>
</tr>
<tr>
<td>Take Data</td>
<td>TakeData.vi</td>
<td>Record Collected Data</td>
</tr>
<tr>
<td>Verify Data Location</td>
<td>Read File.vi</td>
<td>Read Data from File</td>
</tr>
<tr>
<td>Exit Test Program</td>
<td>N/A</td>
<td>Close the Executable</td>
</tr>
</tbody>
</table>

Figure 3.19 VI Reference Chart

Each VI developed for the Instrumented Stake Test has a hierarchy of VIs that are embedded several layers below the initial VI. The fourth switch, Exit Test Program, allows the user to close the program and return to the Windows desktop.

The user interface front panel (StakeMeasure.vi) linked to the Main Menu Screen Button was the first VI developed from the front panel and block diagram. Graphical objects representing switches were added to the front panel from one of the three LabVIEW palettes. Upon completing the front panel another window
called the block diagram was opened to add the graphical source code. The
LData.vi, TakeData.vi, and Read File.vi would later be added to this block
diagram creating the hierarchy. A state machine architecture with a default
startup state was used when creating the Main Menu screen VI to maintain
consistency with LabVIEW programming principles.

The LData.vi (Xducer Set Up Screen switch) uses a separate window (fig
3.8) to call a waveform chart VI, selected from the functions palette, for
displaying the strain gage signal in real time (fig 3.9). The signal is pulled from
the SCXI-1000 chassis on channel ai0 for processing by the VI. Error handling is
handled by a simple error handler VI inserted into the VI from the functions
palette. Case and While Loop structures were used to execute and repeat code
essential to moving data across the chart for viewing. Buttons were added to stop
movement on the chart and return to the main screen. The completed LabVIEW
VI was tested and placed in a case structure located on the StakeMeasure.vi
block diagram and tested for compatibility with the main menu. When the
relationship was confirm between the VIs the simulated virtual signal generators
signal was passed through verify chart functionality.

The TakeData.vi (Take Data switch) provides a separate window (fig 3.10)
to the user displaying a virtual waveform graph selected from the functions
palette. The graphs function is to depict the conditioned transducer signal as it
was collected from the ai0 channel from the SCXI-1000 chassis. The TakeData.vi
also inserts the data into a file and directory specified by the user through a pop
up window (fig 3-12). Once the file is saved a confirmation is displayed to the
user through a File Path Indicator box on the front panel of the Take Data window. The File Path Indicator was placed on the front panel from the controls palette. A General Error Handler VI is used to indicate errors and provide a dialog box for a solution path. The TakeData.vi uses a global channel to pass data to the Read File.vi so the operator does not need to enter the location of the saved data when viewing. Inserting the data acquisition triggers connected to input channel PFI0 through the Feedthrough Module into this VI simplified the operation for the user by not having to change screens. A return button on the Take Data window returns the user to the main menu.

The Read File.vi (Verify Data Location switch) window (fig 3.14) opens displaying an empty wave form graph to display the data stored in a file. Pressing the start button initiates the global channel used in the TakeData.vi which was created to pass data to the Read File.vi. The global path is directed to read the data file and display the information to the graph. The files complete path is displayed to a File Path Indicator on the Read File VI's window. The File Paths Indicator does not use the global instead the source is read from the output of an express VI’s File Name output node insuring to the user the displayed files origination. The internal architecture used inside the case structure located on the Read File.vi block diagram was a flat sequence structure with two sequences. An Indicator was placed inside the first sequence designed to turn on by a Boolean true constant when the start button is pressed for coordination with the retrieval of data from the file. The next sequence uses a local variable of the indicator with a false Boolean constant turning the indicator off alerting the user
the process has been completed. To indicate whether an error occurred during
the process a Simple Error Handler.vi was used in the first sequence panel.

The Exit Test Program switch’s Boolean output activates a front panel
case structure where a constant true property node initiates a Quit LabVIEW
function. The quit LabVIEW function stops all VIs and closes the executable.

The user interface front panel (StakeMeasure.vi) can be reused as a main
menu with future work orders requiring data acquisition. Changes to the text used
for work order information and identifying buttons are easily completed on the
VI’s front panel. Inserting a different VI into the case structure aligns the data
acquisition methods with new requirements without major programming changes.

3.3.2 Interfacing the System

Several interface considerations were coordinated during the construction
phase:

- User interface with the data acquisition system was checked to make sure
  the screens, displays, and buttons were accessible and compliant with
  potential operators.
- The virtual signal generator used to simulate a signal to the VIs was
  replaced with the SCXI-1000 chassis for calibration testing.
- During the bench test, communications between the Vis were verified as
  the hierarchy was created.
- Communication to the test labs LAN and desktop was verified for file
  transfer and storage.
• Data acquisition hardware modules were checked using diagnostics software to insure proper communication between each other.

• Communication between the hardware modules and laptop were verified.

• The sensors were interfaced with the data acquisition hardware modules.

• The hardware triggering devices were installed to start processes.

3.4 Implementation Phase

“When a laboratory test for either a complete machine or a component can be designed to essentially duplicate field loading and pertinent environmental conditions, a great deal of time can be saved and development costs are reduced.”[26] Plans made during the implementation phase for reuse of Instrumented Stake Test hardware/software components provide future users with valuable information to reduce costs related to new tests. Before implementing and moving the completely assembled data acquisition system into the test cell:

• The overall operation of the system was checked for timing.

• Calibration to verify the collected data’s authenticity was performed.

• Safety issues were discussed and precautions implemented.

• Operator training was started.

• Storage was planned for when the system is not in use.

• Documentation guidelines were set.

Having the system available for testing related to the same work order, reusing software/hardware for new tests, or creating a totally new data acquisition
process are options available to the test lab, provided the processes are documented. Cost savings related to future data acquisition set ups are tied to the hardware/software reuse and documentation.

3.4.1 Testing the System

The damage to the stake and lawn mower would be beyond reasonable repair due to cost justifications. Labor costs to repair the damaged components would be higher than purchasing new or used replacement parts. Timing was very important to the Instrumented Stake Test because the window for collecting data would be less than 1.5 seconds. During bench testing a hammer representing the mowers blade was impacted on a strain gaged flat piece of steel to represent the mowers blade striking the stake. Wires were attached to the hammer to simulate the push button switch that would start the electronic data acquisition process. As the hammer fell the wires separated causing the electronic data acquisition process to start. The data was collected the same as when the equipment was moved to the test cell (fig 3.13). The data was saved and verified using the StakeTest1006.executable. Once the data acquisition system bench test was completed it was checked to insure the timing of the system corresponded to the mechanical and human intervention necessary to collect data. This was accomplished by relocating the system to the test cell. At the test cell dry runs were initiated where the process would be stepped through without causing damage. The actual triggers were checked and the instrumented stake was launched into the air to avoid damage.
Items of special attention included:

- Verification of the trigger sequence.
- Operator training.
- Spotting potential safety hazards.
- Identifying mechanical issues.
- Insuring wires were not damaged.
- Equipment location and familiarity with the test cell layout.

At this time any problems identified were addressed immediately since the next step was the actual test.
3.4.2 Calibration Verification

Accuracy and efficiency were criteria used to select the correct testing equipment used for verifying calibration. To verify the calibration of the strain gage channel LabVIEW's MAX computer controlled configuration software was used in conjunction with a 5lb weight. After verifying the 5lb weight to 84 microstrain using a Vishay Measurements Group Model P-3500 Digital Strain Indicator, the set up was rewired to the LabVIEW virtual instrument program to verify the results. The picture below shows a strain gaged flat piece of steel (transducer) connected to the P-3500 sitting at 0000 microstrain without the load applied. When pressure is applied to the steel platform the digital readout will change to indicate the amount of microstrain applied. Pressure can be applied from the top or bottom and the reading will be interpreted on the display with a positive (+) sign or negative sign (-) indicating tension and compression. The picture below depicts the P-3500 reading 84 microstrain with a 5lb weight applied to simulate loading on the transducer. The same procedure was used when the P-3500 Digital Stain Indicator was replaced with the National Instruments data acquisition equipment and laptop running the Xducer Set Up Screen VI from its front panel. The Xducer Set Up VI will also run with the Instrumented Stake VI from its front panel or as the final product called StakeTest1006.exe from the laptop computers Microsoft desktop window.
Figure 3.21 Transducer Unloaded

Figure 3.22 Loaded Transducer
3.4.3 Safety Audit

A full safety team audit is not required for this test because the impact stake process has been reviewed in the past for previous test set ups. Safety requirements still in effect include: no person is allowed in the test cell during the actual test. The stake will be triggered through a pull cord from outside the room. Exhaust fans must be turned on. The test cell will not be entered until all moving parts are stopped. Upgrade to the safety checklist will be made to include:

- The data acquisition must be located outside the test cell.
- Only sensors connected to the test structure and data acquisition equipment will be in the cell when the test is conducted.

Changes to the original audit will require the appropriate approvals before testing can begin.

3.4.4 Storage and Maintenance

The equipment used to collect the data in the test cell is usually left in place until the data has been processed by the customer for their approval. At which time more data may be taken or the test equipment will be broken down and placed in storage until needed for the next test. The laptop computer with LabVIEW installed may be used with another test that may or may not have National Instruments data collection hardware assigned. Storing the laptop will be the responsibility of the individual or test technician whose cell it is assigned since some computers may also be used for control of the test stand through it analog and digital output interfaces.
3.5 Maintenance Phase

The maintenance phase for the test lab consists of:

- **Data Acquisition Hardware Maintenance**
  - Storing the hardware.
  - Tracking the hardware.
  - Upgrading the hardware.

- **Software Maintenance**
  - Insure all Operating system software is virus protested and latest upgrades installed (work with the IT department).
  - Upgrade data acquisition application software.

- **Data Maintenance**
  - Document test data storage locations.
  - Document test procedure locations.
  - Document test requests.
  - Secure and back up stored customer requested data.

3.5.1 Hibernation Stage

Data Acquisition hardware is placed in storage until needed for a test. The storage location documented using an Access database. Users are required to sign the equipment out of storage for tracking purposes.

3.5.1.1 Documentation

The current network drive was available to the test lab for the projects development and future operations. The Information Technology department assigned a directory specifically to the test lab for their projects. The information located in the directory includes test schedules, results, data, procedures, and equipment status.
3.5.1.2 Hardware

Before the data acquisition hardware was placed in hibernation its operation was verified. The equipment was broken down, cleaned and returned to the assigned storage location.

3.5.2 System Reuse

The rising cost of business and competition has impacted the way businesses are run to finite details. Segmenting businesses operations to determine the most practical operations and procedures has resulted in major cost savings. Reuse of the tools equated to businesses normal operations has a positive impact on quality of service, training, and the bottom line. The test lab has implemented reuse strategies that will enable technicians to perform set up of similar test projects in shorter time, resulting in quicker customer responses. Reuse of test equipment and software will have a direct impact towards controlling costs and increasing competitiveness. Documenting the code is good for reuse especially if it is refactored for another test. Reuse of the hardware and software was important to the projects success and consisted of the SCXI equipment, test cells, and computer equipment. Software reuse consists of using existing Microsoft Windows XP software, National Instruments Measurement and Automation software and LabVIEWs VIs.
Purchasing new data acquisition components for the test costs are broken down as follows:

- Computer $ 3,099
- SCXI $ 3,700
- Test Cell $ 10,000
- Total $ 16,799
“Fortunately, there is now a rich variety of off-the-shelf application packages available for most business applications. And many packages contain built-in options that permit different organizations to customize the application to their needs.” [27] One of the goals of this project was to take an off the shelf data acquisition application and develop it to the specific needs of a test. LabVIEW has many features and functions the test lab can utilize to meet criteria set forth by the specifications of the Instrumented Stake Test and other future tests.

Raymond Manganelli and Mark Klein in their book The Reengineering Handbook offers three options:

- Modify the package.
- Extend the package.
- Integrate the package.

Extend the package option was chosen for Instrumented Stake Test Project because LabVIEW has the capability to allow programmers to write code around its functionality. This approach was beneficial to reducing the customized user interface development time during the text based programming process. Once the source program was completed LabVIEW’s compiler created the resulting executable file for use on other laptops in the test lab when needed. Through research an instrumented process was developed using National Instruments LabVIEW virtual instruments and a test fixture. Once the test equipment was selected, measurements of a mower blades impact force was collected using a
strain gage at the base of a test stake. The collected impact force data from the blade stake test was presented in a useable format compatible with the design engineer's analysis software. The designs and documentation of the final solution was stored so it may be reused with similar equipment in future test projects. Cost of development was considered at the design and analysis phase during the process. Examples of controlling cost during the process included making use of existing parts, test equipment, facilities, and software.

4.1 Dynamic Validation Model

The project relied on coordinated development of the sensor configuration and user interface to meet the scheduled test date. Miscellaneous factors obtained through brainstorming techniques that could impact development of the Instrumented Stake Test were realized early during meetings before any lifecycle structures were developed. The extracted critical factors consisted of:

- New data acquisition hardware
- New software
- System evaluation documentation
- Scheduling with the existing equipment
- Learning curves
- Technical skill level of operators
- Documenting the user interface program
- Problems with future software upgrades
- Safety
When these items were factored in a model was composed with allowances for the unknown. A customized model was designed for the two areas of development consisting of sensor and user interface which allow it to be used as a pattern for future test set ups. The Dynamic Validation Model Parallels the two activities of development providing flexibility to allow for bottlenecks, documentation, and research.

Figure 4.1 Instrumented Stake Test Model
4.2 Procedure

Programming the user interface and data acquisition equipment was delayed until computer and mechanical hardware requirements were defined in the analysis phase. This was to prevent unnecessary programming of hardware interfaces and actuators that may alter the desired movement of test stand components. Initially, the configuration interface with the computer and sensors was started about the same time as the user interface. Eventually the development was bounced back and forth because the SCXI-1000 data acquisition hardware was not always available.

The instrumented stake wiring proved to be the most demanding part of the project. One problem was identified during dry runs before the operations phase of the Dynamic Validation Model. During the dry run, the spring loaded instrumented stake was triggered and launched into the air instead of the mowers turning blade. At this time the completed data acquisition system is tested and data is collected and analyzed. The insulation of the wire running from the strain gage down the side of the stake was frayed causing noise and eventual signal loss from the repeated pre test process. Masking tape the wire to the stake worsened the problem because the hole the stake launches out of requires more clearance because the test cell was not designed initially for electronic data collection. The reconfiguration attempts at attaching the wire to the stake eventually led to a new strain gage being installed and attaching the wire to the stake at this time with liquid latex which also served as a protective coating for the wire.
Documentation for the test procedure was another benefit gained from the dry run. Screen shots of the collected data at each step were saved and used in the test procedure. The test procedure (Section 3.25) was constructed in Microsoft Word, converted to a PDF format and stored with other test related documentation on the test labs share drive in a designated folder.

4.3 Summary

The project was completed using the criteria set forth by individual or group meetings with all parties involved. The two major parties involved the customer who requested data collected from testing and management needing data related to product feasibility after an initial hardware investment. The positive results were accomplished by extending the LabVIEW package to implement graphical programming and reusing existing data acquisition hardware. The goals were accomplished through a Dynamic Validation Model tool which served as a guideline to address the projects criteria. The wiring of the stake proved to be the most demanding part of the project because of the extra time and analysis required just moments before executing the actual test. Another problem during interface development concerned availability of the SXCI-1000 chassis because it was in use with another test. A back-up plan was to write the interface software to pick up the low level signals off the transducer using SCB-68 but it would have required a signal conditioner and a completion circuit be designed and constructed. This would have added time to the schedule. The test required recording as much of the impact as possible and using a conditioned
signal would have caused a delay and resolution problems. The solution was to use the SCXI-1000 chassis module during the development by working around the equipments current test schedule and making use of its availability over the weekend.
Chapter 5

Conclusions

The primary focus of the Instrumented Stake Test was to provide a customer with requested data from a simulated scenario standardizing data acquisition was accomplished. Other beneficial outcomes were important processes were developed geared toward implementing graphical programming into the test lab and standardizing data acquisition hardware for reuse. By documenting the results, the test lab has valuable to research information available as references for future test requests, specifically reusing hardware the user interface graphical program. The test lab saved the cost of outsourcing and increased its capabilities to electronically acquire data at the same time using some of its existing data acquisition equipment. The known good user screen VI used for the Instrumented Stake Test is scalable with another hierarchy of lab test project VIs reducing future programming time and costs.

5.1 Results of Instrumented Stake Test

The test was completed after damaging the instrumented stake, lawn mower blade, instrumented stake, and motor beyond repair. The costs of the equipment damaged beyond repair during data acquisition were approximately:

Instrumented Stake $ 50
Lawnmower Blade $ 15
Lawnmower Motor $ 200
Total $ 265
Coordinating the data collection triggering with the mechanical event was more difficult than expected and required a design change. The biggest problem encountered was just before the test was to be performed. The test cell as previously mentioned in this document had never made use of electronic data acquisition so the mechanical action to release stake already existed. The hole where the stake was inserted for launching was barely adequate to fit the transducer wire through causing fraying. This occurred the day before when connecting and testing the system. Moments before the actual test, the Xducer Set Up Screen showed excessive noise on the signals channel, this was caused by the wire fraying. The stake was re-instrumented and problem corrected. After retooling was completed the instrumented one inch diameter steel stake was bent one and one half inches from center as a result of the impact with the lawnmower blade revolving at 3200 revolutions per minute. The lawnmower blade indented the steel stake approximately one inch from the top (refer to section 2.5.2) stopping the stakes upward motion severely damaging the lawnmower motors crankshaft and bending the grass cutting blade. The coinciding trigger action that launched the stake and started the recording of data producing 300,000 microstrain readings in the specified one and one half seconds.
Figure 5.1 Impacted Stake

Figure 5.2 Impact Location
The 1.5 seconds of collected data resulted in a 6,328 kb ASCII text file as per customer request. The text file was formatted in two columns and one header. One column contains the exact time the data was acquired and column two shows the data point represented in microstrain. The header was added as a convenience for the customer and gives information related to the date, time, and file format. Information specific to the test is also included in the header including the total number of samples, y axis label, and x axis label. The text file was delivered to the customer via e-mail. Alternative delivery methods could be to place the file in a directory of the customer’s requests. The data collected as a result of the pre-planned Instrumented Stake Test was accepted by the customer.

Figure 5.3 Collected Data

5.2 Effectiveness of VI Reuse

Reusability is important to contain costs during the testing and data collection process. The reuse hardware and software provide important benefits
to cost control without decreasing quality. The cost of quality could be directly related to the test lab by doing things right the first time and meeting customer expectations. Reuse of existing known good test equipment which has meet requirements of past tests provides a qualitative approach towards meeting the customer expectations. This combination of reusing the hardware with new software tools provides significant savings because of reduced training time due to familiarity of the equipment and the cost of new equipment. After initial development of the VIs produced from developing the software application for each test, cost savings are realized by reusing or refactoring the main VI or its sub VIs.

The information presented in this report confirms the feasibility of using LabVIEW in the test lab. The details presented in the report serve as a starting point for future data collection efforts targeted at reusing data acquisition equipment. Previously the use of data acquisition equipment in the test lab varied with the many different test cells located throughout the building. Some test cells such as the test cell where the Instrumented Stake Test occurred did not use electronic data acquisition equipment as results were defined through the damaged parts. Reuse of hardware components in different test cells using LabVIEW will cut costs by decreasing storage time of the equipment.

The VIs created from the Instrumented Stake Test were cataloged in a directory called Stake Test on the test labs share drive. An index file was created in Microsoft Word providing information about the author, phone number, and purpose of the VI and a hypertext linked to a HTML file. The HTML file was
created with LabVIEW development tools after the VI was completed to meet the test labs quality standard. Contained in the HTML file are pictures, descriptions of data types, and hierarchy information on the VIs. The Stake Test directory also contains test procedures, executables, and build files associated to the VIs used for the Instrumented Stake Test. This information will enable other developers to view information on the VI to determine if it meets their needs. Reuse and refactoring the VIs benefits the test labs bottom line by reducing development time.

An immediate reuse for the Instrumented Stake Test VI called StakeMeasure.vi will be as the main menu screen for another data acquisition test written one year ago for the test lab. The StakeMeasure.vi will be refactored to make use of its cluster shell design for housing switches needed to activate operator controls of the existing tests individual VIs. The plan for refactoring the StakeMeasure.vi will be to replace the existing sub VIs from the Instrumented Stake Test with the each individual VI the existing test employs. This will create a new hierarchy below the StakeMeasure.vi. Completing the refactoring process involves replacing the image of a strain gage on the user screen (Figure 3.7) with a corresponding image related to the test. Renaming the VI and labels will complete the reuse process and save costs related to developing a new user interface.
5.3 Lessons Learned

After weeks of development the actual Instrumented Stake Test was successfully completed in 1.5 seconds. Lessons learned from the project produced an increased expertise in developing LabVIEW programs and the knowledge hardware compatibility is possible with a minimal amount of reconfigurations.

5.3.1 What Went Right

The most important process to go right was the timing involved to electronically capture the event of the blade impacting the stake with the data acquisition equipment. If an individual was trying to capture the moment of the blade impacting the stake with a still camera, they would have trouble isolating that one condition without taking many pictures. It would also be very expensive since the lawnmowers motor would have to be replaced for each missed snapshot. The cost of a new lawnmower motor for each missed shot would add up and negatively influence the test labs budget. The combination of user interface buttons, to start the test, with the mechanical switch programmed into the data acquisition system produced a perfectly centered signal on the laptops display (refer to section J of the test procedure). Having the signal centered on the display was important because it signified all the numerical data representing the signal was captured for insertion into the text file.
5.3.2 What Went Wrong

There were three major barriers to overcome during the development of the Instrumented Stake Test.

(1) The project was initially intended to have all VI programs developed anew during the development cycle. After development was started it was determined the time to develop VIs would be longer than anticipated. This problem led to the use of DAQ assistants for data collection and file manipulation enabling the project to keep close to schedule.

(2) During bench testing it was noted all the data was not being collected during the 1.5 second acquisition window. The triggering process plan was to have the user to push the mechanical data acquisition button and the pull the cord releasing the stake from its spring loaded domain simultaneously. A delay caused by the program trying to initiate the data acquisition process was discovered causing a loss of all or part of the data. To temporarily resolve the problem the operator was instructed to wait three seconds after the data acquisition button was pressed to pull the cord (refer to section E of test procedure). In the future, after pushing the data acquisition button, a three second timer will be programmed to generate a countdown leading to the activation of a visual signal on the user interface panel. The visual signal will be the operator’s key to pull the cord which will release the stake from its spring loaded domain.
(3) During initial dry runs at the test cell, the wire carrying the electronic signal from the stakes strain gage to the data acquisition system was cut. This occurred when a draft resulting from the lawnmowers rotating blade pulled the wire into its path. To prevent damage in future tests the test cell technician rerouted the wires through holes drilled into the concrete floor and steel stake-launch housing.
References


Glossary of Terms

**Analog to Digital (A/D) Converter** – Converts an analog signal to digital form.

**Analog Signal** – The condition of a signal continuously varies.

**Analysis Software** – Used to process and extract raw data for informational purposes.

**Automated Test Stand (ATS)** – A device to safely secure a whole unit or components that may be part of the unit for cyclic testing. Usually the test stand requires no human intervention and will include preset controls and data acquisition.

**Bench Testing** – Testing of equipment and programs outside of their normal environment.

**Data Acquisition (DAQ) System** - Measurement and control of laboratory experiments utilizing computers, specialized I/O circuits, and transducers. DAQ systems could also be used to control industrial processes.

**DAQ Assistant** – Interface software used to configure data acquisition measurement tasks.

**LabVIEW** – A graphical programming language developed through National Instruments. LabVIEW is designed for creating programming applications in the measurement and automation industry.

**Measurement** – Recording the observations made during test and research efforts.

**Measurement & Automation Explorer (MAX)** – Software which communicates between LabVIEW and the software that controls the National Instruments DAQ device.

**Megabyte (MB)** – One megabyte = \(2^{20}\) bytes.

**Microstrain** – An engineering unit used to measure strain. The strain producing one microstrain produces a deformation of one part per million.

**Resolution** - A small change in input that will produce a detectable change in output. Can be represented in proportions, bits, and in percentages of the reading or full scale. An example would be the larger the number of bits representing an analog signal would provide better accuracy to represent the waveform.
**Test Cell** - A dedicated room set aside for testing purposes. The test cell may have a specific use tied to an engineering principle or be used for general test applications.

**Transducer** - A device used to convert information from one form to another. Phenomena such as temperature, sound, light, or pressure can be converted to electrical signals through transducers.

**Sample Rate** – The number of samples per second measured in hertz (Hz) recorded from a continuous signal.

**Sensors** - A device that detects variation and converts the receiving information into another form.

**Signal Conditioning** – Converts the measured signal into another type of measurement signal.

**State** – Different processing segments.

**State Machine** – Used to create user interfaces. Actions selected by the user will transition to different processing functions.

**Strain** – A ratio of the change in length, as a result of the element under stress, to an initial unstressed reference length.

**Strain Gage** - A transducer which measures deformation produced by extension and compression. Converts the results into a small electrical signal used for measurements.

**Tachometer** – An electronic device for measuring revolutions. Usually the measurements are in revolutions per minute (RPM).

**Unit Under Test (UUT)** – The component or vehicle being tested.

**User Interface** – Front panels users work with when conducting tests.

**Virtual Instrument (VI)** – A LabVIEW program.

**Wheatstone Bridge** – An electronic circuit which measures precise resistances and small resistance changes.