Design, Development and Validation of a Lab VIEW-Based Spinal Mobilizer for Treating Back Pain

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Abstract

Lower back afflicts 85% of Americans and is the leading cause of disability in Americans, ages 45 and under. Musculoskeletal pain, arthritis, and back pain produced a total of 10.7 hours of lost productive time. This decrease in productivity leads to an overall cost of $560-$635 billion annually. There is a real need for development of devices that can help treat back pain and enable them to lead productive lives. To this end, a spinal mobilizer was developed and tested at the University of North Texas. The spinal mobilizer was interfaced to LabVIEW, using a data acquisition board. The spinal mobilizer was tested successfully on patients for specific loads. The Therapeutic Spinal Mobilizer passed the tests for reliability, validity, and effectiveness, making it quite beneficial to both patients with spinal issues and physical therapists.

Keywords: back pain, spinal mobilizer, LabVIEW

1. Introduction

Lower back pain is a common condition that affects about eighty five percent of Americans at some point in their lives [1]. Acute lower back pain is usually the result of an injury to the back muscles. This can be targeted and solved relatively easily. Chronic pain, on the other hand, is persistent and can be caused by a multitude of health problems [2, 3].

Lower back pain is the most common among migraines, neck pain, and facial aches. Lower back pain is also the leading cause of disability in Americans ages 45 and under. This pain greatly affects daily life in multiple ways. Adults experiencing lower back pain are limited in their abilities and are in worse physical and mental shape than those without lower back pain [4]. Nearly two-thirds of respondents reported that pain had an impact on their enjoyment of life and 77% of patients said they felt depressed. Pain affects concentration, energy level, and ability to sleep – three very important daily functions.

Pain conditions affect not only social and personal lives, but also the United States workforce. When a person is in any kind of pain, it takes a toll on the body in a way that causes the person to be less productive. Based on the survey, workers lost about 4.6 hours a week due to a pain condition. Musculoskeletal pain, arthritis, and back pain produced a total of 10.7 hours of lost productive time. This decrease in productivity leads to an overall cost of $560-$635 billion annually. The cost of health care due to pain ranges from $261 to $300 billion and about $261 to $336 billion is the cost due to lost productivity. The effects of pain are evident in multiple issues [5, 6, 7]. As the body ages, the spines loses its flexibility and becomes stiffer and less mobile. This is the cause of back pain and discomfort for many people. Spinal mobilization provides a solution to the irritating back pain many people experience as they grow older. Spinal mobilization is a therapeutic technique used to relieve pain from the back. It involves a cyclic motion applied to the spine to increase the spine's range of motion.

Research and experimentation have led to the development of several devices, created to aid in therapeutic spinal mobilization. In 1990, Lee and Svensson created the spinal physiotherapy simulator, which was used to measure spinal stiffness. The simulator was driven by a DC motor connected to a cam and contained a padded load application hooked up to a four-bar linkage under a dead weight. Lee and Svensson also worked with testing load variables. After testing various loading rates, it was concluded that a variety of loading frequencies yielded similar results, except in the case of a prolonged loading (20s). The prolonged loading was not ideal for the measurement of spinal stiffness, but other loading frequencies produced relatively close results.

One of the common modalities used for the treatment of low-back pain is mobilization. Generally, mobilization involves a cyclic application of force through therapists' hands in a postero-anterior direction [8]. Spinal mobilization is divided into four grads based on force applied on the vertebra and its motion elicited. Such division of mobilization regime implies validity of the therapeutic technique and accuracy of its delivery.
In clinical experience, mobilization has resulted in mixed results with widely varying outcome. A significant portion of it may be assignable to non-standardized treatment. Since subjective self-scaling of human activities is going to remain inaccurate and variable, it may be essential to develop a device which may deliver precise dosages of a predetermined mobilization regime. To meet this objective, a therapeutic spinal mobilizer is designed and prototyped.

In this project, the reliability and validity of the Therapeutic Spinal Mobilizer was tested on human subjects at the University of North Texas Health Science Center at Fort Worth. The Spinal Mobilizer was designed, developed and tested at the University of North Texas' College of Engineering in Denton. The project also provided an opportunity for a high school student to interact with faculty and graduate students in engineering on a research project.

2. Methods

The design of the spinal mobilizer was divided into two parts: 1) the actual mechanical design of the device, and (2) the electrical control and interfacing using LabVIEW. The project was entrusted to the department of engineering technology and involved, both mechanical engineering technology as well as electrical engineering technology programs. Laboratory resources necessary for the project were identified. Mechanical design including layout design and actual building of the spinal mobilizer were accomplished in the manufacturing laboratory.

Drawings were created using AUTOCAD and the device was built to meet specifications given by the UNT health Science Center. The assembled device is shown in Figure 1. Once the mechanical structure was completed, it was time to add the electrical features necessary for the interfacing and control of the spinal mobilizer.

The spinal mobilizer consists of a 1/20 horsepower, 16 RPM AC gear motor that will drive a loading piston that applies pressure to a patient's spine. The force applied by the piston onto a patient's back was measured by a load cell that provides feedback to a user, accessed at a LabVIEW GUI on a computer. The loading block with a contact surface area of 2x1 cm, rounded edges, and soft leather coated for proper contact with the patient's back was designed and built. This loading block was attached to the loading piston which is raised and lowered by adjusting the lever. The desired force is obtained by choosing an appropriate static load placed in the load receptacle of the loading piston. Also, the displacement of the piston will be monitored by using a linear variable differential transducer (LVDT) to determine the amount of displacement of a patient's spine during the duration of the treatment.

The following components were used in the development of spinal mobilizer:

- National Instruments LabVIEW 8.6
- National Instruments DAQmx 8.9
- National Instruments USB-6009 Multifunction DAQ
- Loadstar's iLoad Analogy Series Load Cell
- Omega LD621 – 10 High-Accuracy Displacement Transducer
- Dayton 115/230VAC, 16 RPM, Permanent Split Capacitor Parallel Shaft Gear motor
- Single Pole Double Throw (SPDT) Switch with ¾" Roller Lever x 2
- Resistors: 100Ω (1/4 W), 100Ω (1W) x 4
- Diode: D1N4002 1.0A Rectifier
- KEC KN3904 Epitaxial Planar NPN Transistor
- ECE EDR0011A05 Conventional Type Reed Relay
- Meanwell RT-65D, 68-Watt, Triple Outputs Enclosed Power Supply

The therapeutic spinal mobilizer consisted of a capacitive load cell. Unlike conventional resistive load cells based on either strain gauges or piezo-resistive techniques, Loadstar's patented technology harnesses changes in capacitance to measure loads quickly and accurately. It also has signal conditioning electronics built into the sensor itself, and does not need specialized external equipment for output measurement. Moreover, the sensor is powered by a 5V DC input signal and outputs an analog 0.5V – 4.5V DC signal proportional to the applied load. The full scale output range is 4000 mV – two hundred times that of traditional strain-gauge-based load cells. The load cell is mounted onto the loading piston. Load is applied to the spine via a rigid indenter with high dense polymer padding on the surface contacting the spine. To reduce the size of the contact surface, the indenter is slightly curved on its edges.

Displacement of the indenter is measured directly using a linear variable displacement transducer. The LD621-10 DC output displacement transducer has improved IP67-rated sealing, coupled with new polymer guides with rigid carriers. Also, the transducer is excited by a 12V DC input signal and outputs an analog 0V – 10V DC signal proportional to the displacement. The range of the displacement is from 0 mm to 10 mm. Furthermore, four electrical output types are provided; these are standard LVDT, 4-20 mA, isolated DC voltage and digital outputs. The load cell and LVDT are both attached to the loading piston that can be raised or lowered by turning the lever in order to facilitate subject positioning during testing, and assist in achieving the desired pre-load.

An AC gearmotor is used to drive the loading piston. The motor used is a permanent split capacitor motor. A capacitor is connected in series and used to create a second phase from the single phase AC current and it is the interaction between these two phases that causes the motor to run. This introduction of a second phase eliminates the need for the brushes used in a universal AC motor. This greatly increases the both efficiency of the AC motor and increases the life expectancy of the AC motor as brushes are a major source of wear and failure. The advantages of using the permanent split capacitor motor are the high power and high starting torque.

Inside the control box consisted of a power supply and a current buffer. The Meanwell RT-65D triple outputs power supply provides power for the load cell, LVDT, AC motor, and the current buffer. Since the digital output of the DAQ card only supplies up to 8.5 mA per channel and this does not provide enough current to turn on the relay in order to run the motor, therefore, a current buffer is designed and built, as shown in Figure 2.

In the circuit, 4 x 100 Ω resistors are connected in series with the collector terminal of a NPN transistor to provide enough current to drive the relay. Also, a rectifier is connected between the input resistor and the base terminal. This will prevent any back-flow current from going back to the DAQ card to destroy it. The reed relay is placed between the emitter terminal and ground. In this setting, the relay will not be on until a signal coming from the digital output of the DAQ card kicks in.

In order to run the motor and interface the load cell and LVDT with LabView, a multifunction DAQ card is used. The National Instruments USB-6009 provides basic data acquisition functionality for applications. It has 8 analog inputs (14-bit, 48 kS/s), 2 analog outputs (12-bit, 150 S/s), 12 digital I/O, and 32-bit counter. Also, it has built-in signal connectively and bus-powered for high mobility.

Graphical programming with LabVIEW 8.6 was used to implement the system, as shown in Figure 3. It consisted of distinct digital and analog sections.

In order to acquire signal inputs from multiple AI channels at once, they were combined into the same task. Running two analog input tasks in parallel will return error. When running the DAQmx Start function, this reserves the A/D converter, so LabView cannot call it again from another code. To select multiple channels, one has to type in for example Dev1/ai0:1.

Since the NI USB-6009 does not offer hardware timed output and does not have the 'pause trigger' functionality found on other boards, state-machine architecture is designed.

The LabView Graphical User Interface (GUI) is shown in Figure 4. The GUI has functionality provided for the doctor or user to select appropriate channels for input and output. The GUI also enables the user to enter the amount of time (seconds) to apply force on a patient's back. The GUI also enables the user to enter the waiting time (seconds) until the next cycle and the number of cycles to be run. The motor can be run by clicking the 'Run' button on LabVIEW. Once the cycles are completed as specified, the 'Complete?' light turns green, indicating completion of a treatment cycle.

Force and displacement data collected (at 1 kHz) during the measurement procedure are processed using LabView 8.6 to obtain a force-displacement curve. The stiffness coefficient (in N/mm) can be calculated from the slope of the line of best fit using linear regression analysis.

A'Kill-Switch' was designed and added to the system. The switch is a Normally Open Push Button (NOPB) switch that is placed close to the right hand of the patient. The switch was connected to an available channel of the DAQ and was continuously monitored by the LabVIEW VI. When experiencing discomfort from therapy, the patient can depress the switch causing LabVIEW to stop the motor.

3. Results

The spinal mobilizer was run continuously, overnight to test it for consistent performance. Once this was confirmed, force measurements in Newtons from the load cell and displacement measurements in millimeters were logged and plotted in real time in the LabVIEW program that will allow a physical therapist to verify the amount of force that was exerted on a patient's spine and that magnitude of the displacement of the spine. The acquired data was plotted as shown in Figure 5 which shows the amount of force applied and magnitude of displacement over time and the load-displacement hysteresis loop.

After conducting tests on patients, it was found that repeated cycles of loading demonstrated similar load deformation relationship. The stiffness values of these loading cycles remained stable throughout the loading period. The effect of the magnitude of the load on spinal stiffness values were progressive and significant ($p < 0.01$) increasing with load and thereby loading rate at which testing was done [8]. The spinal stiffness at different spinal levels were also significantly different from each other ($p < 0.01$).

4. Conclusion

Currently, spinal mobilization treatment is provided manually by a physical therapist. While this treatment can be effective on increasing spinal mobility for people who suffer lower back pain, the effectiveness of the treatment varies largely depending on the physical therapist. The therapeutic spinal mobilizer has an important role to play in decreasing the variance between therapists and standardize treatment.

The Therapeutic Spinal Mobilizer passed the tests for reliability, validity, and effectiveness, making it quite beneficial to both patients with spinal issues and physical therapists. The mobilizer provides an efficient way to treat patients without needing a physical therapist to perform methods manually.

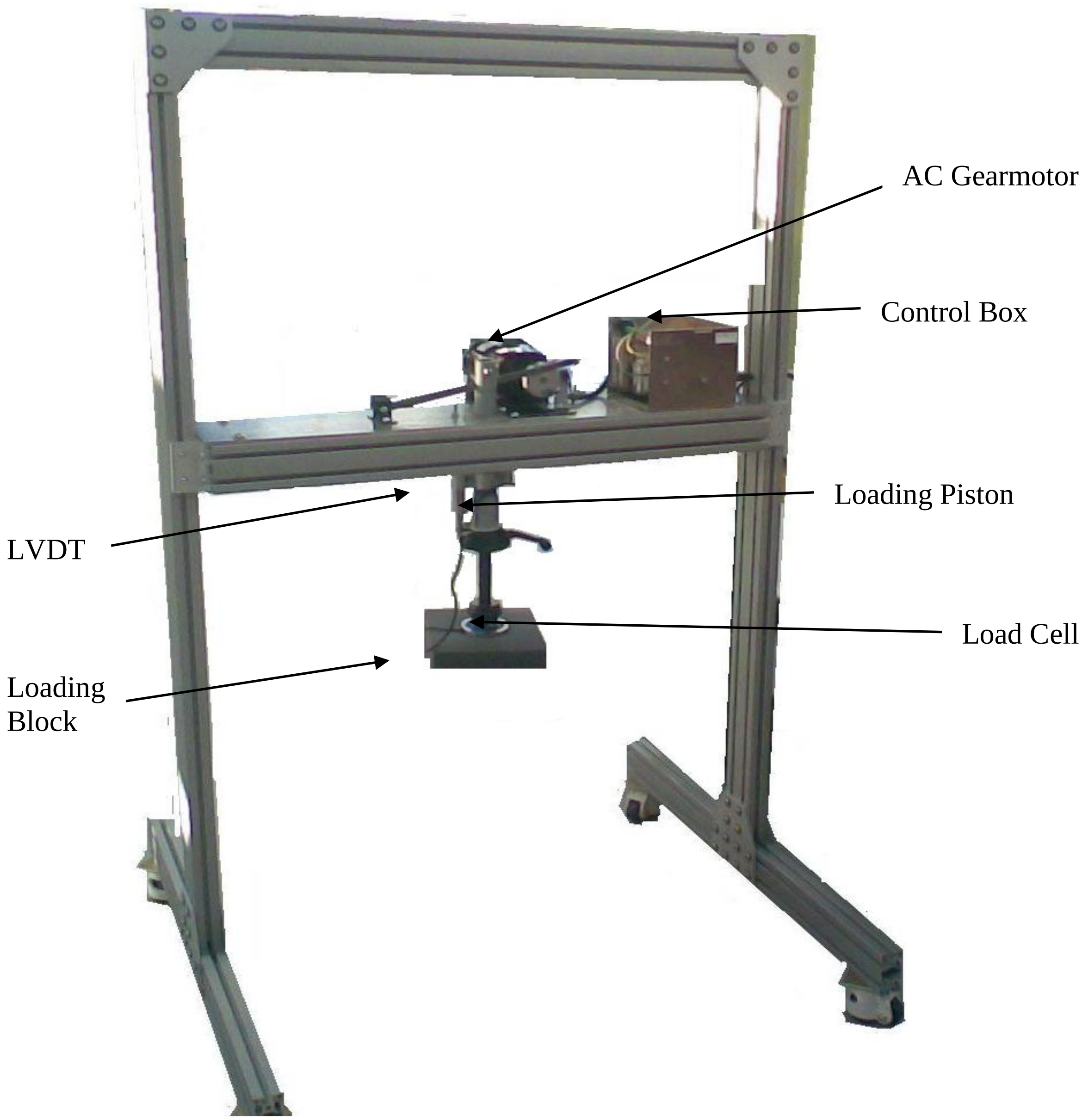


Figure 1: Spinal Mobilizer Treatment System

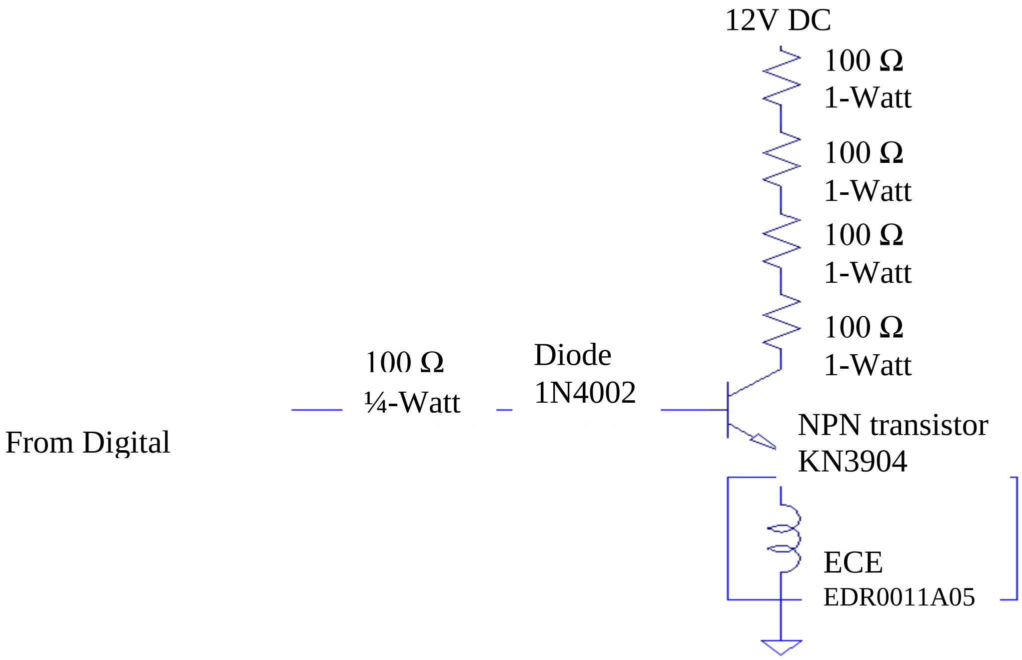


Figure 2: Current Buffer

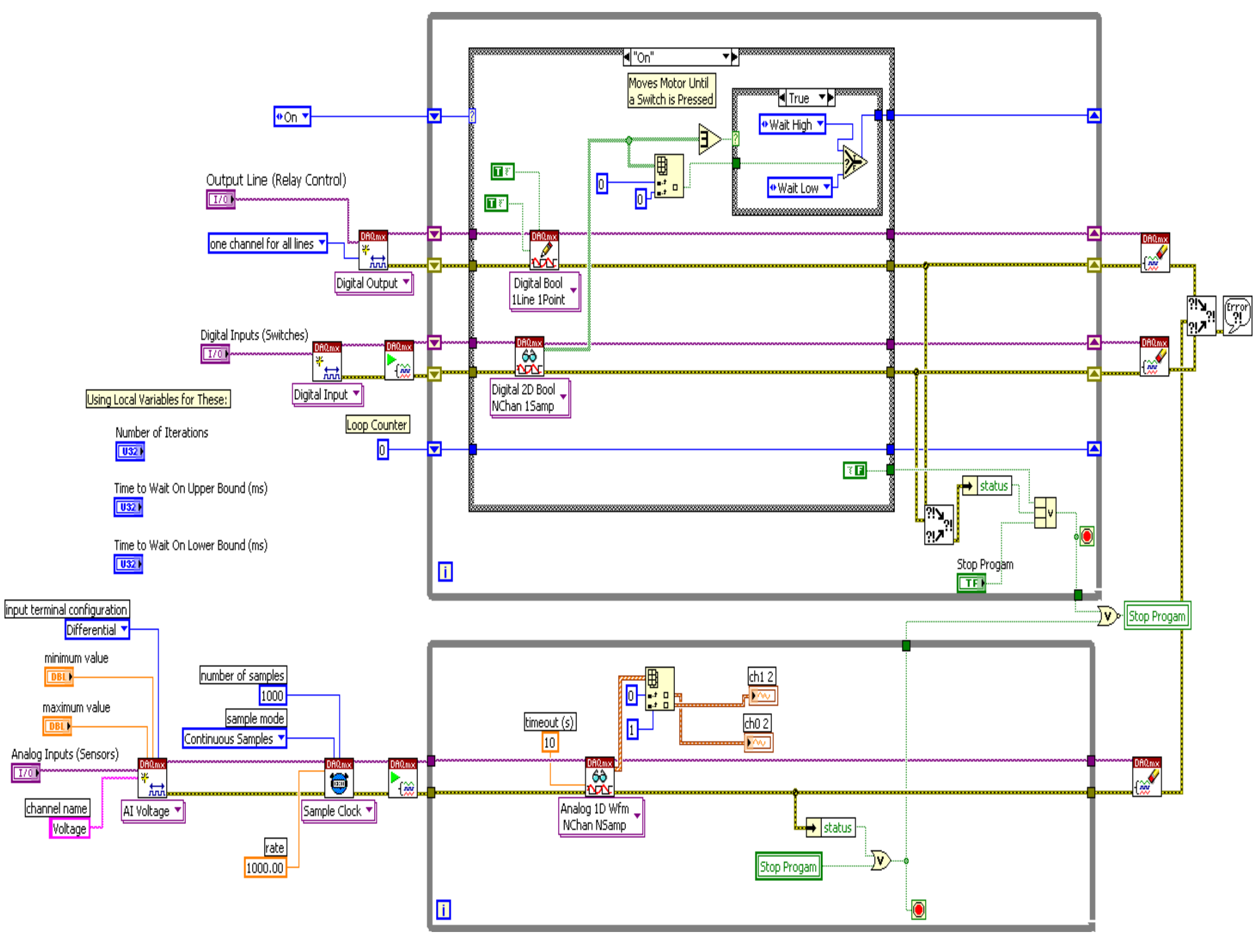


Figure 3: LabVIEW VI used for data acquisition

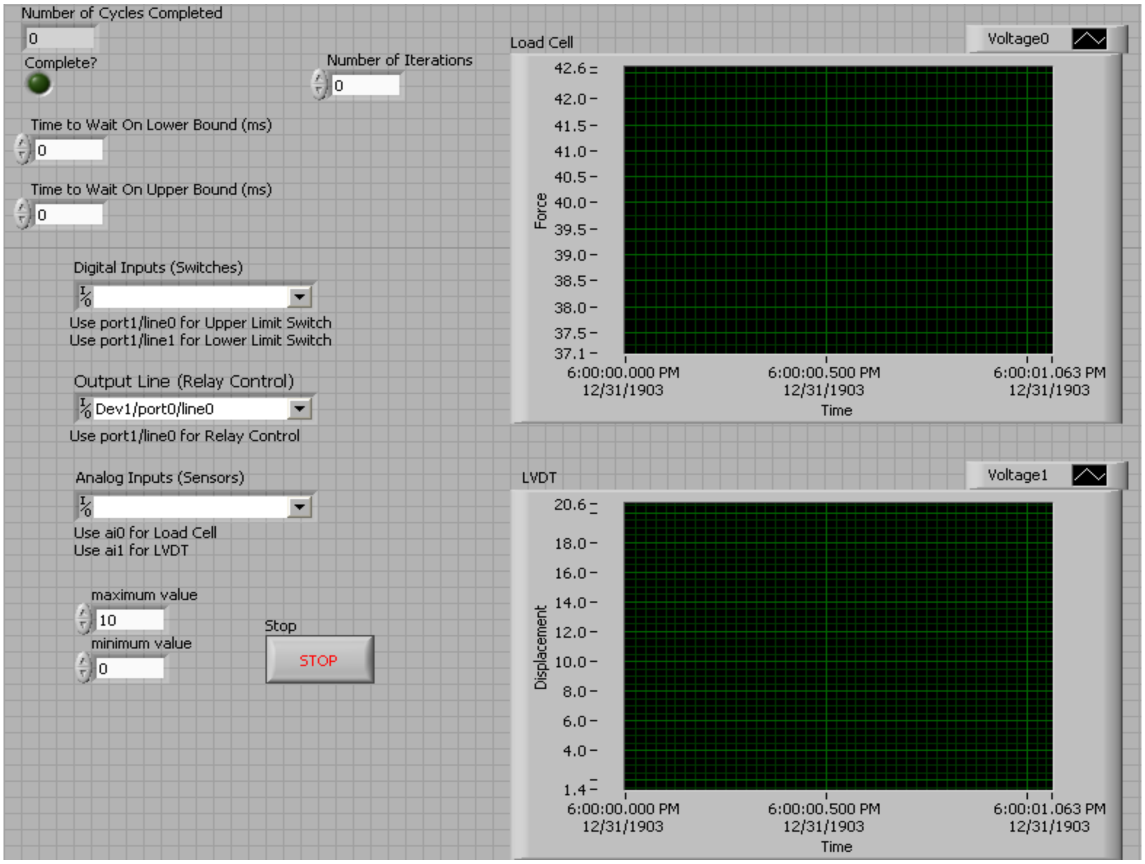
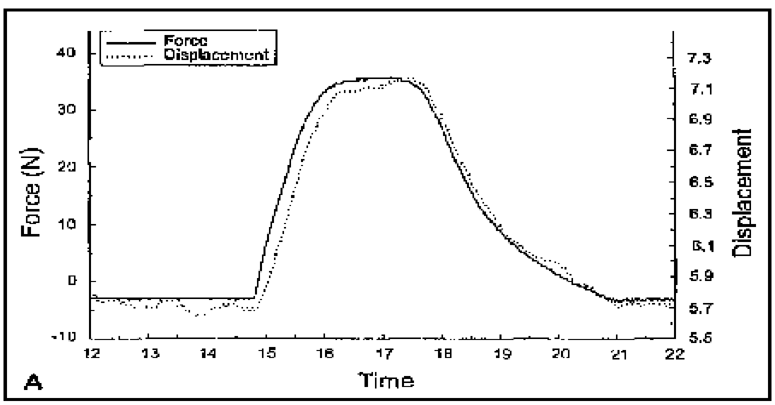


Figure 4: Graphical User Interface (GUI) for the Spinal Mobilizer unit with Control Features and Displays for Load Cell and LVDT Output



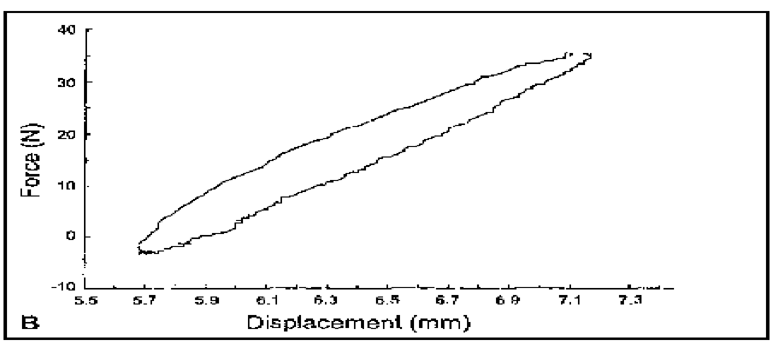


Figure 5: (A) Real Time Load and Displacement (B) Load-Displacement Hysteresis Loop

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