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Automation of anatomic torsion monitor for evaluation and improvement of low back dysfunction

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ABSTRACT

AUTOMATION OF ANATOMIC TORSION MONITOR FOR EVALUATION AND IMPROVEMENT OF LOW BACK DYSFUNCTION

by
Vishal Kumar Singh

The existing Anatomical Torsion Monitor (ATM) to evaluate mechanical stiffness and viscoelasticity of the low back suffers from various inherent defects. This has to be replaced by an improved device. Also the existing ATM cannot provide oscillations to the low back.

The main objective is to automate the existing ATM for evaluating the low back immediately using objective methods. The specific objective is to provide oscillations for improving the low back dysfunction.

The laser platform and the target chart for recording the readings are dispensed with the existing ATM. Instead, the ultrasound transducers are attached to the pads to record the readings for loading and unloading the low back. The voltage readings are directly recorded in the computer through a DAQ card and the Hysteresis Loop Areas (HLAs) are evaluated using MATLAB. In addition to automation of the ATM for evaluating the lows back, a technique is developed for improving the low back dysfunction by imparting oscillations to the low back. These oscillations can be delivered to the subject using a cam mechanism and a DC motor fitted to the automated ATM (A-ATM). The cam mechanism is used with pneumatic cylinders in order to give the oscillation alternately to both contact pads. The frequency of the oscillations can be controlled by using a speed controller switch.

Ten control subjects (nine males and one female) in the age group of (24-77) were given oscillations to the low back for five minutes duration. HLAs were evaluated before and after the treatment in the form of oscillations. The frequency for each oscillation was 20 cycles per minute with amplitude of 2 inches. The percentage change in HLA as well as Range of motion were obtained and summarized.

The existing ATM is successfully automated which results in objectively evaluating the passive low back and obtaining the results quicker compared to un-automated ATM. The automated ATM can also deliver quantifiable oscillations to the passive low back.

It is observed that providing oscillations to the low back results in improved viscoelasticity of the low back for those subjects whose BMI is 25 or less and an insignificant change in range of motion for all the subjects. It is further observed that based on our tests, the optimal duration of oscillations is 5 minutes. However, the correct displacement amplitude, frequency, and duration of treatment will have to be determined from individual medical and physical conditions.

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by
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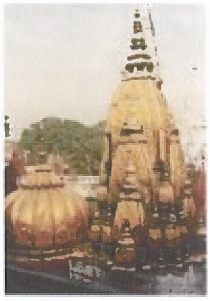

ॐ नमः शिवाय

OM NAMAH SHIVAYA

This thesis is dedicated to my respected grandparents,

The late S.F. Devi and The late Sangram Singh,

And my dear parents, Mrs. Rita Singh and

Er. Satendra Bahadur Singh,

to my loving brother, Vineet Singh and sister, Iti Singh.

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CHAPTER 1

BACKGROUND INFORMATION

1.1 Low Back Problems and Societal Impact

For a society to function, we need a healthy populace. Diseases and injuries have always obstructed the healthy way a society functions, all that is needed is a smart and cost effective way for the Doctors to diagnose the problem. Our focus in this research is on the Low Back Dysfunctions, problems of the low back have a great impact on the quality of life in our society. Most adults experience episodes of back pain that prevent them from working and enjoying relaxing activities [Bigos, et al. 2006]. Low back dysfunction is one of the most persistent of all common reasons to see a doctor [Borenstein, et al. 1995; Atlas, et al. 2004] and is a leading cause of disability [Bigos, et al. 1994; Borenstein, et al. 1995]. According to the data gathered from records of Liberty Mutual Insurance Company, low back pain represents 16% of all claims but account for 33% of all claim costs [Webster and Snook, 1994]. Injury to the low back, represent a quarter of all the reported workplace injuries [Department of Labor, Sept 1990 & October 2006]. An estimate of more than $100 billion is spent yearly for diagnosing and treating low back disorder [Frymoyer, et al. 1991]. The "present therapies are often expensive and limited in efficacy and often create more problems than those being solved" [Burton, 2007].

1.2 Causes of Low Back Dysfunctions

Low back problems, disorders or dysfunctions are often caused due to stress and manifest themselves as lower back pain. Classification of low back problem can be very challenging. It is a difficult task for physician, since they frequently diagnose it differently [Cherkin, et al. 1994; Bogefeldt et al. 2007; Webstezr, et al. 2006]. Low back problem increases as an individual gets older. Many of the problems that cause back pain are the result of injury and degeneration of the intervertebral disc. Degeneration is a process where wear and tear causes deterioration. The disc is subjected to different types of stress as we use our back each day. The disc generally acts like a shock absorber. Bending over results in compression of the disc and also can cause the disc to bulge backwards towards the spinal canal and nerves. The facet joints must also shift to allow the bending to occur. Rowe [Rowe, 1983] found that only 4% of a large sample of low back problem cases in industrial workers was related to traumatic injuries during industrial work. Sprain and strain of the spinal facet joints and soft tissues of the lower back are the most frequently encountered [Jacob, et al. 2004], whereas skeletal causes, disorders of the vertebral discs and spinal fracture are less common causes of low back pain [Fields, 2000]. Only 1% of patients with acute low back pain show compressive nerve root symptoms [Frymoyer 1988].

1.3 Diagnosis

The most reliable source of information for diagnosing the low back dysfunction is the patient's history. Only 10% to 20% of patients with acute low back pain can be given precise patho-anatomic diagnosis. A medical history of back pain and general physical examinations are believed to be the only diagnostic evaluations required for most patients before starting treatments [Sankovis, et al. 1990; KINKADE, 2007]. The standard of care involves performing also a neurological examination. A person suffering with normal deep tendon reflexes, muscle strength and sensation cannot be said to be without lower back dysfunctions. This is also applicable to imaging that involves X-Ray, CT scan, MRI and nerve conduction (EMG) studies. Bulging intervertebral discs are commonly detected by MRI in asymptomatic individuals [Boden, et al. 1990].

These widely used tools and methods for low back dysfunctions are largely inconclusive. Health care providers who practice manual manipulative medicine claim to have the ability to make a musculoskeletal assessment based on factors of quantity and quality. A diagnosis is made by these practitioners by the ability to palpate the low back [Kuchera, 1991, 2005; DiGiovanna and Schiowitz, 1991; Ward, 1997; Jones, et al. 1995; Hungerford, et al. 2007]. Subjective interpretation aside, palpation is at best a rather coarse assessment and may not reveal sufficient detail to render a diagnosis without supportive input from other sources (e.g., patient history, X-Ray, MRI, etc.). Guidelines for active range of motion have been documented [American Medical Association, 1990, 2001]. Instruments called the Goniometers and Inclinometers have been devised to measure angular displacements of the low back and compare it with the guidelines. Complex devices that strap to patients have also been developed and used similarly to dynamically measure active range of motion of the low back [Gomez, 1994; Dillard, et al. 1991; Konstantinou, et al. 2007]. If any deviation from the standard guidelines for a test were found for the patient it was thought to be a means to a diagnosis. Patients under test by these instruments must initiate movement. Unreliable data resulted from coaching, following directions and subjective input by the test patient.

Spinal stiffness is one out of five predictors to evaluate the lower back impairment [Childs, et al. 2004]. Stiffness of the human back has been studied [Maher and Adams, 1994 and Maher and Adams, 1995; Chiradejnant, et al. 2003; Owens, et al. 2007]. A physical therapy research team compared the perception of stiffness among skilled participants group using a series of spring boards. They found that this group accurately identified the known stiffness of the fabricated spring boards. The team then compared posteroanterior stiffness of the lumbar vertebrae in patients with back pain. The authors noted, "mechanical stiffness is not equivalent to the clinical concept of stiffness" [Maher and Adams, 1995]. It challenges the results of this clinical concept of stiffness not being equivalent to the mechanical stiffness. It is the fabricated springboard that is not equivalent to the perceived stiffness of the lumbar vertebra [Warner and Mertz, 1997].

Passive hamstring muscle stiffness was measured during an instrumented straight-leg- raise stretch in 20 subjects to study the role of passive muscle stiffness in symptoms of exercise –induced muscle damage [McHugh, et al. 1999]. The work by Maher and Adams, 1994, 1995 and Chiradejnant, et al. 2003 demonstrates the overall problem when attempting to diagnose a low back problem. The properties of living tissues being measured are either unknown or they are incorrectly characterized. Medical devices and methods in use for diagnosis of low back problems observe some tissue property, but in a very limited sense. MRI, X-Ray, etc. allow for identification of tissue density and displacement. This is useful when observing a fracture, for example. Palpation, the motion assessment of tissue, provides a range of motion and quality measure from its response. Because the human is the instrument, palpation offers limited, subjective information. Complex medical instruments and devices when applied to the low back [Gomez, 1994; Dillard, et al. 1991; Konstantinou, et al. 2007; Maher and Adams, 1994 and Maher and Adams, 1995; Chiradejnant, et al. 2003] have failed to measure any underlying property of living tissue. No method or instrument currently in use for the analysis of the low back has the ability to *objectively* quantify any property of living tissue. Without the ability to measure and quantify a tissue property, no baseline can be established. Thus, a healthy low back cannot be identified. And if this cannot be done, a low back with health problems cannot be differentiated from an healthy one in any meaningful way. This is why robust diagnosis of a low back condition remains elusive.

1.4 A Solution

Living tissue exhibits the natural behavioral property of hysteresis. This fundamental property exists at the level of just a few cells and up to the levels of complex systems of the human body (e.g., joint capsules, etc.) A new, patented medical instrument called the Anatomic Torsion Monitor (ATM) can measure this behavioral living tissue property from motion analysis of a human subject's low back. The ATM rotates a passive supine subject's pelvis, collecting torsion data that plots a hysteresis loop. The range of motion from this data measures the stiffness also. This rotational motion is shared among numerous structures such as myofascial tissues, sacroiliac joints, thoracic, and the lumbar spine [Warner, et al. 1997].

1.5 Un-automated ATM

ATM is a noninvasive device used for assessments of human subject's low back. The device has been developed by an engineer and an osteopathic physician to quantify the clinical examination of the low back as practiced by osteopathic physicians, specifically focusing on rotational motion of lower spine. This instrument measures a fundamental scientific property of stiffness and viscoelasticity of the low back. For each human spine subject tested, the ATM measures a dissipated energy based upon the difference between the energy supplied in pelvic rotation by loading the pelvis tangentially and energy recovered after unloading the pelvis. This measure is inversely proportional to the elastic behavior of the low back. The greater the dissipated energy, the more in-elastic the low back or more impaired functioning of the low back. Similarly ATM also measures the range of motion. The less the range of motion i.e. deflection, the more stiff the low back is.

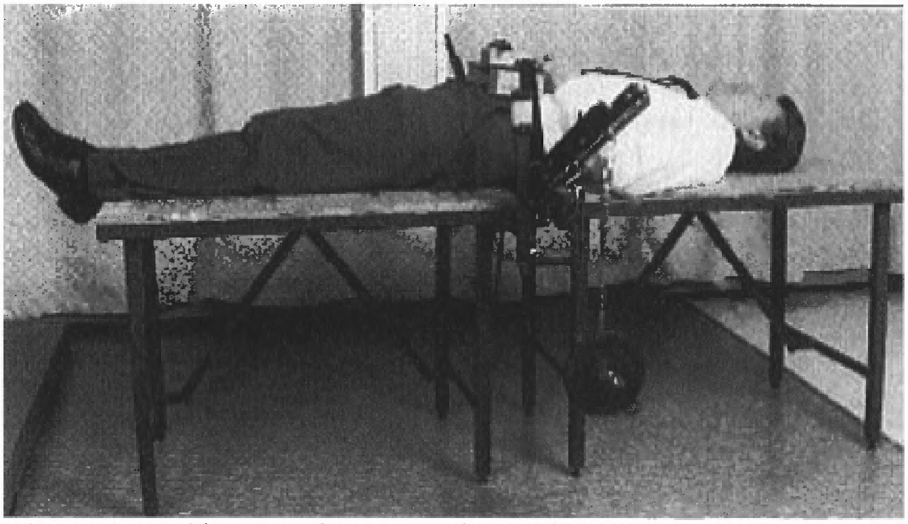

Figure 1.1 Subjects on the Anatomic Torsion Monitor (ATM).

1.5.1 Procedure

A subject is assessed on the ATM using the following protocol:

1. The subject lies supine on the ATM.

2. The laser platform is strapped to the subject's anterior superior iliac spine (ASIS); laser pointer projects a dot on target which is set at zero degrees angular displacement with no weight on weight carriers.

3. Initially, lever arms are without weight at zero angular displacement.

4. Weights are added to the right lever arm weight carrier in five-pound increments up to twenty-five pounds quickly. (This causes the right pad to rise displacing the right posterior superior iliac spine (PSIS) anteriorly. The right ASIS also rises in response causing the projected dot on the target to move upward. Right lever arm applied weight and dot above the zero mark on the target are recorded as positive numbers.).

5. Angular displacement for each applied weight is read from the target by the operator. It may be noted that the final reading is recorded after it settles down due to the creep effect encountered in visco-elatic tissues of the low back.

6. Weights are removed from the lever arm weight carrier in 5-pound decrements.

7. Angular displacement for each removed weight is read from the target through zero weight.

8. Steps 3 through 7 are repeated for the left lever arm.
(Application of weight to the left lever arm weight carrier raises the left pad. This displaces the left PSIS anteriorly, raises the left ASIS and the projected dot is deflected downward on the target grid. Left lever arm applied weight and dot below the zero mark on the target are recorded as negative numbers.)

9. Steps 3 through 8 are one series. Multiple series can be run. As an example, a force-displacement Cartesian plot resulting from an ATM subject assessment is shown in Figure 1.2. It is a hysteresis loop.

10. The area of the hysteresis loop is measured using J-imaging software both for the right and the left hip separately and combined. The greater the area, the more impaired is the low back. The zero area means the perfect elastic low back, which is never attained.

11. The body mass index is determined to compare the results of unhealthy low back with the healthy low back of same ratio, as the deflections vary largely with large bmi in comparison to small bmi.

The un-automated ATM suffers from the following defects.

a. The personal error in reading the wall chart.

b. Laser platform can shift during the test

c. The subject's breathing can affect the readings

d. The hysteresis loop area (HLA) is determined after plotting the graph manually

e. The results cannot be immediately evaluated

It may be noted that the laser platform is removed from the automated ATM, i.e. in the automated ATM, there is no laser platform and no paper graph at a distance of 57 inches.

Pilot Data of the patients with low back dysfunctions (Confirmation of ATM results with clinical findings)

Data for developing the graphs and resulting computations in the pilot study were taken. The results of the ATM assessment of two patients are presented below. A brief history and analysis of each subject's assessment is presented. The brief analysis is just a sample of what can be obtained from the rich content of the subject's hysteresis loop. Eleven Subjects of this study were volunteer patients who gave informed consent. The treating chiropractor performed the analysis on the patients before the analysis on any of his patients was performed by the ATM, thus ascertaining that his diagnosis was not influenced by the results from the ATM results. His analysis was based upon his experience and his medical qualifications.

For the purpose of reference a classic textbook hysteresis loop is used. This is also helpful when discussing a subject's hysteresis loop. A classic textbook hysteresis loop is presented below. As the applied force begins to displace the material, the displacement continues until the maximum force is reached (OB in quadrant 1 on the graph). A residual displacement remains when the applied force is made zero (0C portion of the curve). This residual displacement at C is known as *retentivity or remanence*. The applied force now growing in magnitude but applied in the opposite direction causes the retentive displacement to zero (curve portion CD in quadrant 2). This force at D is called *coercive force*. As the applied force grows to an opposite maximum, DE is traced on the graph in quadrant 3. Relaxing the applied force back to zero, EF is completed. Displacement F is also a *retentive value*. Increasing the applied force in the original direction (curve portion FA traced in quadrant 4) produces a zero displacement at A (a *coercive force*) and a maximum displacement at B (curve portion AB traced in quadrant

1) at maximum applied force. From this point, cyclically decreasing the applied force through zero and to a maximum in the opposite direction at E and then increasing the applied force through zero to a maximum in the original direction at E continually produces a retraced curve BCDEFAB. Note that OB is never retraced.

Summary:

Point O: The *beginning of the force application*; curve starts at the origin.

Points C, F: *Retentivity, Remanence*

Points D, A: *Coercive Force*

Points B: *Maximum Displacement at Maximum Force (initial applied force direction)*

Points E: *Maximum Displacement at Maximum Force (opposite applied force direction)*

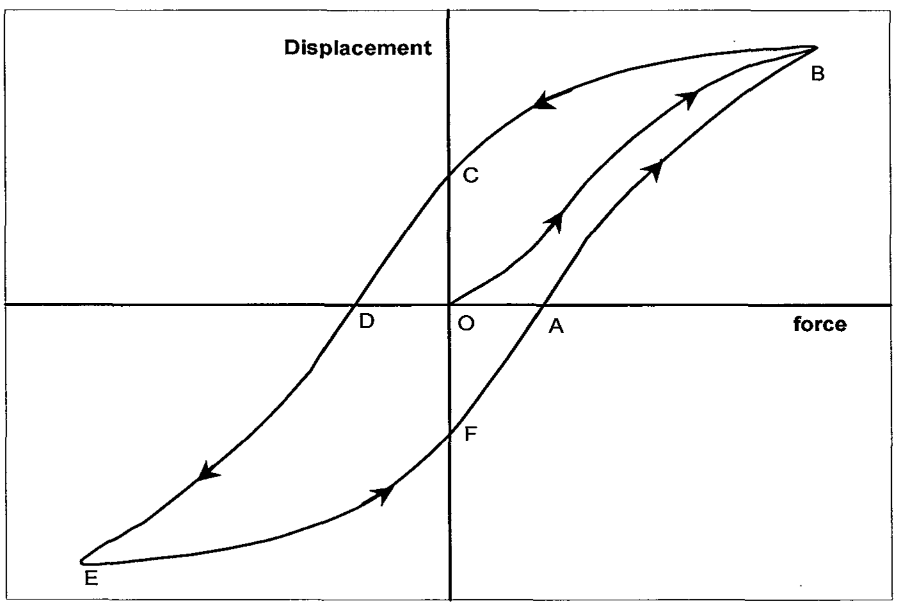

Figure 1.2 Classic textbook hysteresis loop.

Subject 1 is a 33 year old woman, 5' 4" tall weighing 135 lbs and is right handed. She is 6 weeks pregnant. She developed central bilateral low back pain two week after an automobile accident. At the time of this assessment, she reported very mild centralized, intermittent low back pain.

Movement analysis was done using the hysteresis loop (HL) of her low back (LB) which indicated a larger deflection on her right side when compared to her left. This is seen from the third quadrant of the graph where displacement has reached 3.4 degrees. Further, she dissipates more energy on her right side than her left. This observation comes from noticing that there is more area enclosed in the HL on the subject's right side than her left side. Her left side requires more input energy to get the same ROM as the right side. Left side shows slightly restrictive ROM. The overall HL is narrow (low enclosed area), has equal left and right coercive forces and equal left and right receptivity and, based upon past HL analysis of normal subjects, indicates subject has a healthy LB (low amount of dissipated energy on the LB tissues). This subject has not had a LB X-Ray or a MRI. Based upon the HL analysis (Figure 1.2), a comparison given below is made to confirm the results of HL.

Chiropractic assessment of subject 1:

- Left side movement restriction (identified through palpation)
- More ROM on subject's right side (identified through palpation)
- Subjective LB complaints on left side by the patient

Observations/ Interpretation from HL.

- Left side movement restriction confirmed by the HL.
- More ROM on subject's right side is also confirmed by the HL.

- Left side would be where LB pain should originate.
- Right side LB is vulnerable to injury because of large dissipated energy signature.

X (wgt - lbs)	Y (ang. disp)
0	0
5	0.25
10	0.7
15	1.1
20	1.6
25	2.4
20	2.1
15	1.8
10	1.35
5	0.9
0	0.45
-5	0
-10	-0.8
-15	-1.7
-20	-2.5
-25	-3.4
-20	-3.1
-15	-2.6
-10	-2
-5	-1.2
0	-0.4
5	0
10	0.65
15	1.2
20	1.8
25	2.45

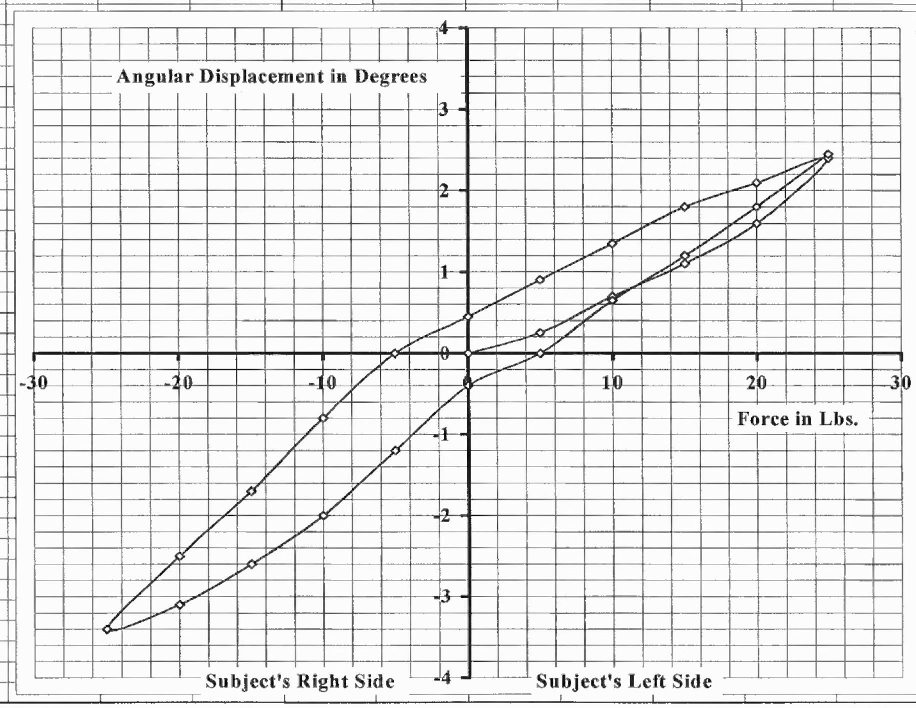

Figure 1.3 ATM Assessment of Subject 1 at Dr. Bryson's Office.

Subject 2 is a 59-year-old woman, 5' 2" tall, weighing 150lbs and right handed. She has been seeing the doctor for more than 6 months for non-specific LB pain. Her LB pain is not associated with any trauma or disease. LB pain is recently subsiding as a result of physician treatment.

HL analysis (Figure 1.3) indicates she needs more coercive force on her right side to return right side retentivity to zero displacement. She has larger ROM on her right side. Last point of HL plotted in the first quadrant is within instrument error. ATM angular displacement is plus or minus 15%. This point could have been misread from the target.

Chiropractic assessment of subject 2:

- Mild left side sciatica pain and left side movement restrictions first
- Mild central bilateral pain next
- Her right side is now exhibiting some pain as well as the left side
- Age and lack of exercise are her major problems

Observations:

- HL confirms left side movement restrictions and potential for left side LB pain
- Central bilateral pain unknown at this time from HL analysis
- Right side has a potential problem; by observation of her HL after a series of cycles, there is more area in the loop on her right side than her left. More energy is dissipated on her right side than left. Chiropractic treatment may be causing pain on her vulnerable right side of her LB.

HL in this case is not definitive about age or exercise.

X (wgt - lbs)	Y (ang. disp)
0	0
5	0.1
10	0.4
15	0.65
20	1.05
25	1.7
20	1.45
15	1.2
10	0.8
5	0.35
0	0.05
-5	-0.1
-10	-0.5
-15	-1
-20	-1.55
-25	-2.3
-20	-2.1
-15	-1.65
-10	-1.2
-5	-0.65
0	-0.25
5	-0.1
10	0.25
15	0.75
20	1.3
25	2

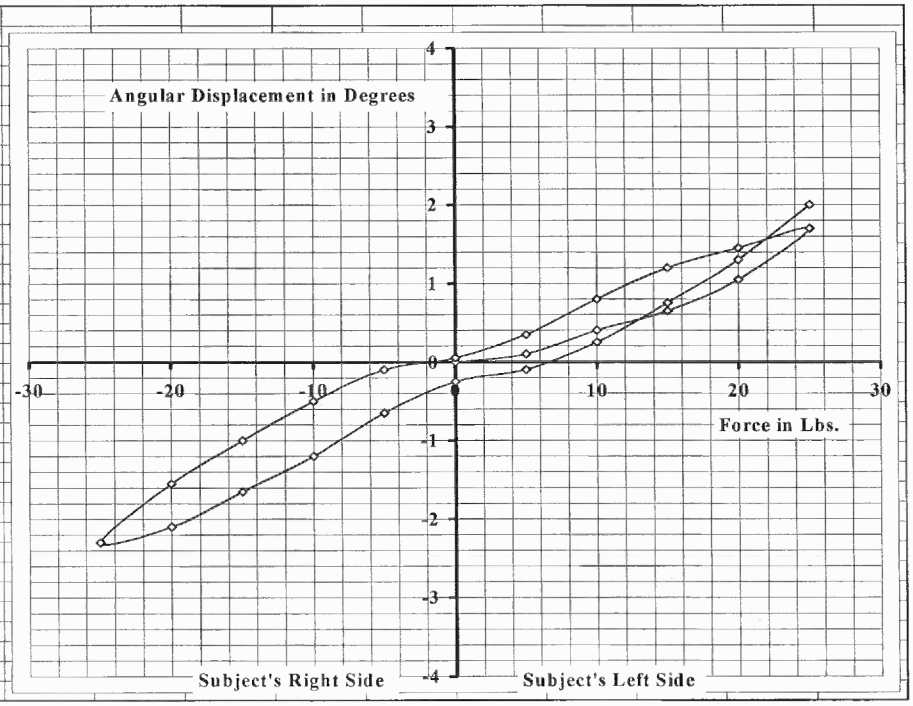

Figure 1.4 ATM Assessment of Subject 2 at Dr. Bryson's Office.

1.6 Utility of Anatomic Torsion Monitor

The main significance of this research project is to quantitatively and objectively establish whether or not a specific treatment such as osteopathic manual medicine, chiropractic manipulation, acupuncture, physical therapy, massage, bed rest, efficacy of drugs and surgery for persons with low back pain is effective in changing the mechanical functioning of the low back by evaluating the dissipated energy and range of motion before and after treatment. The ATM measures, without invasion, a known property of living tissue known as hysteresis. This property allows quantification of low back dysfunction and the ATM is the only medical instrument capable of this measurement. ***Several undergraduate students in BME NJIT performed some experiments on Un-Automated ATM to determine, if mechanical massaging, Leg Hip Raise Exercise and Acupuncture treatment improved the low back dysfunction in 2007. The results were inconclusive because the numbers of subjects tested were very small.***

1.7 Device Similar To ATM

One method of most interest is a computer-interfaced testing device system. Very recently, Owens, et al. 2007 has developed a system called the Polhemus Liberty electromagnetic tracking system (EMTS). This electronic driven system measures displacement. A rod tip comes into contact with a specific point on the lower back. A specific force is then applied that allows the rod to displace. The data for the displacement is then recorded on a software program that allows the user to interpret the parameters such as stiffness values; the force threshold; the force range used for stiffness calculation; the number of cycles accepted for the calculation; and the times for indentation and release of the force (Owens Jr., et al. 2007). This is non invasive device to measure the displacement accurately, but it can still vary from user to user since it is dependent on the placement of the rod can. Achieving a specific force can allow inaccuracies if not placed in the correct position. It is observed that the stiffness is force and time dependent. The stiffness has been calculated in the loaded region only of the force-displacement curve. It is not calculated when the force is unloaded. So one cannot conclude about the overall stiffness of the low back. The above mentioned drawbacks are removed from the ATM which is a mechanical non invasive device, independent of the expertise of the users. By measuring the dissipated energy and the range of motion, the elastic behavior and the stiffness of the low back are simultaneously evaluated.

1.8 Current Treatments

Over the years, many devices such as Neurostimulator, Infrared Belt, Magic Spine Wand, Flexible Fusion, Stem Cells have been introduced to alleviate the low back pain. Neurostimulator is a small battery operated device that sends mild electrical impulses along the spine blocking pain to the brain. Infrared Belt device uses low level infrared energy that releases heat to improve blood flow circulation and promote healing. Magic Spine Wand is a surgical technique known as Percutaneous Diskectomy that removes excess tissue to relieve pressure on nerves causing pain. Flexible Fusion is plastic tubing that provides stable support and greater movement. Stem Cells approach uses the patient's own bone marrow cells to regenerate damaged intervertebral disks.

1.9 Frequency Oscillations Applied to Low Back

Numerous researches were done on the effect of controlled frequency oscillations on the low back stiffness, the following observations were made:

The importance of spinal musculature is highlighted, in the level of stiffness of the lower back in Merino sheep, wherein different mechanical excitation frequencies showed different levels of stability of the lumbar spine [Keller et al. 2007]. There has been success in implementing systems to measure the spinal stiffness in clinical trials of manipulation of low back pain when the human operator provides the force of indentation [Owens et al. 2007]. Three dimensional movements of the lumbar spine were analyzed in some studies which suggested rotational mobilization of the lumbar spine may be able to restore lost movements in the lumbar spine in any of the three anatomical planes [Latimer et al. 1998]. Hysteresis loop of the human lumbar spine has been assessed under conditions of varying load and the stiffness properties were correlated to the same in a mechanical assessment of human cadaver lumbar spinal segments [Gardner-Morse et al. 2004]. A new chair concept using dynamically changing rotational stimuli was found to most likely improve the spinal discs and to prevent low back pain [Lengsfeld et al. 2000]. Experiments have showed, a resonant frequency associated with a three dimensional model of the lumbar-sacral spine which proved the effects of the mechanical stimulation frequency on the mechanical characteristics of the spine [Goel et al. 1994]. Studies on Merino sheep have shown the effects of mechanical excitation frequency and body mass on the stiffness of the lumbar spine; in such studies, the mechanical excitation frequency was randomly applied in given sets for a particular interval and across a continuous range of frequencies across another interval [Keller et al. 2007]. Electromyography studies also show the effect of varying loads on the viscoelastic tissues constituting the musculature, responsible for stiffness [Solomonow et al. 2003].

In vitro mathematical models developed for the lumbar spine have also shown the existence of a fundamental natural frequency of oscillation [Keller et al. 2002]. A five degree of freedom equivalent model of the lumbar spine was developed to predict the posterior anterior motion of the lumbar spine. The study suggested that the modeling of the posterior anterior motion response of the lumbar spine to the poster anterior forces would definitely help us develop better techniques for understanding the biomechanics of the lumbar spine [Keller et al. 2002]. Some other studies conducted have also shown a difference in the spinal stiffness which has been measured by the neuromuscular reflex response of subjects having constant low back pain versus subjects having intermittent or no low back pain [Colloca et al. 2001]. In vivo studies showed the posterior anterior mechanical behavior of the human thoracolumbar spine was sensitive to the mechanical stimulus frequency and that there were significant region-specific and gender differences; the most suitable frequency inducing the least stiffness was in the range of 30 to 50 Hz [Keller et al. 2000]. Varying levels of stiffness are felt at different times depending on the amount of force applied by the therapist [Latimer et al. 1998]. This surely calls for an automated intervention which would give a varying force, both by frequency and amplitude to the lumbar spine.

1.10 Objective and Goal of Research

Three qualities of an ATM important for medical situations are minimizing the error, getting quick results and establishing reliability of the device. Keeping these aspects in view, the automation of the existing ATM has been done.

Therefore, the main objective of this research is to do the Automation of the ATM. The specific objective of the research is to see if the Rotatory Oscillations applied to the low back improves the dysfunction of the low back.

CHAPTER 2

MOTIVATION FOR AUTOMATION OF ANATOMIC TORSION MONITOR FOR EVALUATION OF LOW BACK (ATM)

Automation suggests more advanced and futuristic technology. Automated Anatomic Torsion monitor (A-ATM) given in Figure 2.1, below has been developed by us as an advanced medical tool that can be used to improve the quantification and evaluation of low back dysfunction which will result in significant benefits to the medical community. It is a highly innovative automation system where physicians can now measure the low back muscle and fascia stiffness and viscoelasticity associated with it with full ease by just using some customized software and electronic switches synchronized with ATM. In order to improve efficiency and reliability of automated torsion monitor, it becomes mandatory to provide technological touch to the existing device.

Physicians operating Un-automated torsion monitor generally encountered severe difficulties which have been rectified using automatic version of the ATM. Laser light platform and reading chart plays very crucial role in the analysis of the data. Proper balancing of laser platform on the human body and its synchronization in order to get proper focusing on the reading chart is to be implemented with utmost accuracy. But this job done at present suffers from personal error and needs to be done with great skill and accuracy. It is not possible to achieve accuracy manually. The idea of automating the machine generated to minimize the human intervention and personal error is essential. Introducing ultrasonic sensors which have been placed beneath the circular plates in automated anatomic torsion monitor replaces laser platform and reading chart used in earlier version. A customized software used for analyzing readings and plotting area under curve reduces the time and cumbersome job required to find accurate area. Being more sensitive than laser beam, the ultrasonic sensor plays very important role in maintaining accuracy in the whole process.

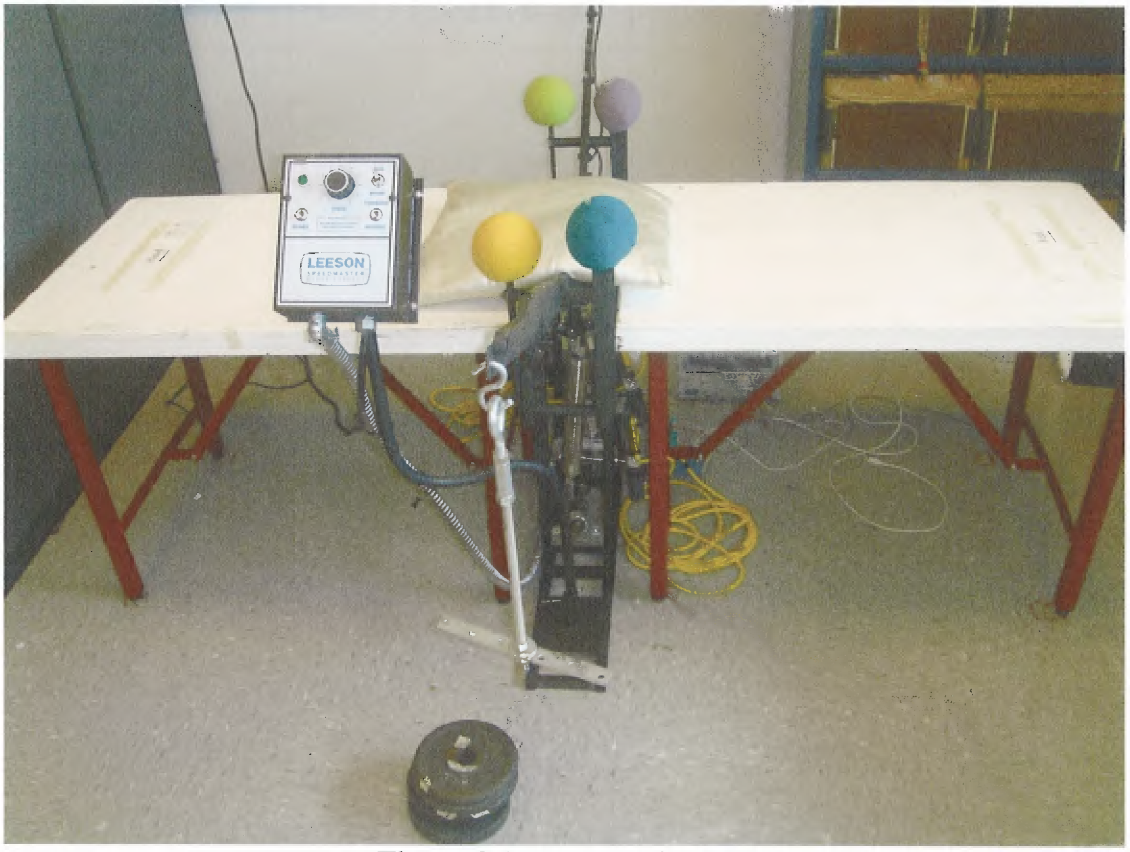

Figure 2.1 Automated ATM.

2.1 Components Involved In A-ATM

a) Ultrasonic Sensors

How Ultrasonic Sensor Works

Ultrasonic signals are like audible sound waves, except the frequencies are much higher. This ultrasonic transducer has piezoelectric crystals which resonate to a desired frequency and convert electric energy into acoustic energy and vice versa. The illustration shows how sound waves, transmitted in the shape of a cone, are reflected from a target back to the transducer. An output signal is produced to perform some kind of indicating or control function. A minimum distance from the sensor is required to provide a time delay so that the echoes can be interpreted. Variables which can effect the operation of ultrasonic sensing include: target surface angle, reflective surface roughness or changes in temperature or humidity. The targets can have any kind of reflective form - even round objects.

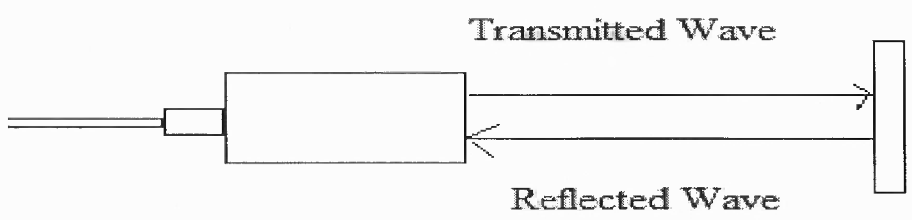

Figure 2.2 Working of ultrasonic sensors.

Advantages of Ultrasonic Sensors

When used for sensing functions, the ultrasonic method has unique advantages over conventional sensors:

- Discrete distances to moving objects can be detected and measured.
- Less affected by target materials and surfaces, and not affected by color. Solid-state units have virtually unlimited, maintenance free life. Can detect small objects over long operating distances.
- Resistance to external disturbances such as vibration, infrared radiation, ambient noise, and EMI radiation.

The RPS-409A-IS

It is an intrinsically safe, analog ultrasonic sensor. It is a self-contained sensor in 30mm PVC barrel housing. It is powered by 16-30VDC with reverse polarity protection. It also has a narrow beam angle, which enables it to get into tight places. A flat target can tilt up to 10 degrees and still be detected. The RPS-409A-IS has a short circuit protected analog 0-10VDC output. The analog voltage is a fixed volts per inch based on the maximum range of the unit. The RPS-409A-IS has built-in temperature compensation to provide accurate readings throughout the entire operating temperature range.

An LED indicator is provided. The LED is green when not detecting and changes to red when a target moves into place. The sensor is completely sealed and the connection is made by way of IP and NEMA rated cables. Besides the input and output lines there is a sync/enable line provided. This can be used for connecting multiple sensors together to prevent cross talk, or to fire the sensor at a particular time. The RPS-409A-IS is designed to take advantage of today's PLC and computer analog input cards. The numerical values that are programmed into the PLC or computer will determine the zero and span.

Specifications:

Model Number:	Sensor Range:	Transducer Frequency:	Response Time:
RPS-409A-40-IS	4" to 40"	160kHz	85ms

1. Power Input: 16 - 30VDC Reverse Polarity Protected
   (A minimum of 24VDC must be applied to the barrier)

2. Input Current: 24mA maximum with 24VDC
   applied to the barrier

3. Ambient Temperature: -40° to 60°C (-40° to 140°F)

4. Humidity: 0% - 95% Non-Condensing

5. Housing: PVC Housing with a PVC sensing face

6. Output: Analog Voltage Output 0-10V
   (Load 100k Ohms to infinity)

7. Short Circuit Protected

8. Weight: Sensor 4 ounces

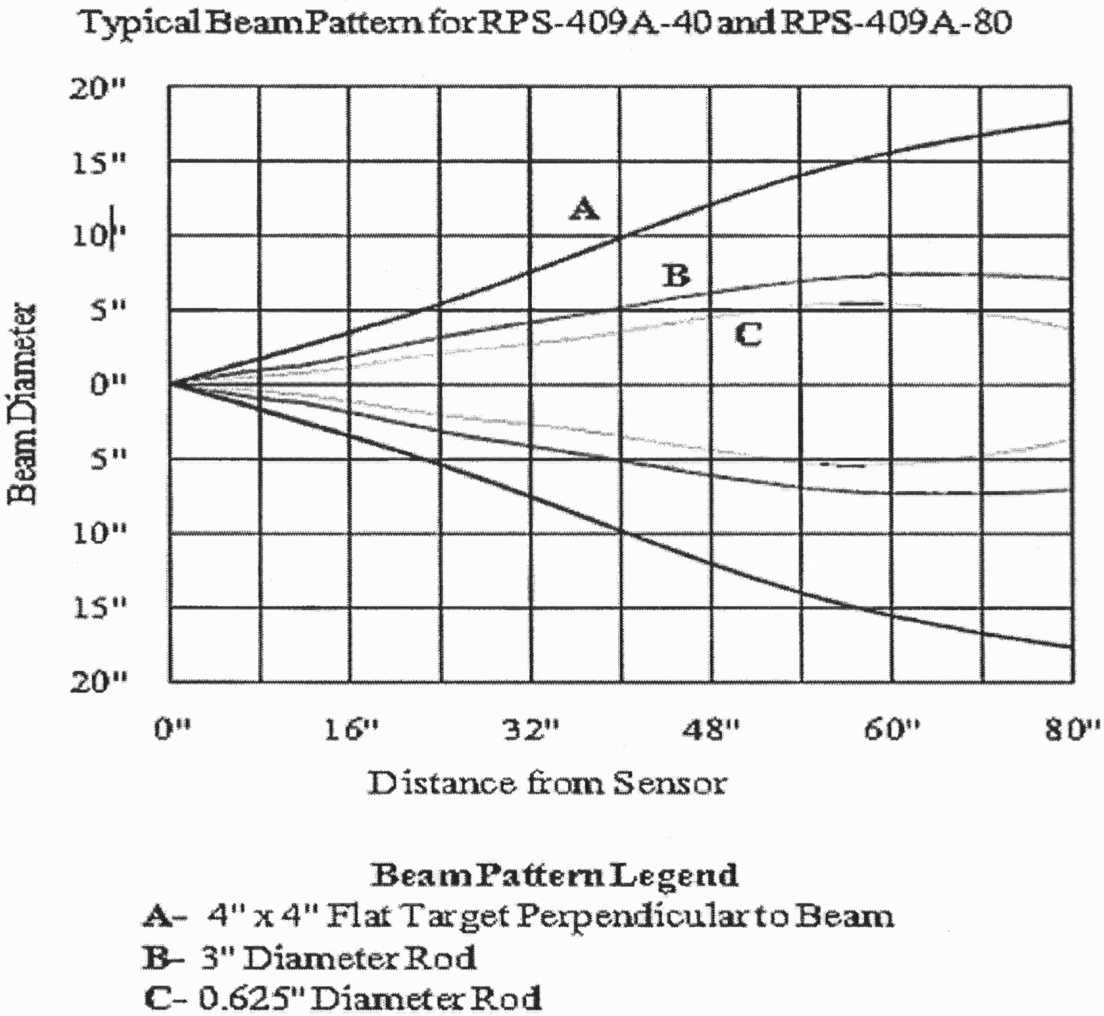

Figure 2.3 Beam pattern methods for ultrasonic sensors.

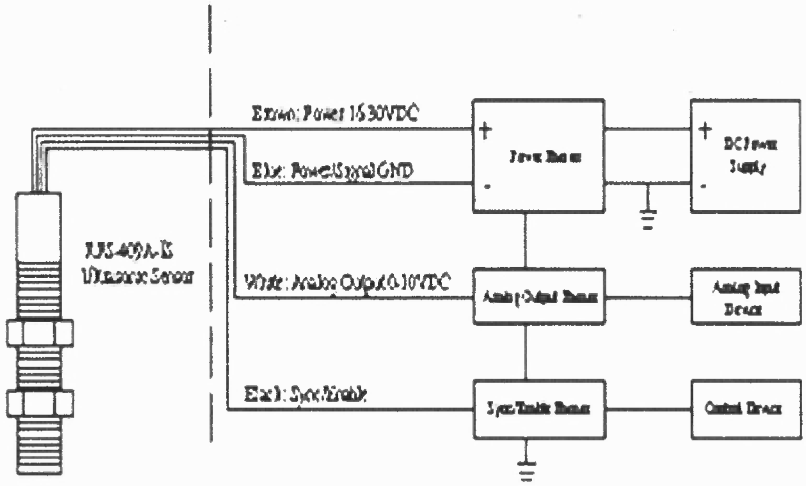

Figure 2.4 Wiring for intrinsically safe applications.

UL listed Intrinsically Safe For use in Hazardous Locations when used with approved Intrinsically Safe Barriers

Class I Division 1 Groups A, B, C and D

Class II Division 1 Groups E, F and G

Class III Division 1

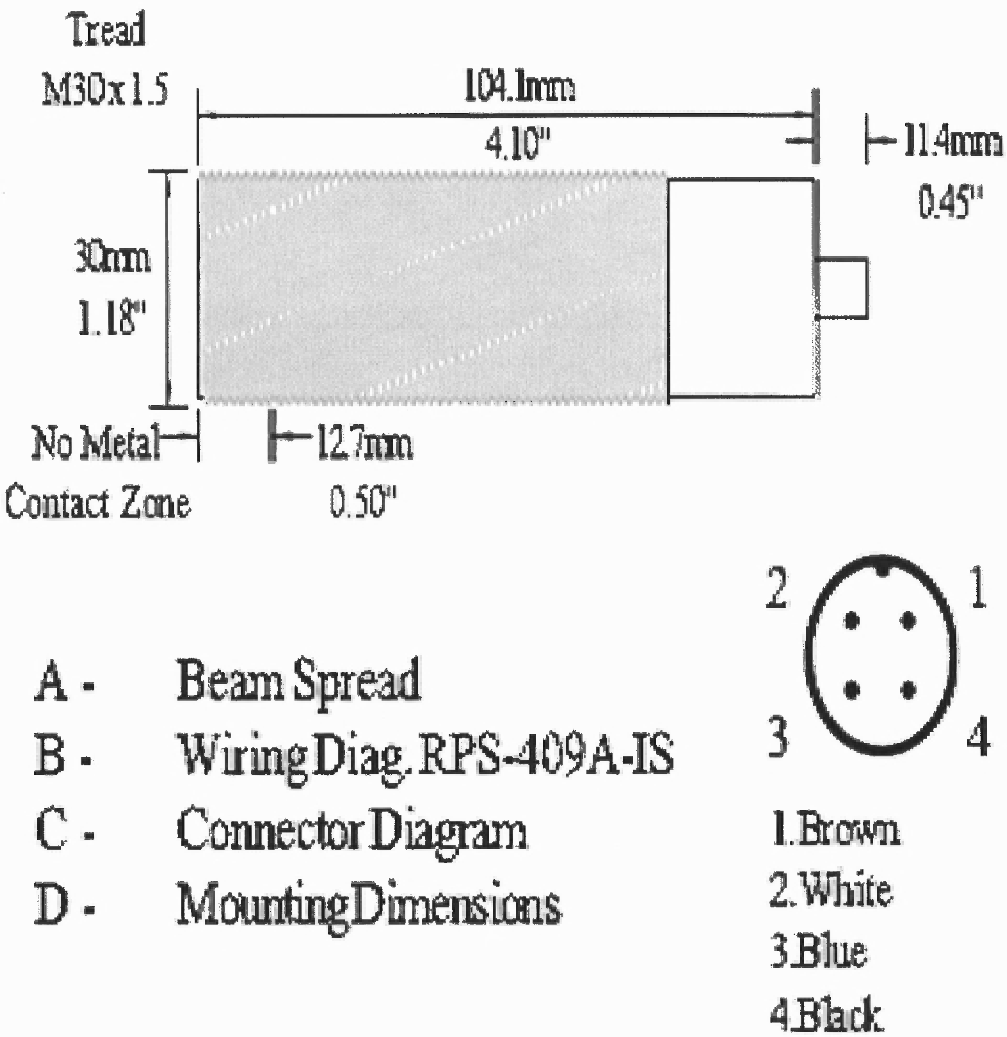

Figure 2.5 Connections for ultrasonic sensors.

b) DAQ Card

Introducing the USB-1208FS

The USB-1208FS is a USB 2.0 full-speed device supported under popular Microsoft Windows operating systems. It is designed for USB 1.1 ports, and was tested for full compatibility with USB 2.0 ports. The USB-1208FS features eight analog inputs, two 12-bit analog outputs, 16 digital I/O connections, and one 32-bit external event counter. The USB-1208FS is powered by the +5 volt USB supply from computer. No external power is required. The analog inputs are software configurable for either eight 11-bit single-ended inputs, or four 12-bit differential inputs. Sixteen digital I/O lines are independently selectable as input or output in two 8-bit ports.

A 32-bit counter can count TTL pulses. The counter increments when the TTL levels transition from low to high (rising-edge). A SYNC (synchronization) input / output line lets you pace the analog input acquisition of one USB module from the clock output of another. I/O connections are made to the screw terminals located along each side of the USB-1208FS.

Figure 2.6 DAQ card.

BLOCK DIAGRAM:

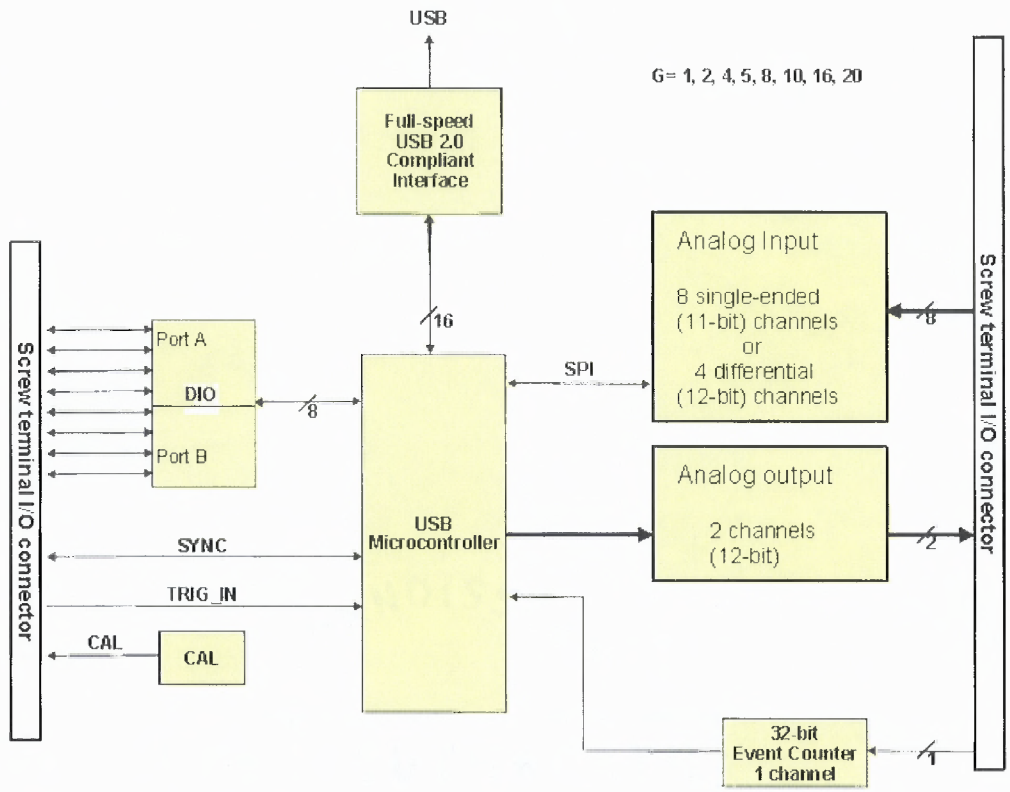

Figure 2.7 Block diagram for DAQ card.

CONNECTIONS:

Screw terminal – pins 1-20
The screw terminals on the top edge of the USB-1208FS (pins 1 to 20) provide the following connections:

1. Eight analog input connections (**CH0 IN** to **CH7 IN**)
2. Two analog output connections (**D/A OUT 0** to **D/A OUT 1**)
3. One external trigger source (**TRIG_IN**)
4. One SYNC terminal for external clocking and multi-unit synchronization (**SYNC**)
5. One calibration terminal (**CAL**)
6. Five analog ground connections (**AGND**)
7. One ground connection (**GND**)

8. One external event counter connection (**CTR**)

9. Screw terminal – pins 21-40

10. The screw terminals on the bottom edge of the (pins 21 to 40) provide the following connections:

11. 16 digital I/O connections (**PortA0** to **Port A7**, and **Port B0** to **Port B7**)

12. One power connection (**PC+5 V**)

13. Three ground connections (**GND**)

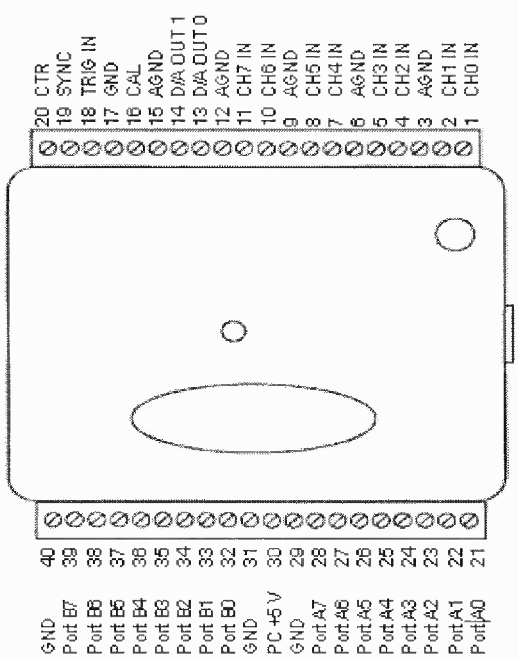

Figure 2.8 Eight channel single ended mode pin out.

c) Direct Current Motor

It is base-mount and C-face configurations. These motors are brush style with an internal permanent magnet. Their brush/spring assembly is removable for easy maintenance. Motors are rated for continuous duty and have ball bearings, Class F insulation rated to 311° F and a junction box with lead wires for electrical connection. They can be used in either clockwise or counterclockwise rotation. A speed controller can also be used to change the motor speed. Torque remains constant over the entire speed range. Housing is aluminum and steel. This is High-Voltage Motors having a high starting torque to handle heavy loads. It has totally enclosed fan-cooled (TEFC) enclosure.

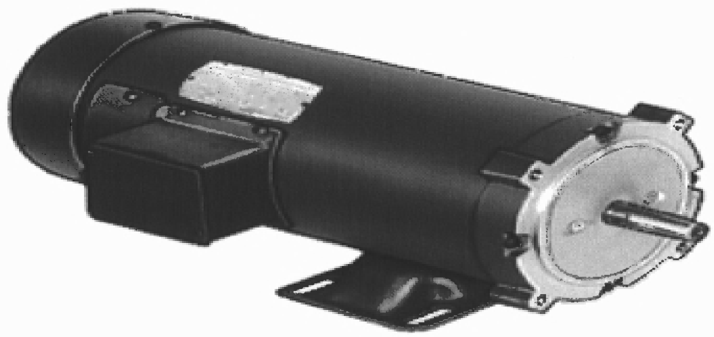

Figure 2.9 Direct Current Motor.

Specifications:

1. Horse Power: 1 hp
2. RPM: 1750
3. Torque in -lbs: 36
4. Shaft Lg.: 1 7/8”
5. O’all Lg.: 16.31”
6. Full Load Amps: 10

d) AC to DC Speed Controller

Input a single-phase (50/60 Hz) AC voltage and get a variable DC voltage output to control the speed of 90 VDC or 180 VDC permanent-magnet motor. Controllers have an on/off switch, knob for DC output adjustment and screw-terminal connections. Reversing controllers allow us to reverse the motor's shaft rotation.

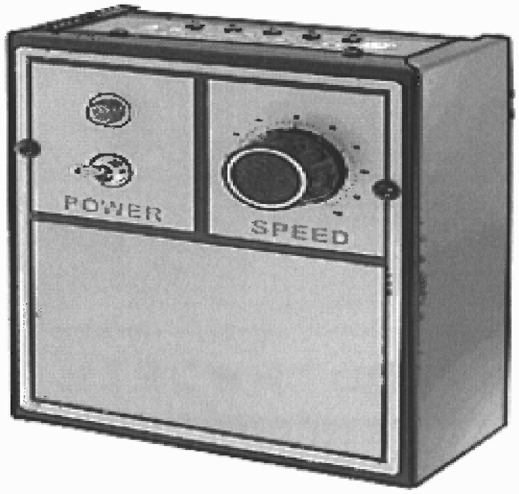

Figure 2.10 Speed controller.

e) High Efficiency Speed Reducer

Designed with spur gears, these speed reducers transfer torque more efficiently than speed reducers with worm gears. They also boast a compact parallel shaft design. All have a die cast aluminum housing, a steel shaft with a 0.33" dia. through hole, and hardened steel gear teeth. Input shaft operates clockwise or counterclockwise; input and output shafts turn in opposite directions. Maximum input speed is 1750 rpm.

Specifications:

1. Ratio: 11:1:1
2. Max. Input hp: 0.75
3. Output rpm: 156
4. Output Torque in-lbs: 290
5. Overhung Load Cap.,lbs : 242

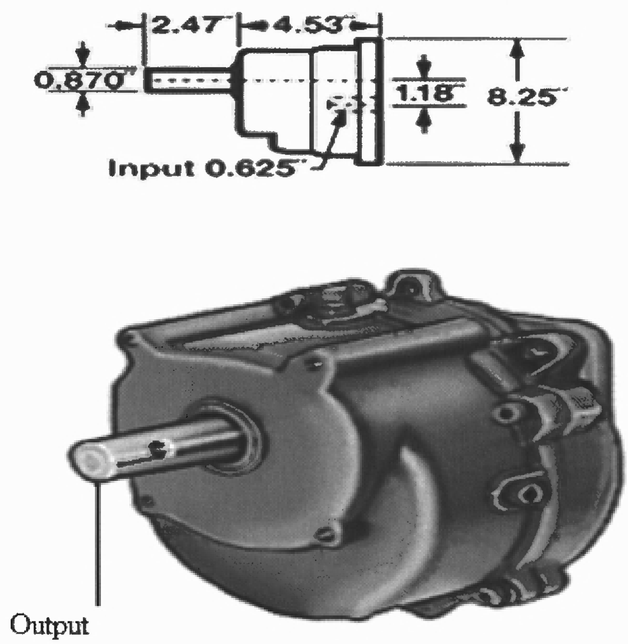

Figure 2.11 Speed Reducer.

f) Pneumatic Cylinders

Pneumatic cylinders (sometimes known as air cylinders) are mechanical devices which produce force, often in combination with movement, and are powered by compressed gas (typically air).

To perform their function, pneumatic cylinders impart a force by converting the potential energy of compressed gas into kinetic energy. This is achieved by the compressed gas being able to expand, without external energy input, which itself occurs due to the pressure gradient established by the compressed gas at greater pressure than the atmospheric pressure. This air expansion forces a piston to move in the desired direction.

Specifications:

Bore Size: 5 inches

Force: 162 lbs

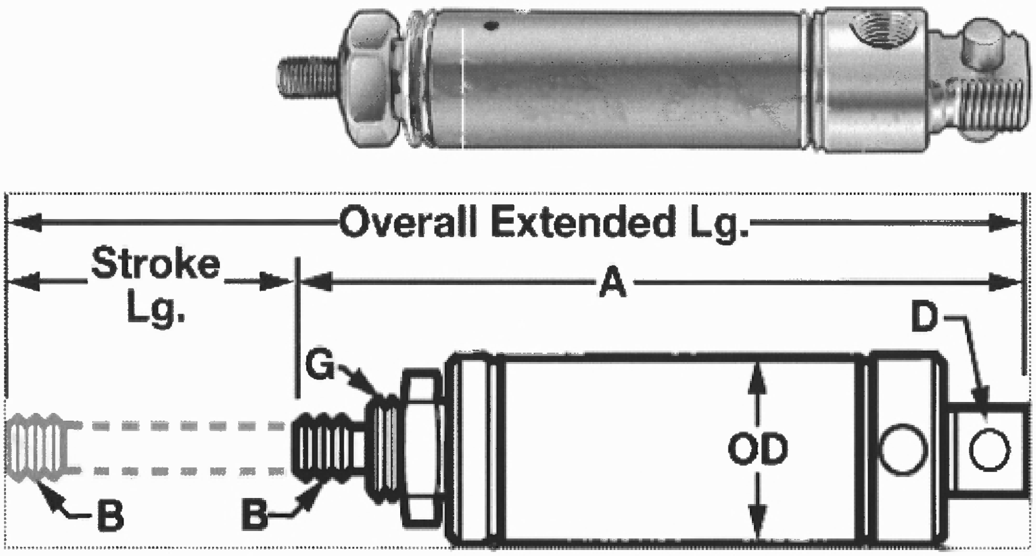

Figure 2.12 Pneumatic Cylinders.

g) Direct Current Supply

A Switching power supply (also known as switch mode power supply) regulates the output voltage by the use of a complex high frequency switching technique. They have good load and line regulation, but somewhat higher ripple and output noise than linear regulated power supplies in high frequency. They also have slower transient response, but higher efficiency. Typical applications for switching power supplies include: general purpose use, high power, small size & light weight, long hold-up time, high efficiency, Power Factor Correction, wide input range and digital circuits.

Specifications:

1. Dual adjustable outputs: 0-50V and 0-5A
2. Three operating modes: independent, series, parallel
3. Input voltage: 110V/220V AC switchable
4. Line regulation: CV <= 0.01% + 2 mV, CC <= 0.2% + 2 mA
5. Load Regulation: CV <= 0.01% + 3mV, CC <= 0.2% + 3 mA
6. Ripple noise: CV <= 0.5 mV RMS, CC <= 3 mA RMS
7. Protection: constant current and short-circuit protection
8. LCD reading accuracy: +/-1% for voltage and +/-2% for current
9. Environment: 0-40C, relative humidity < 90%
10. Size: 14" x 10" x 8"
11. Weight: 33 lbs

Figure 2.13 Direct current supplies.

h) Cam Mechanism

A cam is a rotating or sliding piece in a mechanical linkage used especially in transforming rotary motion into linear motion or vice versa. It is often a part of a rotating wheel (example an eccentric wheel) or shaft (example a cylinder with an irregular shape) that strikes a lever at one or more points on its circular path. The cam can be a simple tooth, as is used to deliver pulses of power to a steam hammer, for example, or an eccentric disc or other shape that produces a smooth reciprocating (back and forth) motion in the follower which is a lever making contact with the cam.

The reason the cam acts as a lever is because the hole is not directly in the centre, therefore moving the cam rather than just spinning. On the other hand, some cams are made with a hole exactly in the centre and their sides act as cams to move the levers touching them to move up and down or to go back and forth.

CHAPTER-3

METHODS AND PROCEDURE FOR A-ATM

It has been describe below the methods for two aspects of the A-ATM. One aspect pertains to Evaluation of low back dysfunction; the other is giving Rotatory Oscillations to low back.

3.1 Method for Evaluation of Low Back Dysfunction

PROCEDURE:

A subject is assessed on the A-ATM using the following protocol:

1. The subject lies supine on the A-ATM (Figure 3.1)

2. Initially, lever arms are without weight at zero angular displacement.

3. Weights are added to the right lever arm weight carrier in five-pound increments up to twenty-five pounds. (This causes the right pad to rise displacing the right PSIS anteriorly. The right ASIS also rises in response causing the projected dot on the target to move upward. Right lever arm applied weight and dot above the zero mark on the target are recorded as positive numbers.).

4. Angular displacement for each applied weight is read from the ultrasonic sensors through DAQ card and software installed on the computer by the operator. Ultrasonic transducers are attached to the pads to measure the displacement in terms of voltage. One volt measures a displacement of 4 inches. In other words, the resolution of the transducer is 0.004 inches.

5. Weights are removed from the lever arm weight carrier in 5-pound decrements.

6. Angular displacement for each removed weight is read from the ultrasonic sensors through zero weight.

7. Steps 3 through 7 are repeated for the left lever arm.
   (Application of weight to the left lever arm weight carrier raises the left pad. This displaces the left PSIS anteriorly, raises the left ASIS and the projected dot is deflected downward on the target grid. Left lever arm applied weight and dot below the zero mark on the target are recorded as negative numbers.)

8. Steps 3 through 8 are one series. Multiple series can be run if necessary.

9. Using the software, the plots for Displacement vs. Weights are plotted.

10. The voltage readings are directly recorded in the computer through a DAQ card. As in the un-automated ATM, the final reading is recorded after it settles down due to the creep effect encountered in visco-elatic tissues of the low back. The HLA is evaluated using MATLAB.The area under the curve is calculated using trapezoidal rule for loading and unloading curves. The HLA is determined by subtracting the area calculated under loading and unloading curves with respect to y-axis. The greater the area, the more impaired is the low back. The zero area means the perfect elastic low back, which is never attained.

11. The body mass index is determined to compare the results of unhealthy low back with the healthy low back of same ratio, as the deflections vary largely with large bmi in comparison to small bmi.

Figure 3.1 Subject on the automated anatomic torsion monitor (A-ATM).

3.2 *Improving* the Low Back Dysfunction by Imparting Rotatory Oscillations to Low Back

In addition to automation of the ATM for evaluating the low back, a technique has also been developed for improving the low back dysfunction by imparting oscillations to the hips. This is the simplest and non-invasive method for improving low back dysfunctions. In this technique the patient needs to lie down on the A-ATM. Then according to the conditions of the low back problem faced by the patient, appropriate oscillations and displacement imparted to the pelvis. These oscillations can be delivered to the subject using a cam mechanism and a DC motor fitted to the A-ATM. Cam mechanism are used with pneumatic cylinders in order to give the oscillation alternately to both the pelvises. Frequency of the oscillations can be controlled by using speed controller switch. Duration of oscillations depends on the severity of dysfunction of the low back. After giving oscillations, evaluation is needed to be done again in order to compare the results before and after imparting oscillations.

Figure 3.2 Subject on the automated anatomic torsion monitor (A-ATM).

PROCEDURE:

1. The subject lies supine on the A-ATM.

2. Lever arms are without weight at zero angular displacement.

3. The mechanism is turned ON and the voltage from speed controller box is increased from 0 to 20 which is the break off voltage. In addition to this the displacement of circular pads can be controlled depending upon the condition of the low back.

4. After the test is completed the mechanism is turned OFF.

5. Evaluation process is repeated as mentioned in first stage.

CHAPTER 4

EXPERMENTAL SECTION

4.1. Reproducibility Test for Evaluation of Low Back

The procedure mentioned in the method section was applied to subject, 1, 2 and 3.

Two tests were performed after duration of five minutes to each subject for reproducibility. Negative sign of load on horizontal axis and negative displacement on vertical axis mean reading from left side of subject's low back. The following graphs show the reproducible results. For numerical data refer Appendix (A1-A3).

Subject 1. Hysteresis Loop for Both Right and Left Side Combined

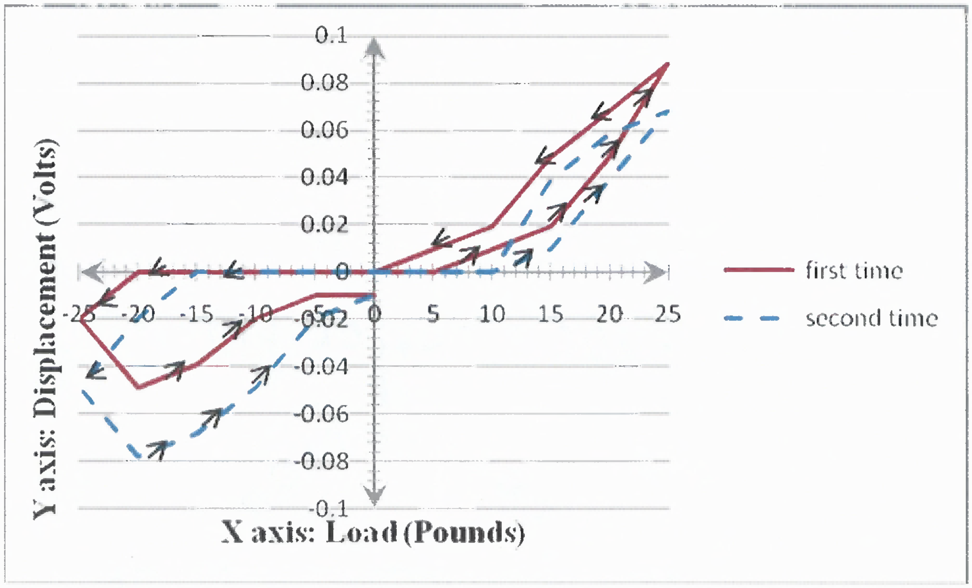

Figure 4.1 Plot showing displacement versus load for subject 1.

Subject 2. Hysteresis Loop for Both Right and Left Side Combined

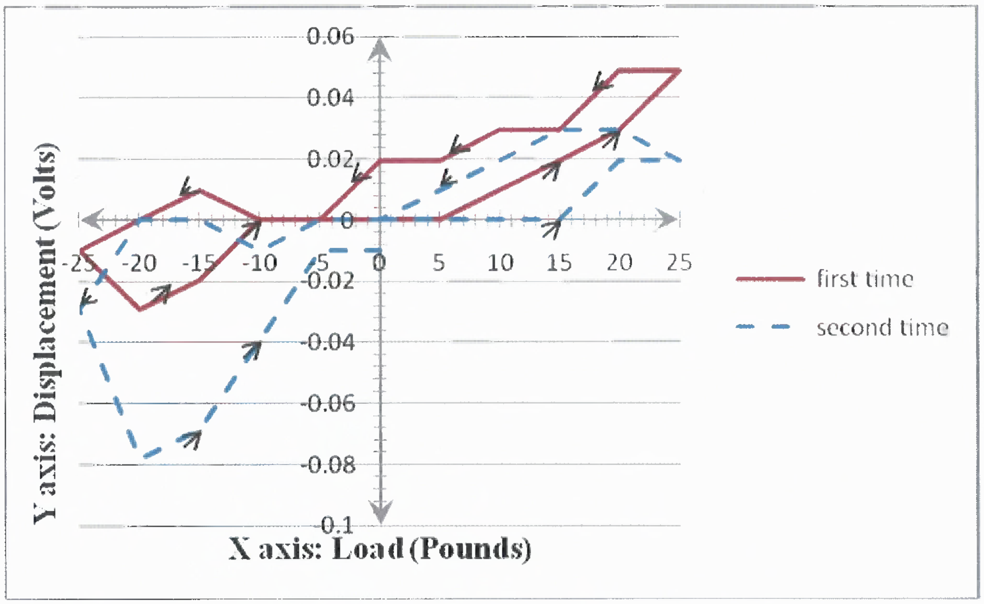

Figure 4.2 Plot showing displacement versus load for subject 2.

Subject 3. Hysteresis Loop for Both Right and Left Side Combined

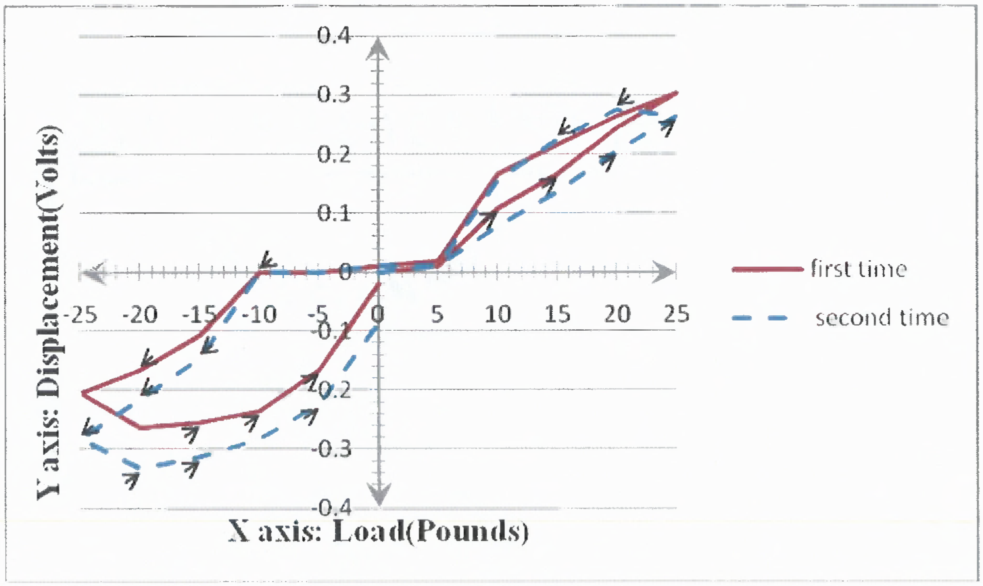

Figure 4.3 Plot showing displacement versus load for subject 3.

4.2 Effect of Rotatory Oscillations Applied to Low Back for Five Minutes Duration

Ten control subjects (nine males and one female) in the age group of 24-77 were given oscillations to the low back for five minutes duration in the Biomechanics Laboratory of Biomedical Engineering Department, New Jersey Institute of Technology (NJIT). NJIT IRB approval was obtained for this project. HLAs were evaluated before and after the treatment in the form of oscillations using cam mechanism for the automated ATM. The frequency for each oscillation was 20 cycles per minute with amplitude of two inches. The percentage change in HLA as well as Range of motion is given below. Percentage Change in HLA and range of motion was calculated according to the formula (Values after- Values before)/ Value before, multiplied by 100.The following graph show the results. For numerical data refer Appendix (B1- B10).

Subject 1.Hysteresis Loop for Both Right and Left Side Combined

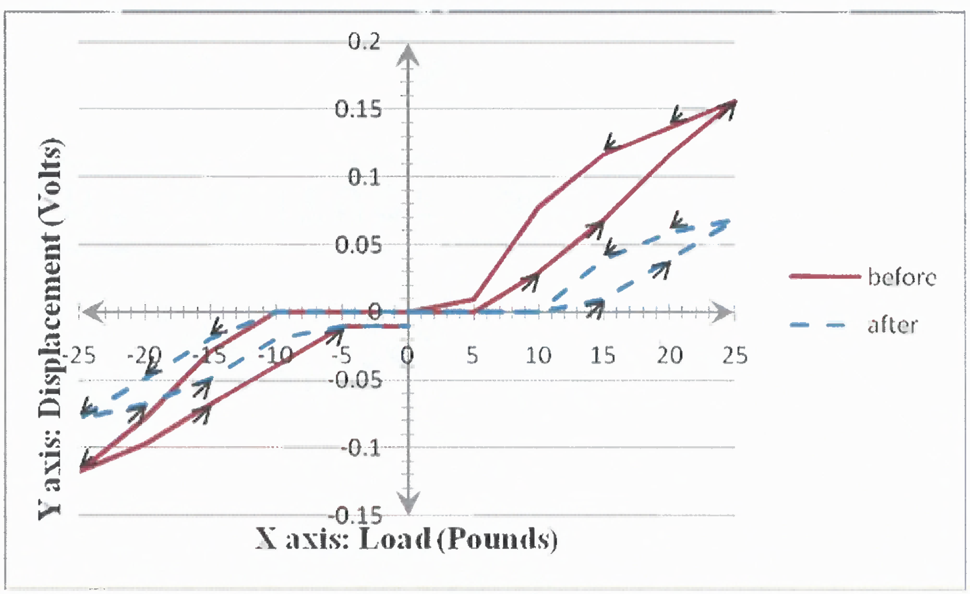

Figure 4.4 Plot showing displacement versus load for subject 1.

Subject 2.Hysteresis Loop for Both Right and Left Side Combined

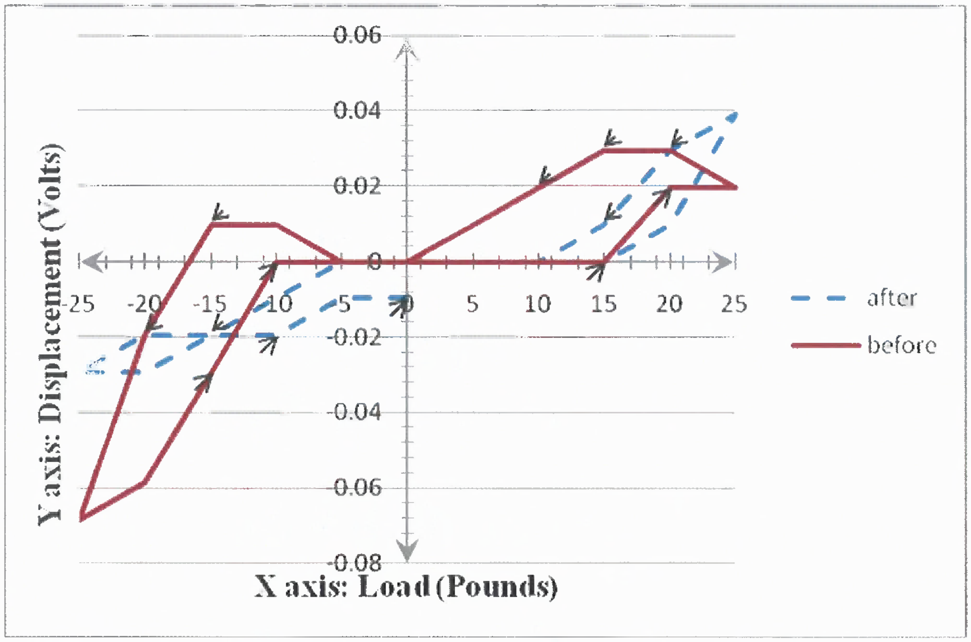

Figure 4.5 Plot showing displacement versus load for subject 2.

Subject 3.Hysteresis Loop for Both Right and Left Side Combined

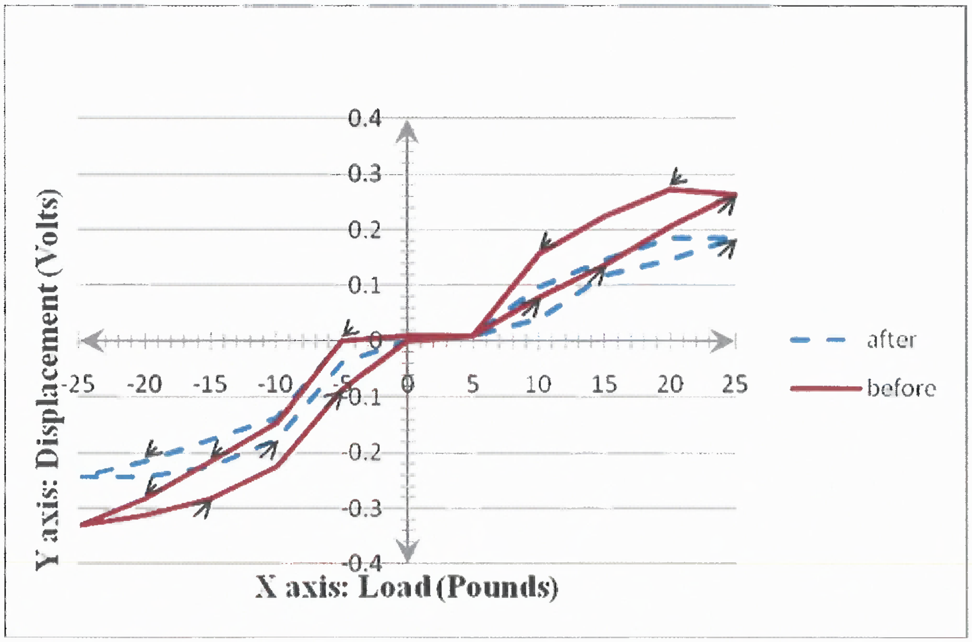

Figure 4.6 Plot showing displacement versus load for subject 3.

Subject 4.Hysteresis Loop for Both Right and Left Side Combined

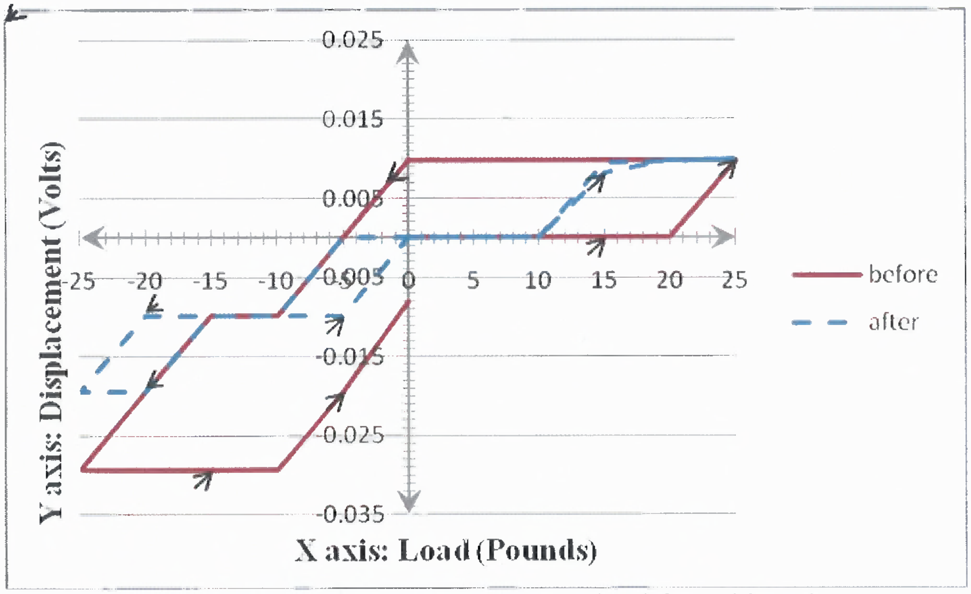

Figure 4.7 Plot showing displacement versus load for subject 4.

Subject 5.Hysteresis Loop for Both Right and Left Side Combined

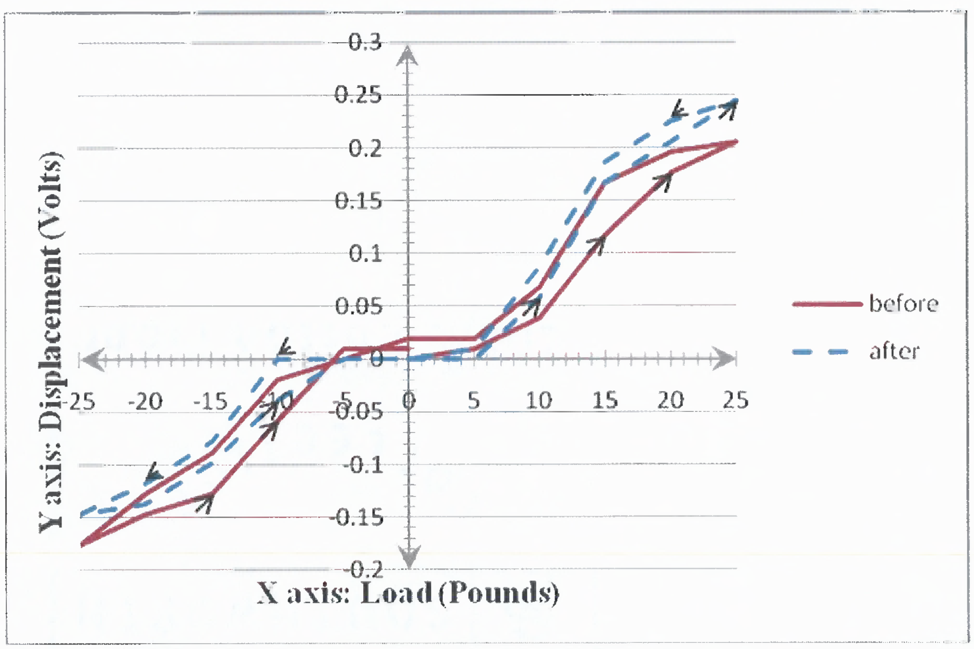

Figure 4.8 Plot showing displacement versus load for subject 5.

Subject 6.Hysteresis Loop for Both Right and Left Side Combined

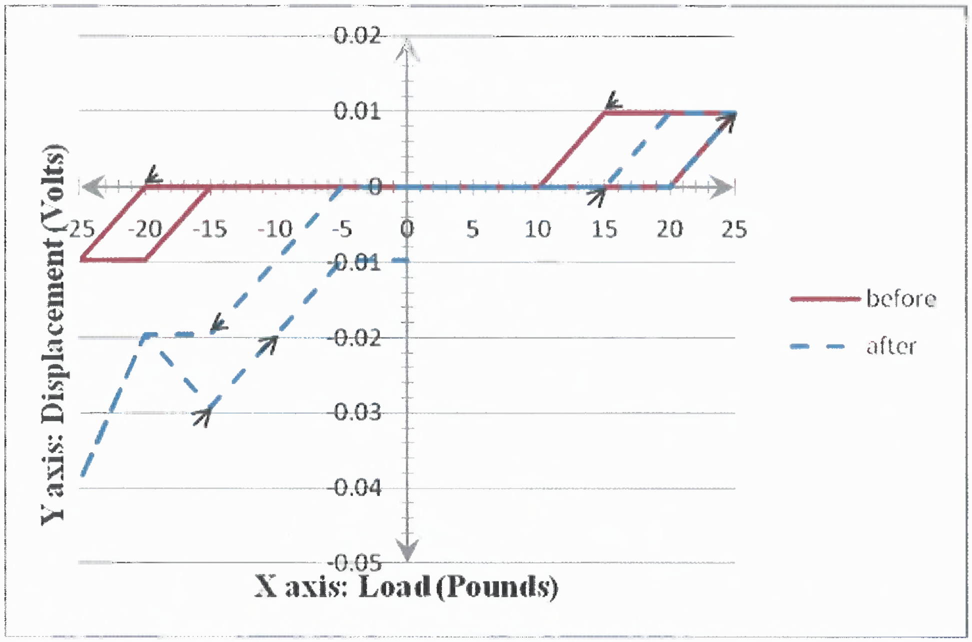

Figure 4.9 Plot showing displacement versus load for subject 6.

Subject 7.Hysteresis Loop for Both Right and Left Side Combined

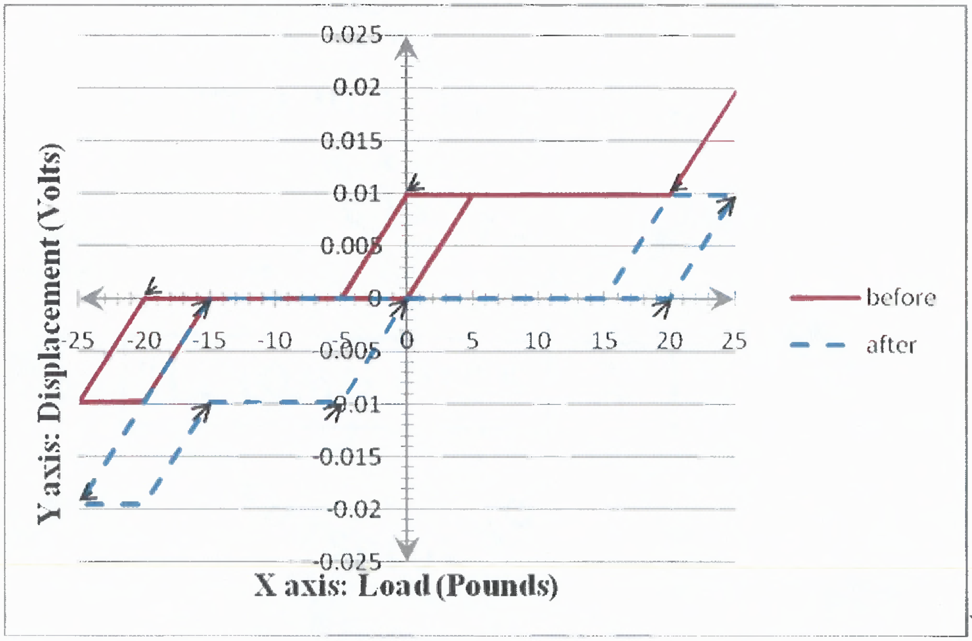

Figure 4.10 Plot showing displacement versus load for subject 7.

Subject 8.Hysteresis Loop for Both Right and Left Side Combined

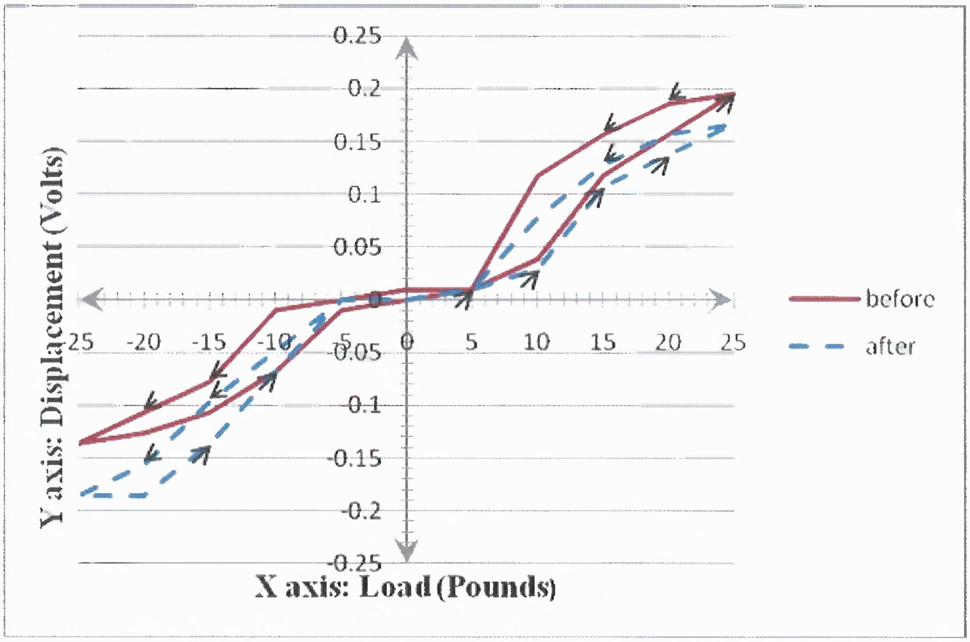

Figure 4.11 Plot showing displacement versus load for subject 8.

Subject 9.Hysteresis Loop for Both Right and Left Side Combined

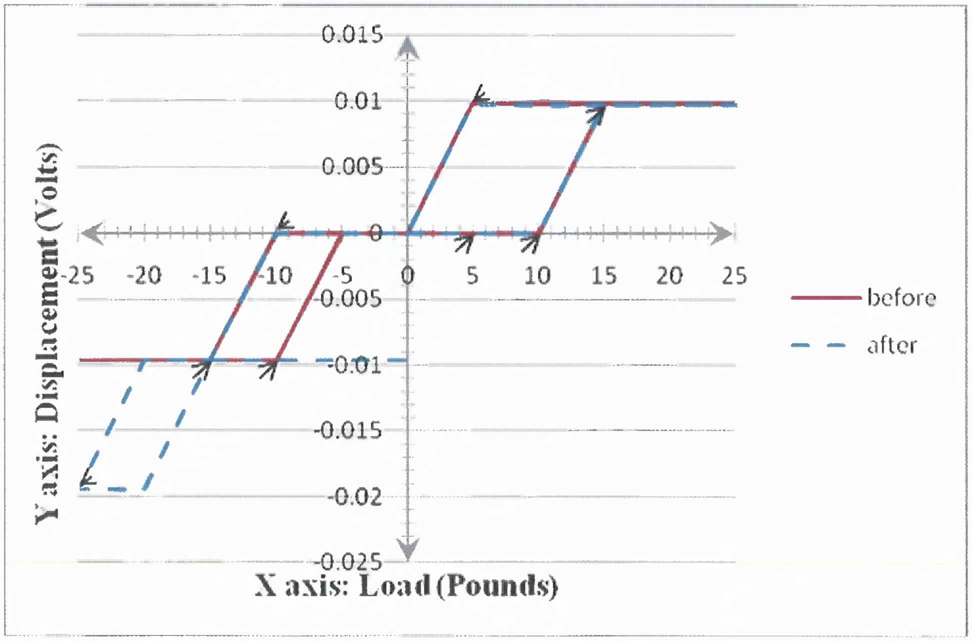

Figure 4.12 Plot showing displacement versus load for subject 9.

Subject 10.Hysteresis Loop for Both Right and Left Side Combined

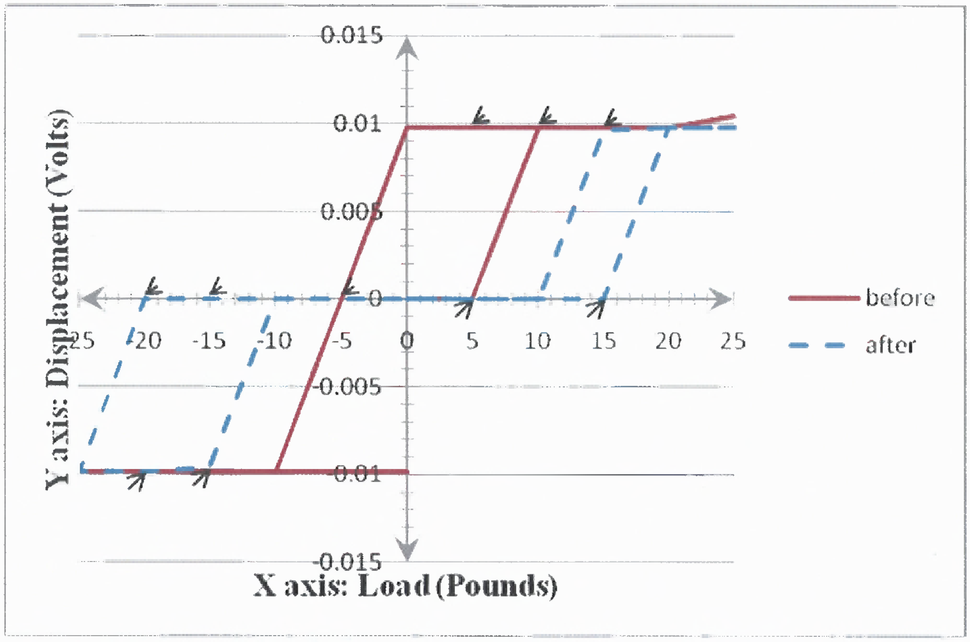

Figure 4.13 Plot showing displacement versus load for subject 10.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Reproducibility Test

From the experiments performed as mentioned in experimental section, the following results are observed. Reproducibility Test: Each subject was tested twice .The maximum difference in HLA between two tests was 4%, which was calculated by using the formula

$$\% \text{ Change in HLA} = \frac{\text{Final Reading} - \text{Initial Reading}}{\text{Initial Reading}} \times 100$$

Table 5.1 Summary of Reproducibility Test

Subject	Percentage Change in HLA
1	4%
2	2.2%
3	2.8%

5.2 Effect of Rotatory Oscillations Applied to Low Back for Five Minutes Duration

The results for all the subjects are summarized in Table 5.2

Table 5.2 Summary of results obtained after 5 min oscillations.

Subject	Age	Sex	Weight Pounds	Height	BMI	Change in HLA	Change in Range of Motion	
							Right	Left
1	24	MALE	143	5'9"	21	-30%	8.00 %	0.00 %
2	24	MALE	154	5'8"	23	-75%	5.00 %	11.00 %
3	22	FEMALE	119	5'4"	20	-51%	-1.20 %	-11.70 %
4	77	MALE	167	5'8"	25	-45%	-6.11 %	-05.60 %
5	39	MALE	150	5'11"	21	-98%	1.20 %	0.00 %
6	23	MALE	143	5'11"	20	-55%	-1.60 %	2.30 %
7	23	MALE	160	5'6"	26	14%	2.70 %	-1.30 %
8	25	MALE	141	5'8"	21	-97%	1.70 %	0.40 %
9	24	MALE	200	5'6"	32	47%	2.00 %	-1.00 %
10	24	MALE	204	5"11	28	46%	-2.00 %	2.70 %

From the Table 5.2, the HLA is decreased after applying the oscillations for five minute duration for seven subjects out of ten whereas the HLA is increased for three subjects (7, 9 &10). It is observed from the column of BMI, that for those subjects (1-6 and 8), whose BMI is less or equal to 25 (the BMI for normal persons), the change in HLA is negative. This means that oscillations have improved effect on the viscoelasticity of the low back. For three subjects (7,9 &10) , the BMI is greater than 25 and the change in HLA is positive. This means that oscillations have no effect in improving the viscoelasticity of the low back for these three subjects. Such subjects whose BMI is greater than 25 need greater force to lift them up during oscillations. Tests were performed on subjects for two minutes duration as well. However it was found that this duration was not sufficient to show any consistent results. Therefore it can be concluded that a minimum of five minutes duration is required to achieve beneficial results. Regarding the range of motion, it is observed that there is insignificant change in eight subjects, taking into consideration that a maximum of 4% allowance is to be given in the readings as observed in the reproducibility test.

It may be kept in mind that one should not determine the change in HLA as well as range of motion from the graphs. These can be determined from the actual data only. This is due to the reason that the initial reading of the displacement transducer is very large (about 2.1074 volts) and it becomes difficult to plot the graphs on a limited space, when the displacement during loading and unloading are very small, of the order of 0.02-0.10. The large initial value of the transducer is due to its height from the ground level. Therefore, the initial reading of 2.1074 was taken as corresponding to zero for no load, and the graphs were plotted accordingly to only show how the hysteresis loop is formed.

CHAPTER 6

CONCLUSIONS

The existing ATM was successfully automated, which can objectively evaluating the passive low back and the results are obtained quickly as compared to un- automated ATM. The automated ATM allows us to deliver quantifiable oscillations to the passive low back.

It was observed that providing oscillations to the low back will result in improved viscoelasticity of the low back for subjects whose BMI is normal, i.e. less or equal to 25. For subjects whose BMI is greater than 25, need a greater force to lift them up during oscillations. Improved viscoelasticity can be interpreted that the subject will regain his/her position. Encouraged by these results of five minutes duration, it has been recommend that the oscillations can be considered as treatment for improving the low back dysfunction related to a facet joint or muscle spasm, but not to other dysfunctions resulting from herniated disk or injury. The correct displacement amplitude, frequency and duration of treatment will have to be determined from individual medical and physical condition. The doctors in osteopathy can make use of the results obtained from this work, by manually lifting the left and right side of the pelvis alternately with a frequency of 20 cycles per minute for five minutes duration for beneficial results.

6.1 Future Work

The present design of imparting rotatory oscillations to the low back using single motor will be replaced by two motors, each attached to respective pneumatic cylinder. This is to be done to ensure synchronized, semi synchronized and unsynchronized motion. This is assumed to be a better approach in understanding the dynamics of the lower back. To eliminate the possibility of any play in the pneumatic cylinders due to constant use, which might affect the results, it is proposed that the ultrasonic transducers may be attached to the ends of the lever arms instead of fixing these to the pneumatic cylinders.

The present pneumatic cylinders and the levers may be replaced by microcontroller based shockers for providing loads automatically instead of manually. To ensure that the positioning of the subject is not changed before and after giving oscillations, it is desirable that positions sensors may be attached to the table of the ATM.

APPENDIX A

DATA FOR REPRODUCIBILITY TEST

The Reproducibility Data is provided in Tables A.1 to A.3

A.1 Reproducibility Test for Subject 1

Loads(lbs)	Displacement(volts)	
	First Time	Second Time
0	0	0
5	0	0
10	0.0098	0
15	0.0196	0.0098
20	0.0489	0.0391
25	0.0879	0.0684
20	0.0684	0.0586
15	0.0489	0.0391
10	0.0196	0
5	0.0098	0
0	0	0
-5	0	0
-10	0	0
-15	0	0
-20	0	-0.0195
-25	-0.0195	-0.0488
-20	-0.0488	-0.0782
-15	-0.0391	-0.0684
-10	-0.0195	-0.0488
-5	0	-0.0195
0	0	-0.0098

A.2 Reproducibility Test for Subject 2

Loads(lbs)	Displacement(volts)	
	First	Second
0	0	0
5	0	0
10	0.0097	0
15	0.0195	0
20	0.0293	0.0196
25	0.0488	0.0196
20	0.0488	0.0293
15	0.0293	0.0293
10	0.0293	0.0196
5	0.0195	0.0098
0	0.0195	0
-5	0	0
-10	0	-0.0098
-15	0.0098	0
-20	0	0
-25	-0.0098	-0.0293
-20	-0.0293	-0.0782
-15	-0.0195	-0.0684
-10	0	-0.0391
-5	0	-0.0098
0	0	-0.0098

A.3 Reproducibility Test for Subject 3

Loads(lbs)	Displacement(volts)	
	First	Second
0	0	0
5	0.0098	0.0098
10	0.1075	0.0782
15	0.1661	0.1368
20	0.2442	0.2052
25	0.3028	0.2638
20	0.2638	0.2735
15	0.2149	0.2247
10	0.1661	0.1563
5	0.0196	0.0098
0	0.0098	0.0098
-5	0	0
-10	0	0
-15	-0.1075	-0.1465
-20	-0.1661	-0.2149
-25	-0.2051	-0.2833
-20	-0.2637	-0.3321
-15	-0.254	-0.3126
-10	-0.2344	-0.2833
-5	-0.1661	-0.2247
0	-0.0195	-0.0879

APPENDIX B

DATA OBTAINED BEFORE AND AFTER FIVE MINUTE OSCILLATION

The data obtained after five minute oscillation on the ATM is given in Tables B.1 to B.10

B.1 Data after five minute oscillation for Subject 1

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0	0
10	0	0.0293
15	0.0098	0.0683
20	0.0391	0.1172
25	0.0684	0.1563
20	0.0586	0.1367
15	0.0391	0.1172
10	0	0.0781
5	0	0.0097
0	0	0
-5	0	0
-10	0	0
-15	-0.0195	-0.0293
-20	-0.0488	-0.0781
-25	-0.0782	-0.1172
-20	-0.0684	-0.0977
-15	-0.0488	-0.0684
-10	-0.0195	-0.0391
-5	-0.0098	-0.0098
0	-0.0098	0.0098

B.2 Data after five minute Oscillation for Subject 2

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0	0
10	0	0
15	0	0
20	0.0196	0.0097
25	0.0196	0.039
20	0.0293	0.0293
15	0.0293	0.0097
10	0.0196	0
5	0.0098	0
0	0	0
-5	0	0
-10	0.0098	-0.0098
-15	0.0098	-0.0196
-20	-0.0195	-0.0196
-25	-0.0684	-0.0293
-20	-0.0586	-0.0293
-15	-0.0293	-0.0196
-10	0	-0.0196
-5	0	-0.0098
0	0	-0.0098

B.3 Data after five minute oscillation for Subject 3

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0.0098	0.0097
10	0.0782	0.039
15	0.1368	0.1172
20	0.2052	0.1465
25	0.2638	0.1856
20	0.2735	0.1856
15	0.2247	0.1465
10	0.1563	0.0976
5	0.0098	0.0097
0	0.0098	0.0097
-5	0	0
-10	-0.1465	-0.1367
-15	-0.2149	-0.1758
-20	-0.2833	-0.2149
-25	-0.3321	-0.2442
-20	-0.3126	-0.2442
-15	-0.2833	-0.2246
-10	-0.2247	-0.1758
-5	-0.0879	-0.039
0	0	0

B.4 Data after five minute oscillation for Subject 4

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0	0
10	0	0
15	0	0.0082
20	0	0.0097
25	0.0097	0.0099
20	0.0097	0.0096
15	0.0097	0.0094
10	0.0097	0
5	0.0097	0
0	0.0097	0
-5	0	0
-10	-0.0098	-0.0098
-15	-0.0098	-0.0098
-20	-0.0195	-0.0098
-25	-0.0293	-0.0195
-20	-0.0293	-0.0195
-15	-0.0293	-0.0098
-10	-0.0293	-0.0098
-5	-0.0195	-0.0098
0	-0.008	0

B.5 Data after five minute oscillation for Subject 5

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0.0098	0
10	0.0391	0.0586
15	0.1173	0.166
20	0.1759	0.2051
25	0.2052	0.2442
20	0.1954	0.2246
15	0.1661	0.1856
10	0.0684	0.0879
5	0.0196	0.0097
0	0.0196	0
-5	0	0
-10	-0.0195	0
-15	-0.0879	-0.0781
-20	-0.1269	-0.1172
-25	-0.1758	-0.1465
-20	-0.1465	-0.1367
-15	-0.1269	-0.0976
-10	-0.0586	-0.039
-5	0.0098	0
0	0.0098	0

B.6 Data after five minute oscillation for Subject 6

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0	0
10	0	0
15	0	0
20	0	0
25	0.0098	0.0098
20	0.0098	0.0098
15	0.0098	0
10	0	0
5	0	0
0	0	0
-5	0	0
-10	0	-0.0098
-15	0	-0.0196
-20	0	-0.0196
-25	-0.0098	-0.0391
-20	-0.0098	-0.0196
-15	0	-0.0293
-10	0	-0.0196
-5	0	-0.0098
0	0	-0.0098

B.7 Data after five minute oscillation for Subject 7

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0.0098	0
10	0.0098	0
15	0.0098	0
20	0.0098	0
25	0.0195	0.0098
20	0.0098	0.0098
15	0.0098	0
10	0.0098	0
5	0.0098	0
0	0.0098	0
-5	0	0
-10	0	0
-15	0	0
-20	0	-0.0098
-25	-0.0098	-0.0195
-20	-0.0097	-0.0195
-15	0	-0.0098
-10	0	-0.0098
-5	0	-0.0098
0	0	0

B.8 Data after five minute oscillation for Subject 8

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0.0097	0.0097
10	0.039	0.0293
15	0.1172	0.1074
20	0.1563	0.1367
25	0.1953	0.166
20	0.1856	0.1562
15	0.1563	0.1269
10	0.1172	0.0781
5	0.0097	0.0097
0	0.0097	0
-5	0	0
-10	-0.0098	-0.0489
-15	-0.0781	-0.0977
-20	-0.1074	-0.1563
-25	-0.1367	-0.1856
-20	-0.127	-0.1856
-15	-0.1074	-0.1368
-10	-0.0684	-0.0684
-5	-0.0098	0
0	0	0

B.9 Data after five minute oscillation for Subject 9

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0	0
10	0	0
15	0.0098	0.0097
20	0.0098	0.0097
25	0.0098	0.0097
20	0.0098	0.0097
15	0.0098	0.0097
10	0.0098	0.0097
5	0.0098	0.0097
0	0	0
-5	0	0
-10	0	0
-15	-0.0097	-0.0097
-20	-0.0097	-0.0097
-25	-0.0097	-0.0195
-20	-0.0097	-0.0195
-15	-0.0097	-0.0097
-10	-0.0097	-0.0097
-5	0	-0.0097
0	0	-0.0097

B.10 Data after five minute oscillation for Subject 10

Loads(lbs)	Displacement(volts)	
	Before	After
0	0	0
5	0	0
10	0.0098	0
15	0.0098	0.0096
20	0.0098	0.0098
25	0.010425	0.0098
20	0.0098	0.0098
15	0.0098	0
10	0.0098	0
5	0.0098	0
0	0.0098	0
-5	0	0
-10	-0.0098	0
-15	-0.0098	-0.0096
-20	-0.0098	-0.0098
-25	-0.0098	-0.0098
-20	-0.0098	0
-15	-0.0098	0
-10	-0.0098	0
-5	-0.0098	0
0	-0.0098	0

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