Fatigue Testing of Rubber Component with Hybrid Control of Force and Displacement

Author

Malik Faheem Abbas

Regn Number

MS ME 319365

Supervisor

Dr. Mian Ashfaq Ali

DEPARTMENT NAME

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

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Author

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Thesis Supervisor:

Dr. Mian Ashfaq Ali

Thesis Supervisor's Signature: ____

DEPARTMENT NAME

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Declaration

I certify that this research work titled "*Fatigue Testing of Rubber Component with Hybrid Control of Force and Displacement"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

Malik Faheem Abbas

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Abstract

During the design and development process Mechanical fatigue testing and component life prediction are critical factors for safe and reliable behavior of component. Before being used in real-world applications, parts, components, and prototypes must be fatigue tested to determine how long they will last. A machine setup capable to generate desired load is required for the prediction of component life under continuous loading or under fatigue. The current work displays a fatigue testing system for rubber components that is powered by a pneumatic mechanism. Continuous loading is applied to a rubber component for a predetermined number of cycles, and the resulting load and distance are calculated. The entire system is further separated into two sections: electrical and mechanical.

Entire setup comprises of base structure, air compressor, pneumatic cylinder actuator, proportional servo valve, buck module, load cell transducer, laser distance sensor, signal generator, DC power supply, load cell amplifier and Data Acquisition Card. Obtained parameters are transferred into an integrated computer system and Data Analysis is carried out using Lab VIEW.

Key Words: *Mechanical Fatigue Testing, Life Prediction, Continuous loading, Pneumatic Mechanism and Data Analysis*

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1. INTRODUCTION

1.1. Contextual Background

Fatigue cracks are initiated and then grown in material due to repeated load applied. Once fatigue crack is started it will develop more every time load is applied to material. This crack will grow from micro level to macro level till critical limit at which material will completely fail. For rubber material fatigue is demonstrated by S-N curve denoting stress applied at number of cycles causing failure of material. Fatigue normally occurs due to stress concentration at points where defects like dust particles, faulty manufacturing, ozone cracking are present.

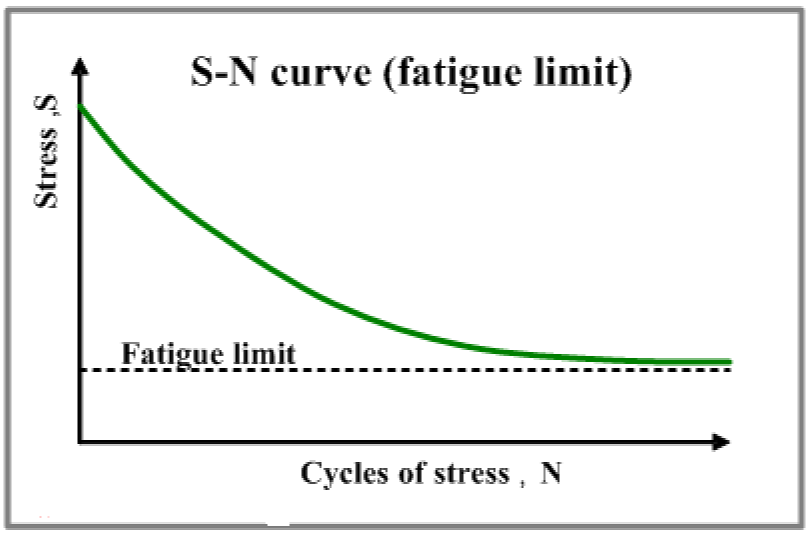

Figure 1 S-N curve example

1.2. Problem Statement

There are various fatigue testing equipment available in market, but the fundamental issue with all of these machines is cost. This cost rises dramatically when the consumer specifies a custom-made design. So, in order to overcome this problem, an indigenous solution that is not only trustworthy but also significantly less expensive than machines presently on the market was required.

1.3. Goals and Objectives

The main purpose is to design and create a system that is paired with an electric setup for assessing the fatigue of rubber components. This system should be pneumatic and able to resist high force. To perform fatigue testing on rubber components, a pneumatic actuator with a proportional valve and a sinusoidal waveform with an amplitude of 0-10 V and an air pressure of 0.8 MPa (8 bar) is used. With a high frequency, this pneumatic actuator will apply force to a rubber portion. A laser sensor is installed on a system that will measure the distance travelled by a pneumatic actuator with a 300 μm precision. The load cell is installed beneath the rubber component. Load Cell Amplifier is linked to load cell to amplify its signal. Using LabVIEW software, data from the load cell amplifier, laser sensor, and proportional servo valve will be gathered and presented by the integrated data collection system

1.4. Modelling and Manufacturing

In this phase design of machine’s basic concepts are used to design mechanical base structure and assembly of system as a whole. Using SolidWorks complete model of assembly was developed. Once modelling of proposed system is completed, it was then moved towards manufacturing and fabrication phase. First of all manufacturing of every part was done and then these parts were assembled to form a single assembled unit.

2. Literature Review

A customized fatigue testing machine driven by pneumatic operation that can generate force up to 3000 N is designed and developed. This machine will be able to work at high frequencies and will be far less expensive than competing devices on the market. This machine will be easy to use, with a user-specified number of cycles and the ability to test rubber components with varied measurements.

2.1. LiTeM

LiTeM's vertical column machine, manufactured in Italy, serves as our reference system for the design and manufacture of our fatigue testing equipment. This reference machine is made up of a proportional servo valve, a pneumatic cylinder actuator, a load cell with an amplifier, an air compression pump, and a foundation structure for assembly support. [23]

This reference machine is capable to produce force of 2000 N. Pneumatic cylinder actuator is operated by a bi directional proportional servo valve. A contactless displacement sensor that is integrated with pneumatic cylinder actuator measures the distance moved by pneumatic actuator. Pneumatic cylinder actuator applies force on rubber part. Load cell is used to measure force generated. Waveform charts/graphs are used to illustrate measurements obtained from the load cell amplifier and displacement sensor. [25]

Figure 2 LiTeM Prima PN Fatigue Testing Machine

Price Quotation for our reference Machine was obtained on December 23, 2019. It costs around 27000 Euros. Quotation is presented below.

LiTeM Life Testing Machines	Power by EnginLAB Testing Systems DRC	Pag. 1 / 4
	Offerta / Quotation N°: MMS-LTM-191223	Data/Date 23 December 2019

Fornitore / Service Provider	**LiTeM Life Testing Machines**
Oggetto / Subject	**Sales quotation**
Descrizione prova / Test description	**Demo testing system MF-P VDC 3-10**
Modalità di richiesta/Inquiry	**email**
Nome documento / Doc. Name	**MM-LTM-191223**
Data / Date	**23 December 2019**
Validità offerta / Validity	**30 days**
Operatore commerciale / Sales Operator	**Michele Massaccesi**
Indirizzo posta / Mail	
Telefono / phone	
Operatore tecnico_1 / Technical Operator_1	**Michele Massaccesi**
Indirizzo posta / Mail	
Telefono / phone:	
Operatore tecnico_2 / Technical Operator_2	
Indirizzo posta / Mail	
Telefono / phone	

Figure 3 Price Quotation Date

SUBJECT: Quotation for modular testing system MF-P VDC with actuator 3 kN S-10

Sales quotation number MM-LTM-191223

Code	Description	Q.ty
VDC 3-10	**Vertical Single Column VDC 3kN-10 mm** Pneumatic fatigue testing system VSC -1.5-50, include: • No. 1 MF-P VDC Vertical single column testing frame • Real Time Controller RTC 9001 • Software RTC 9000 • Proportional servo valve • Pneumatic Actuator LTM-AP-80-10 with contact less displacement sensor • Force transducer (LT-TC4 D100 mm M12-500 kg – Class 1) • Air preparation line • PC-Monitor-Keyboard-Mouse **Position included on the offer from 1 to 8**	1
	Total (euro)	**27.000,00**

Figure 4 Price Quotation

2.2. Pneumatic Cylindrical Actuator:

Pneumatic cylindrical actuator is device in which air is compressed to convert its energy to mechanical motion. Inside of hollow cylinder usually it is air or some pressurized gas or mixture of both. This motion of pneumatic actuator can be in straight line or in rotational mode subjected to model of device. [11] For piston movement along the internal side of empty cylinder to generate force it requires an external source of compressive force usually an air compression pump. This generates force to apply load in a linear direction equal to the pressure difference of the piston multiplied by the area of the piston's surface. [1][12]

Its reaction time is very quick making it much applicable for bi directional force generation. They are much preferred over other alternatives because of their safety aspects as they don't need any kind of combustion or electrical connections. Also there maintenance cost is almost negligible. The only drawback they have is that they are vulnerable to pressure loss poor compressibility performance at high loads. So care must be taken in choosing the correct size of pneumatic cylindrical actuator for any specific application. [3]

Figure 5 Pneumatic Cylinder Actuator

2.2.1. Types of Pneumatic Cylindrical Actuators

Types of Pneumatic Cylindrical Actuators are described on basis of 3 things [7] [8]

- Type of motion they exhibit
- Design of its Cylinder
- Cylinder moving action

There are further described here

- Type of motion they exhibit
  - Linear
  - Rotational

- Restricted Angle
- Rod-less

➢ Design of its Cylinder

- Diaphragm
- Single act spring retracting
- Single act gravity retracting
- Roller diaphragm

➢ Cylinder moving action

- Singular Acting
- Dual Acting

2.3. Proportional Servo Valve

It is a device that when provided with variable electric input changes its output. These are used as controller valves for flow regulation, directional regulation and pressure regulation. [2] But most of the times they are opted for regulating direction of flow. They are opted for both systems open-loop feedback and close-loop feedback. These can be regulated by two methods. [4][5]

➢ Open loop Regulation

➢ Close loop Regulation

Feedback is not available in Open loop regulation, so for desired outcomes it needs target specification. Meanwhile in Close loop regulation due to feedback availability it continuously compares and corrects irregularities according to specified set-point signal and valve position.[6]

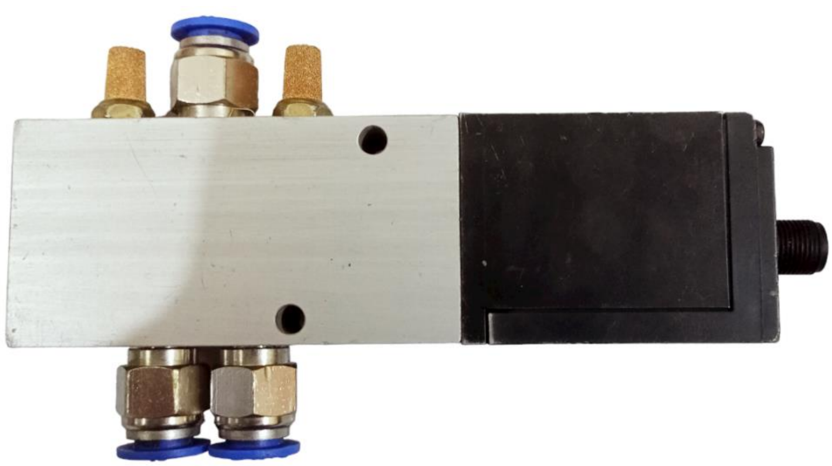

Figure 6 Proportional Bi Directional Valve

To correctly select the proportional valve for desired application one must take care of following things [10]

- Type of output needed i.e. flow regulation, direction regulation and pressure regulation
- Temperature of working environment where it will be placed
- Required flow rate
- How much change in output happens in response to received input

2.3.1. Types of Proportional Valves

These are classified based on

- Output
  - Directional Regulation
  - Flow Regulation
  - Pressure Regulation
- Regulatory Principle
  - Directly Regulated Valves
  - Piloted Regulated Valves

Even at excessive speeds, these valves have much safer functioning then their alternatives. Also output regulation in response to input regulation makes them more viable and reliable. These valves are applicable in Seismic/earth related sectors, Control and automation, hydraulic and production. [13]

2.4. Air Compressor

It is pneumatic device in which power from sources like electric motor or gasoline powered engine is converted into potential energy that is then stored in air that is compressed in smaller space. In air compression device air is added continuously to storage chamber by force. This additional air compresses already present air in storage chamber, thus pressure inside chamber is increased. Compression shuts off when pressure inside it has reached upper level of pressure allowed. Also when pressure inside device reached minimum allowed level it is started to allow air inside chamber and then compresses it. There is head valve at the upper surface of device that regulates inlet of discharge valves. When pressure inside chamber is low, piston goes at bottom position due to which vacuum produces in upper part of chamber. So outside air that has atmospheric pressure is drawn into chamber via inlet valve to fill upper part of chamber.

When piston goes in up direction it compresses air present inside upper part. This compressed air moves inside storage chamber via discharge and hence pressure inside storage chamber is increased. Pressure regulation switch present inside chamber senses pressure and switches it off when it reaches upper level defined by manufacturer. A safety valve is present that opens in case device breaks down. [30]

Figure 7 Air Compressor

2.4.1. Types of Air Compressors

Mainly there are two types that are further classified in multiple types

- Displacement
    - Vibrating
    - Rotational
    - Roller
    - Diaphragm
    - Scrolled
    - Ion fluid
    - Rotational Screw

- Dynamic
  - Axial
  - Bubbling air
  - Rotational Impeller
  - Transverse and blended flow

The overall horsepower of the compressor motor is the most significant factor to consider for selection of an air compressor. Other necessary thing is examine that how much quantity of pressurized air at particular pressure is provided by air compressor. Unit for compressed air provided by compressor is (cfm) i.e. cubic feet per minute. Temperature, humidity and atmospheric pressure of surrounding environment has an effect on rate of air entering compressor. Particularly atmospheric pressure produces variation on rate i.e. it effects cfm. To get ideal and reliable results it is recommended that CFM is found with air at temperature of 68° and humidification level of 36 percent at sea level. So to use compressor for particular application cfm and pressure required are most important factors to be considered

2.5. Load Cell

It is a sensor on which when mass or impact is applied it provides output in form of electrical voltage or current signal. Numerous categories of load cell transducer exist but strain gauge type is most commonly opted.

- Principle of Measurement

Load cell mainly comprises of strain gauge and spring. Spring when subjected to tension or compression makes strain gauge give output based on variation in internal resistance. This change in resistance causes change in voltage. This voltage is used to find mass or impact applied. First calibration is done and then transducer is opted for finding load.

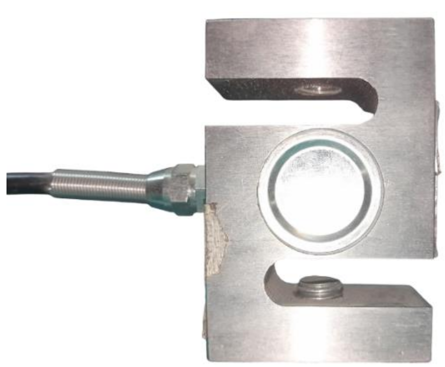

Figure 8 S Type Load Cell

2.5.1. Types of Load Cell Transducer

Multiple factors are responsible for classifying load cell transducer. Different classes of load cell are based on

- Sensor Category
  - Resistance type
  - Capacitance type
- How load is applied
  - Tensile loading
  - Compressive loading
  - Universal
  - Bending direction
- Outer profile of transducer
  - Bar shape
  - Cylindrical shape
  - S shape
- Profile of spring
  - Pillar shape
  - Hollow circle shape
- Air compactness
  - Sealed
  - Exposed
  - Blast resistant
- Precise measurement
  - Highly precise
  - Regular
- Other categories
  - Singular and variable point type
  - Mini type
  - Torsional ring type

2.6. Signal Generator

An electronic object that yields waveform signals. These are usually applicable in electronics operations like designing of circuit, testing of parts and repairing of malfunctioning equipment. They can be classified into different types as following

- RF generator
- Function generator
- Random waveform
- Digital arrangement
- Rate generators
- Pulse generators

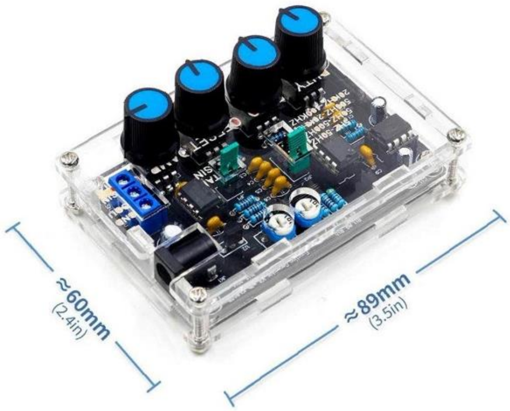

Figure 9 Signal Generator

2.7. Function Generator

These are electronic instruments that generate plain cyclic form of waves. When provided with audible frequency range of 20 kilohertz they would have operations like peak to peak modulation, phase, and rate and off set modulation. They can create different types of waveforms. These are following

- Square shaped
- Sinusoidal
- Triangle shaped
- Step wave
- Saw tooth

Figure 10 Function Generator

2.8. Buck Module

It is electronic instrument that is capable of converting DC-DC voltages. It steps down high DC voltage to low DC voltage with great efficiency. Module LMDC 2596 is selected in our system. They are comprised of two switches (normally a diode and transistor) and an inductor which is regulated by diode and transistor. [29]

- When it's on, there is no voltage drop at switch and diode
- When it's off, current does not flow and for conductor there is no resistance in series.

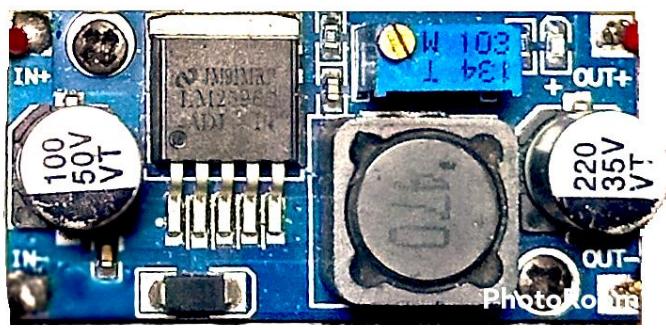

Figure 11 Buck Module

2.9. Vero-boards

It is a strip board. It is a beforehand shaped electrical circuitry board material Cu stripes that are placed on paper board with insulated bond. These are opted for electronic circuitry formation. Regular grid of 0.1 inch holes is present on its one side or both depending upon type. These holes allow insertion of electrical/electronic parts. On plain side parts are placed in such way that their leads are extended throughout holes. These leads are soldered on Cu stripes side to form required electrical circuit.

Excessive leads are then cut off. These stripes offer continuous tracks if a break is needed to form more than one electrical circuit on single Vero-board. These tracks are provided with breaks at ends of electrical circuits and all circuits will be operated simultaneously without effecting other circuits. They are much less costly and less time consuming in operation than PCB's.

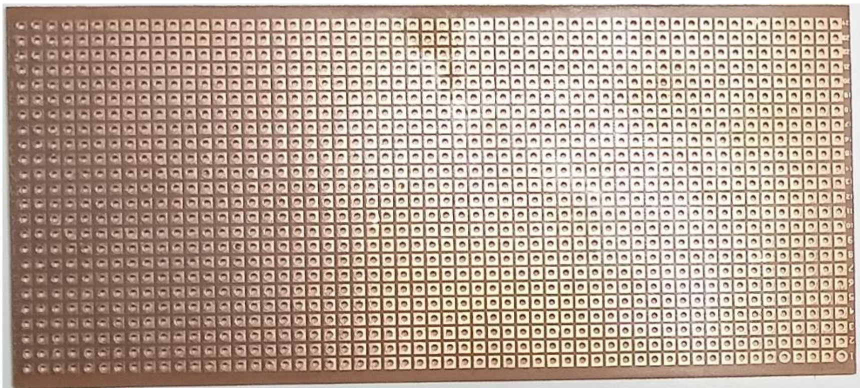

Figure 12 Vero board

2.10. Distance Sensor

These are devices and instruments that are opted for finding the distance between object (whose distance is required to be measured) and sensors. They normally work by generating a signal that will be received again by them to give an output based on amount of change in sent and received signals.

2.10.1. Types of Distance Sensor

There are two main types' i.e. contact and non-contact displacement/distance sensors. They are further classified as

- Contact
  - LVDT
  - Potentiometers
  - Cable Transducers
  - Electronic scale
  - Proximity Switch
- Non-Contact
  - Lidar
  - Ultrasonic
  - Infrared

- Time of flight
- Eddy current
- Capacitive
- Magneto resistive
- Hall effect

Sensor to be chosen depends upon various elements. Some of these are

- Application
- Accuracy/Repeatability
- Resolution
- Measurement Range
- Update Rate

So care must be taken while choosing correct distance sensor for intended use.

2.11. Laser Sensor

These are devices to determine distance/displacement and for detection of object. It works on principle that a laser beam is emitted from them which strikes with object and then reflects back to sensor. The variance between time of sending and receiving laser beam is computed by sensor and distance of object from sensor is evaluated. Laser sensors have 4 types

- Charge-Coupled Devices (CCD)
- Complementary Metal Oxide Semiconductors (CMOS)
- Position-Sensitive Detectors (PSD)
- Photoelectric

2.12. HGC-1400 Panasonic Laser Distance Sensor

It is compact and lightweight laser distance sensing device that works on principle of Complementary Metal Oxide Semiconductors (CMOS) technology. Distance from 200 mm to 600 mm with accuracy of 300 μm can be measured by it. Its response time is very quick i.e. 1.5 to 10 ms. It works in way that a beam of laser is transmitted from laser sensor and is reflected back after striking object.

This reflected laser beam is focused on CMOS linear imager through lens in form of little spot. Angle of reflected light received by linear imager is changed due to object's distance.

Figure 13 Laser Sensor

2.13. Distribution Box

It is used for power distribution to components present inside. It houses components like DC power supply, Vero-boards for power distribution, Buck module for supply of adequate voltage to laser sensor, Signal generator, load cell amplifier and DAQ card. It has wire connectors to provide wire connection to wires from components like proportional valve, laser sensor, and load cell.

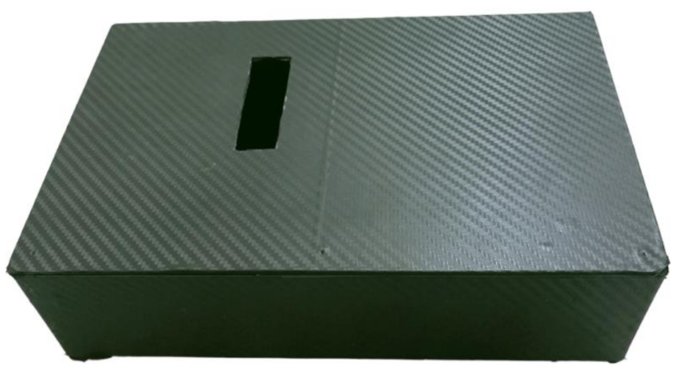

Figure 14 Power Distribution Box

3. Working Methodology

3.1. Proof of Concept 1

Air Cylinder that has bore of 80 mm and 350 mm length of stroke is opted for development of this fatigue testing system. Suitable Proportional valve is opted for switching flow to operate pneumatic cylinder actuator. A signal generator provides analog sinusoidal signal of 0-10 V to proportional valve as driving force for switching of flow direction. A load cell of 500 kg load range that is pre-calibrated is placed at front of pneumatic cylinder actuator to measure force generated by it. Signal of load cell is very minute and must be amplified. So load cell amplifier is employed to amplify the signal and deliver an output in form of analog signal of 5-10 V range. Laser sensor computes the distance moved by pneumatic air cylinder and provides output in analog sinusoidal signal waveform of 0-5 V.

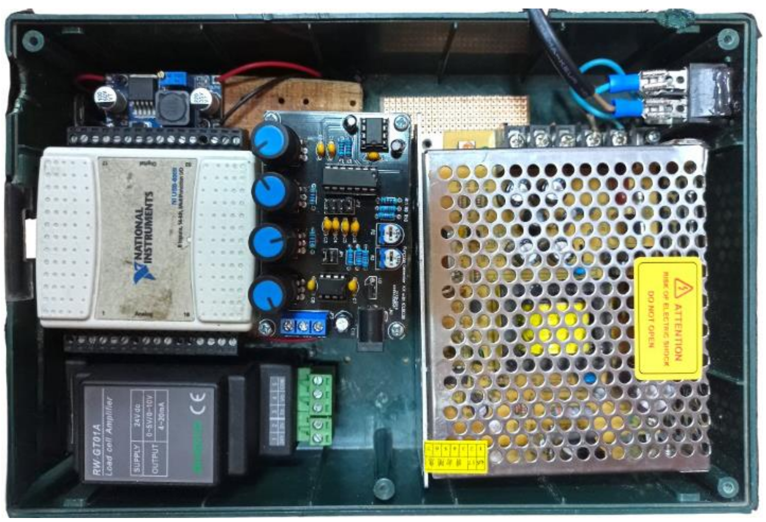

Figure 15 Proof of Concept 1

3.2. Proof of Concept 2

In this proof of concept Analog voltage of 0-10V that is provided to proportional valve is generated by DAQ Card and not the signal generator. Compact DAQ CARD NI 9174 is used for this purpose it has two cards NI 9215 and NI 9263. NI 9263 is used to generate Analog output that is provided to proportional valve and NI 9215 is used to acquire Analog Input from Distance sensor and Load cell amplifier.

Figure 16 Proof of Concept 2

3.3. Finalized System

Complete assembly of system is split into two portions

- Non-Moveable
- Moveable

3.3.1. Non-Moveable

It comprises of following components

- Supporting Structure
- Signal Processing Unit
- Load Cell
- Proportional servo Valve
- Load Cell Amplifier
- Laser Distance Sensor

3.3.2. Moveable

It consists of following components

- Pneumatic Cylinder Actuator

3.4. Supporting Structure

It comprises of 3 parts

- Bottom plate
- Upper plate
- Solid Circular bars

These have following specifications

- Bottom plate

Area = 450 x 450 mm^2

Thickness of plate = 18 mm

Supporting table of U shape for mounting of Load Cell is placed on this plate

- Upper plate

Area = 250 x 250 mm^2

Thickness of plate = 16.2 mm

Pneumatic Cylinder, Proportional Valve and Laser Distance Sensor are placed on top of this plate

- Solid circular bars

Length = 550 mm

Diameter = 30 mm

These shafts are used to join upper plate and bottom plate

Figure 17 Base Structure for Fatigue Testing Machine

3.5. Force Computation

This machine is intended for fatigue testing of Rubber parts. A minimum force of 3000 N is needed for this purpose. Keeping this in mind force is calculated from diameter of pneumatic cylinder actuator and pressure provided to this actuator. Pneumatic Cylinder Actuator that was used for this machine development has specification of 80 mm x 350 mm i.e. 80 mm bore and 350 mm length of stroke. [9][27]

$$Bore = 80\ mm$$

$$Radius = r = \frac{Bore}{2 * 1000}\ m$$

$$Radius = r = \frac{80}{2 * 1000}\ m$$

$$Radius = r = 0.04\ m$$

$$Area = A = \pi r^2$$

$$Area = A = \pi * 0.04^2$$

$$Area = A = 0.0050265482\ m^2$$

$$Pressure = P = 8\ bar$$

As

$$1\ bar = 100000\ Pa$$

$$8\ bar = 800000\ Pa$$

So force can evaluated as following

$$Force = F = P \text{ x } A$$

$$Force = F = 800000 \text{ x } 0.0050265482$$

$$Force = F = 4021.2 \text{ N}$$

This is the force that is generated by Pneumatic Cylinder Actuator at pressure of 8 bar.

Factors like safety factor and Air compressibility were taken into consideration while performing calculations. Different values of pressure from air compressor can be provided to produce other values of Force. [16]

*Figure 18 BOGSH Pneumatic Cylinder 80 * 350*

3.6. Proportional Valve Selection

For this machine a proportional servo valve capable of switching flow or pressure variation with high speeds and large frequency is needed. Festo Proportional directional servo valve having positional restrained spool 5/3 way is chosen for this purpose. It needs 17-30 VDC power supply and has a response time of 4.8ms. [26]

Valve Function	5/3 way normally closed
Construction Design	Piston Spool Directly Actuated
Power Supply	17-30 VDC
Response Time	4.8 ms
Set Point Voltage	0-10 Analog Voltage
Critical Frequency	95 Hz
Standard Nominal Flow	750 liter/min

Table 1 Proportional Valve Specification

This valve required an analog sinusoidal signal of 0-10 V to perform its operation. This voltage is provided by signal generator in our machine in concept 1 configuration and by NI 9174 in concept 2 configuration.

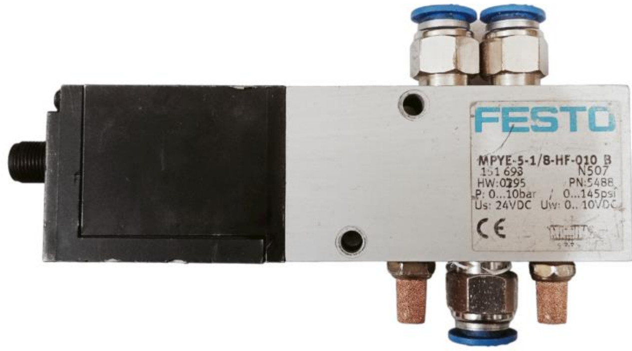

Figure 19 FESTO MPYE-5-1/B-HF-010 B Proportional Valve

In this analog signal opens corresponding cross section at outlets of valve. Precise pneumatic positioning control system can be made by application of distance sensor and exterior position regulator. Experimentation was carried out with both higher and lower flow valve. Only difference in both of these valves is how much flow of air was allowed to pass through them. Lower flow valve can allow maximum flow of 350 liter/min meanwhile higher flow valve can allow maximum flow of 700 liter/min.

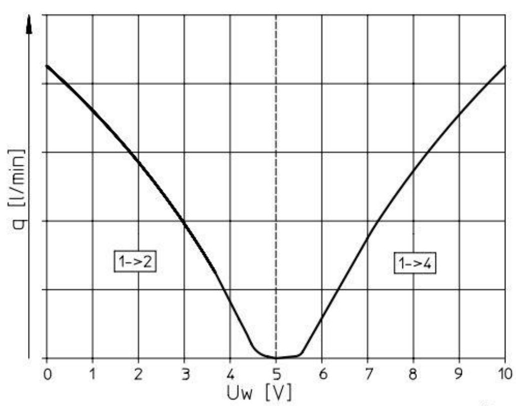

Figure 20 FESTO Proportional Valve Working Voltage Signal

With actuation of valve location of spool is altered due to which cylinder is moved in onward direction. When valve is unactuated spool goes back to its initial location due to exhaust of air via outlet port.

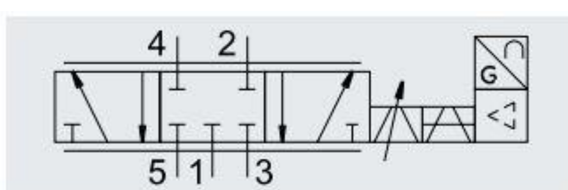

Figure 21 FESTO Proportional Valve Electrical Circuit

3.7. Load Cell Transducer Selection

We have already computed force that is 3000 N. To measure this force we require a load cell transducer that is able to withstand this much force and also capable to provide accurate readings of force/load applied to it. So to do this

$$Force = F = mg = 3000\ N$$

$m = \frac{F}{9.81} = \frac{3000}{9.81}$ =305.81 kg

So it implies that a load cell of 350 kg or more is needed. So load cell LCS-1 having 500 kg load capacity was selected. Its sensitivity is 2mV/V. [33]

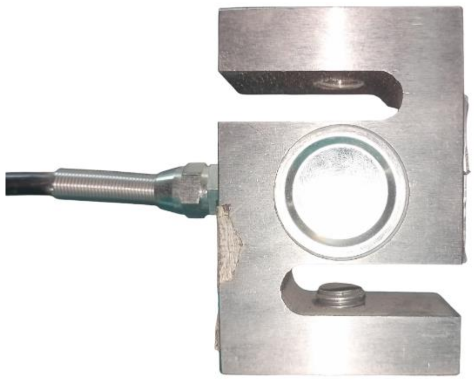

Figure 22 LCS-1 S Type 500 kg Load Cell

Transducer is placed on U shaped structure that is mounted on bottom plate of base structure to hold it in vertical position.

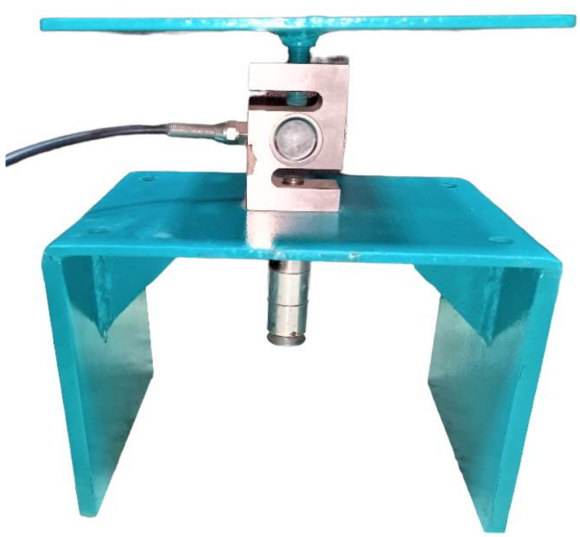

Figure 23 U shaped Structure for Load Cell Placement

Transducer’s output is very low and is in mV. So amplifier is opted for filtering, amplifying and adjusting electrical signal from transducer to produce readings in 5-10 V range which is then fed to DAQ for data analysis. [31]

Figure 24 RW-GT01A Load Cell Amplifier

Below is table demonstrating terminal connections of Load Cell Amplifier.

Terminal	Definition
1	Power Supply (24 V)
2	Ground (0V)
3	Current Output
4	Voltage Output (V+)
5	Output Common
6	Excitation Voltage (E+)
7	Signal (S+)
8	Signal (S-)
9	Excitation Voltage (E-)
10	Shield

Table 2 Load Cell Amplifier Connection Terminals

3.7.1. Calibration

Any sensor must be calibrated before use. So calibration for load cell was performed. For this weights with variable values were loaded on transducer at varying time gaps and for each weight reading was observed on amplifier. Similarly unloading of weights was carried out and readings were observed to evaluate hysteresis by plotting graph of loading vs unloading.

No considerable hysteresis was found. Waveform graph is plotted using weights and amplifier output for corresponding weight. A linear relationship was observed between said variables. A table of calibration values and corresponding waveform chart is shown below.

Weight (N)	Weight (kg)	Loading	Unloading	Voltage	Voltage Avg
0	0	0.0002	0.001	-0.00015	-0.0005
20	2.038735984	-0.0416	-0.042	0.0418	0.0415
40	4.077471967	-0.0838	-0.0845	0.08415	0.0835
60	6.116207951	-0.1261	-0.1268	0.12645	0.1255
80	8.154943935	-0.1688	-0.1694	0.1691	0.1675
100	10.19367992	-0.2112	-0.2118	0.2115	0.2095
120	12.2324159	-0.2543	-0.2544	0.25435	0.2515

Table 3 Load Cell Calibration Table

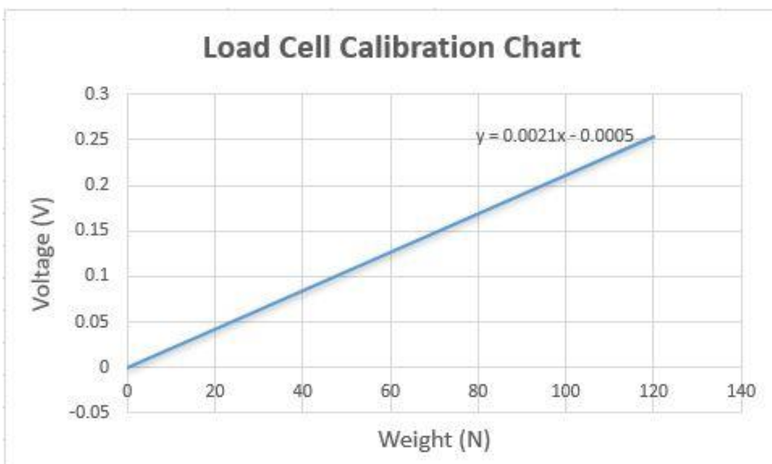

Figure 25 Load Cell Calibration Chart

3.8. Signal Generator Selection

We need a signal generator that can provide 0-10V analog voltage at variable frequencies and is capable to provide offset if needed. ICL 8038 signal generator was selected for this as it can provide 0-10V analog voltage with offset. [28]

Parameters	Specifications
Model	ICL 8038
Supply Voltage	12-15 VDC
Frequency Range	5 Hz to 400 kHz
Duty Cycle	2-95%
Output Amplitude Range	0.1-11 Vpp
Wave Output Form	Sine/Triangle/Square

Table 4 Signal Generator Specifications

It has frequency range of 5 Hz to 400 kHz. It requires 12-15 VDC supply for power. It can provide Sinusoidal, Triangular and Square waveform. It is opted for operation of proportional servo valve.

Figure 26 ICL 8038 Signal Generator

3.9. DAQ Card Selection for concept 1

For proof of concept 1 USB 6009 of NI is opted to acquire data from 3 devices i.e. load cell amplifier, signal generator and laser sensor. This DAQ is capable of taking 8 Analog Inputs and providing 2 Analog Outputs. It can provide maximum sampling rate of 48kS/s for single or multiple channels.

Pins AI 0, AI 1, AI 2 are used to acquire data from devices that are discussed above. [35]

Figure 27 NI DAQ 6009

3.10. DAQ CARD Selection for concept 2

Compact DAQ CARD NI 9174 is used. Two cards NI 9215 and NI 9263 are used inside it. NI 9215 acquires Analog input from Distance sensor and Load Cell Amplifier and NI 9263 generates Analog output of 0-10V that is then provided to proportional valve.

The cDAQ 9174 Compact DAQ USB chassis is designed for tiny, portable sensor measurement systems. The chassis connects USB sensors and electrical measurements in a plug-and-play fashion. It is also in charge of controlling the timing, synchronization, and data transmission between C Series I/O modules and an external host. This chassis may be used with a mixture of C Series I/O modules to provide a mix of analogue I/O. [34]

Figure 28 Compact DAQ 9174

3.11. LabVIEW Interface

Software opted for data collection and analysis was LabVIEW from National Instruments (NI). Front panel of program in application is shown below.

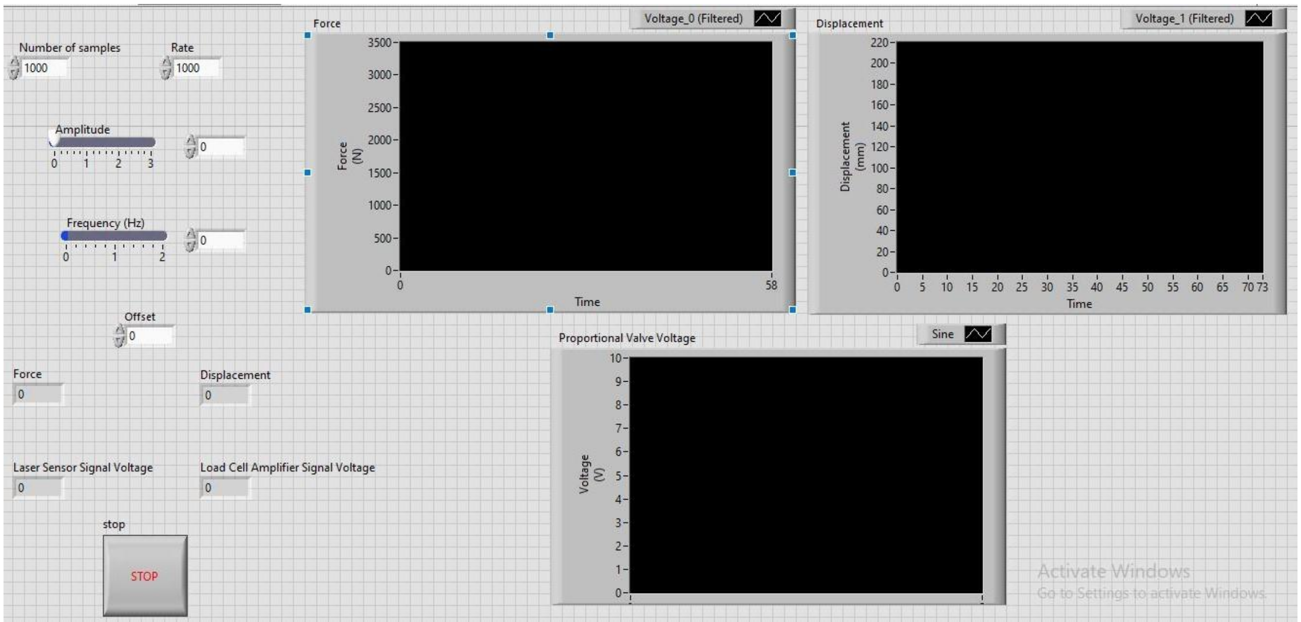

Figure 29 LabVIEW Program Front Panel

3.12. Distance Sensor Selection

Distance sensor is needed that is able to measure distance of range 400 mm with accuracy of 0.0002 m (200 µm) and response time of $10ms$. Following calculation is used to get required response time from 100 Hz frequency.

$$Time\ Period = t = \frac{1}{frequency} = \frac{1}{f}$$

$$t = \frac{1}{100}$$

$$t = 10\ ms$$

So Panasonic's HGC 1400 laser distance sensor is chosen as it provides all necessary requirements. HGC 1400 can provide 400 mm range with 300 µm accuracy and response time of 1.5-10ms. It can provide output in digital as well as in analog voltage (0-5V) form. [32]

Figure 30 Panasonic HGC 1400 Laser Distance Sensor

HGC 1400 Panasonic Laser distance sensor provides analog voltage of 0-5 V for corresponding distance of 200-600 mm. Waveform chart was plotted for said values and is shown below.

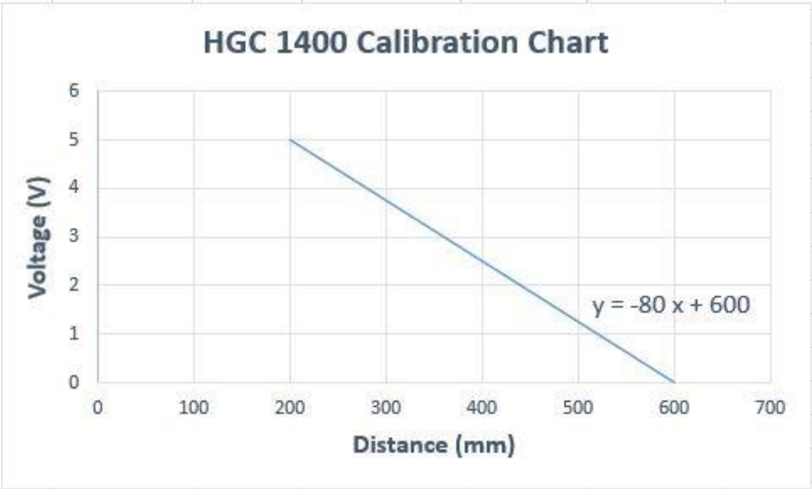

Figure 31 HGC 1400 Laser Sensor Calibration Chart

3.13. Electrical Connections

Figure 32 Complete D.B Box

This is finalized Power Distribution Box of our system. Here voltage of 220 V from AC source is provided to DC Power Supply that gives output of 24 VDC. This 24 VDC is provided to Vero board. Due to voltage in parallel this 24 VDC is then used to power three devices i.e. Proportional Valve, Load Cell Amplifier and Buck Module. Buck Module lower down 24VDC to 13.5 VDC that is then provided to Displacement Sensor for power. DAQ NI 9174 has two cards NI 9215 and NI 9263. DAQ Card NI 9215 acquires data from Displacement Sensor and Load Cell Amplifier. DAQ 9263 provides set point voltage (0-10 V analog) to proportional valve.

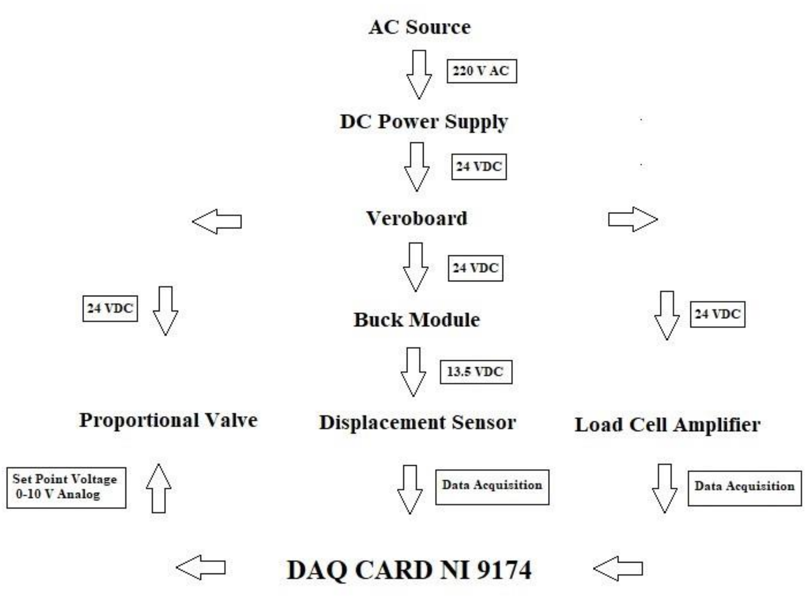

Figure 33 D.B Box Electrical Block Diagram

Three Pin Connectors are used in Power Distribution Box and fourth one is of Load Cell Amplifier.

Figure 34 D.B Box Terminals

Pin Connectors used for Proportional Valve and Displacement Sensor have 4 pins each. They have such a configuration that [Pin 1 (+ve), Pin 2 (-ve)] from left are used for Power voltage and [Pin 3 (+ve), Pin 4 (-ve)] from left are used for Signal generation in case of Displacement sensor and for set point voltage generation in case of Proportional Valve.

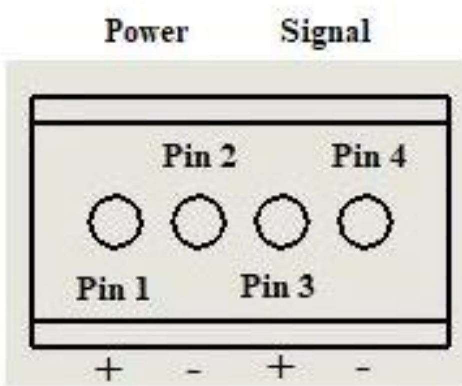

Figure 35 4 Pin Connectors Complete Schematic

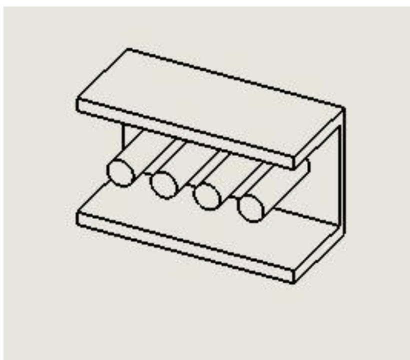

Figure 36 4 Pin Connector

Pin Connector for DAQ CARD has 6 pins. Pin 1 (+ve) and Pin 2 (-ve) from left are used for generation of set point voltage for proportional valve. Pin 3 (+ve) and Pin 4 (-ve) from left are for signal acquisition from Load Cell Amplifier. Pin 5 (+ve) and Pin 6 (-ve) from left are used for signal acquisition from Displacement Sensor.

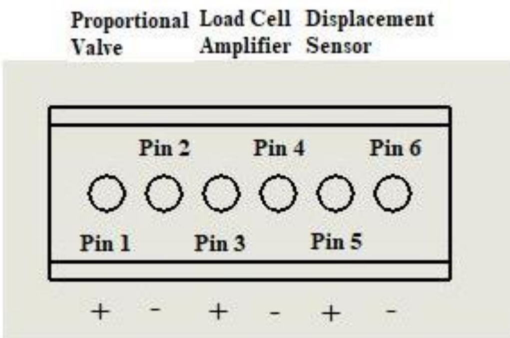

Figure 37 6 Pin Connector Complete Schematic

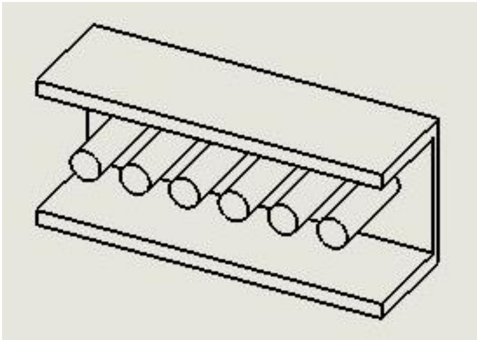

Figure 38 6 Pin Connector

Proportional Valve has main cable that has 4 cables inside. They are following

- Brown (Power +ve 24 VDC)
- White (Power –ve 0 VDC)
- Green (Set point +ve 10 V Analog)
- Black (Set point –ve 0 V Analog)

Load Cell has main cable that has 5 cables inside. They are following

- Green (Signal +ve)
- White (Signal -ve)
- Black (Excitation +ve)
- Red (Excitation -ve)
- Yellow (Shield)

Load Cell Amplifier has 4 wires. They are following

- 24 VDC (Power +ve)
- 0 VDC (Power –ve)
- Vo (Signal Out +ve)
- COM (Signal Out -ve)

Displacement Sensor has main cable that 6 cables. Only 4 are used in our case. They are following

- Brown (Power +ve 12-24 VDC)
- Blue (Power –ve 0 VDC))
- Grey (Signal Out +ve 0-5 V Analog)
- Shield (Signal Out –ve 0 V Analog)
- Pink (External Input) (not used in our case)
- Black (Control Output) (not used in our case)

Buck Module has 4 wires. They are following

- IN +ve
- IN –ve
- OUT +ve
- OUT –ve

Throughout inside Power distribution box red color wires are used for positive connections and black color wires are used for negative connections.

3.14. Complete System's Block Diagram

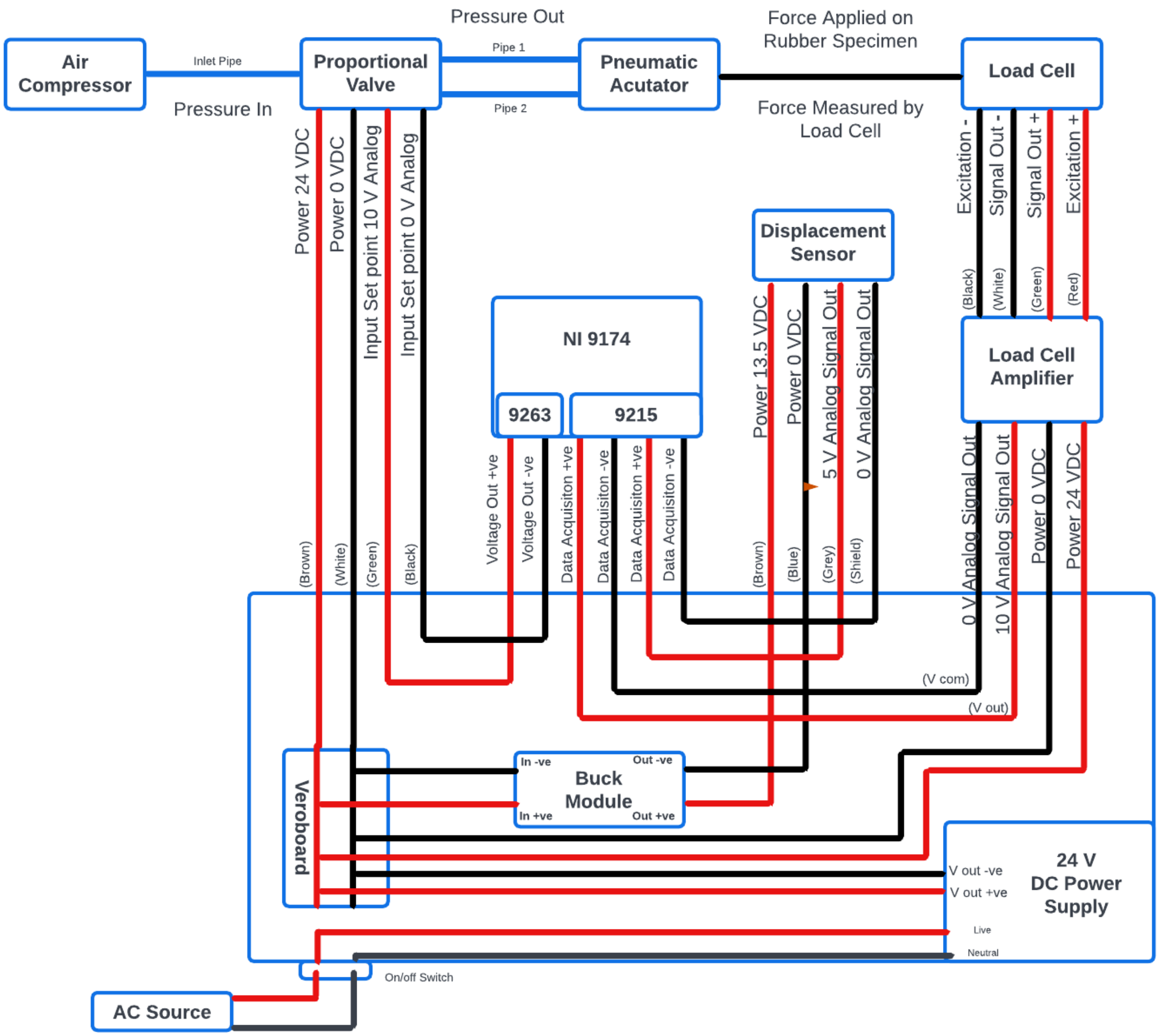

Figure 39 System's Block Diagram

4. Results and Discussions

4.1. CAD Model

Complete CAD Model of Proposed System is

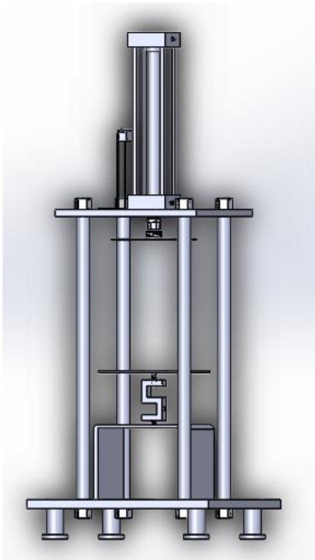

Figure 40 Complete CAD Model

4.2. Complete System

Complete Actual System is

Figure 41 Complete Actual System

4.3. System Layout

System Layout is

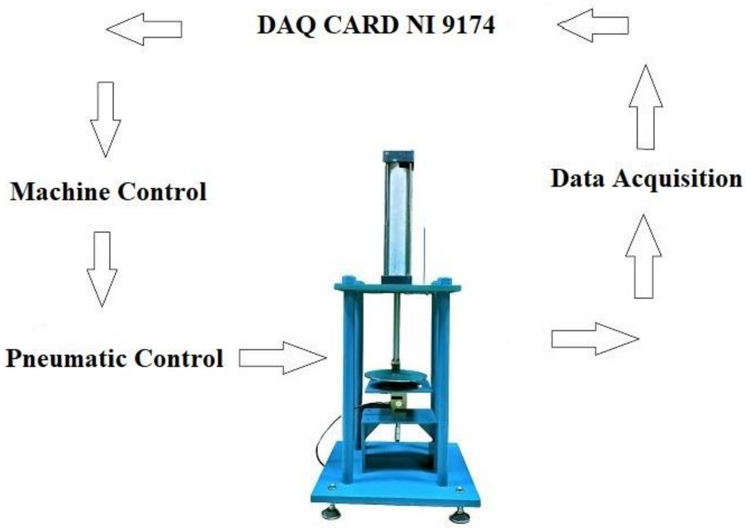

Figure 42 System Layout

4.4. Concept 1 Configuration

In Concept 1 configuration front panel of LABVIEW program is

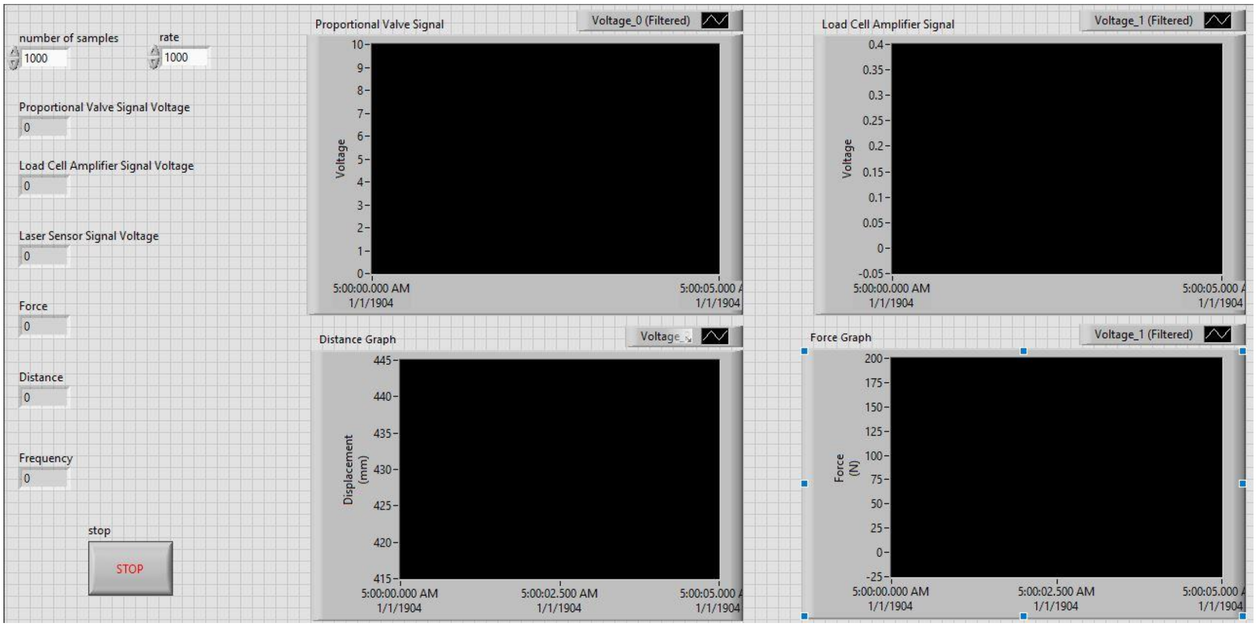

Figure 43 Concept 1 Front Panel

Block Diagram of above program is

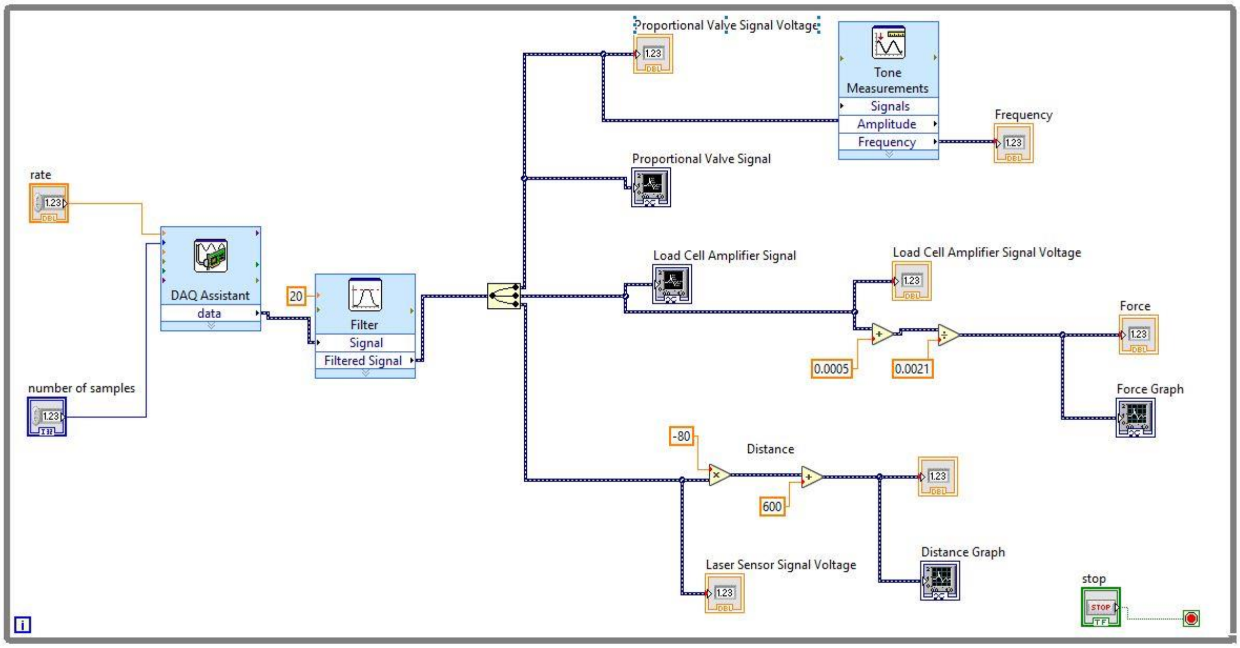

Figure 44 Concept 1 Block Diagram

In Concept 1 configuration Signal Generator applies set-point analog voltage signal (0-10V) to proportional servo valve. DAQ card also measures this voltage via DAQ card's Analog input 0. Waveform graph was plotted on LabVIEW front panel interface. USB NI 6009 is used to acquire data in this configuration. NI 6009 terminals AI0 AI1 AI2 are used to acquire data from proportional valve, load cell amplifier and distance sensor respectively.

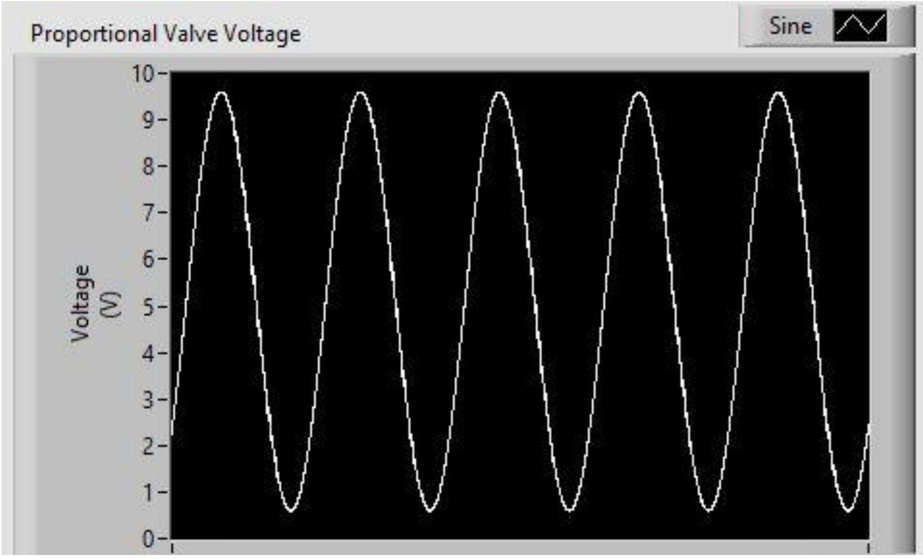

Figure 45 Proportional Valve Set point Voltage

50 liter/min air flow at pressure of 8 bar was provided by an air compressor, which is used for proportional valve operation that ultimately operates pneumatic cylinder actuator. On multiple frequencies pneumatic cylinder actuator's force at pressure applied is determined. Operating at higher frequencies, pneumatic cylinder actuator do not get sufficient time to withdraw back so rubber specimen is kept under loading condition continuously. At such frequencies proportional valve actuation is at such high speeds that it appears there is static loading applied on specimen. So offset can be provided to alter actuator's position according to needs. System was operated on variable frequencies and multiple pressures to test capabilities of machine. At 3 Hz frequency and 6 bar pressure around 200 kgF (approximately 2000 Newton) Force is generated. This force is measured by DAQ and is displayed in form of waveform chart on front panel of LabVIEW's program.

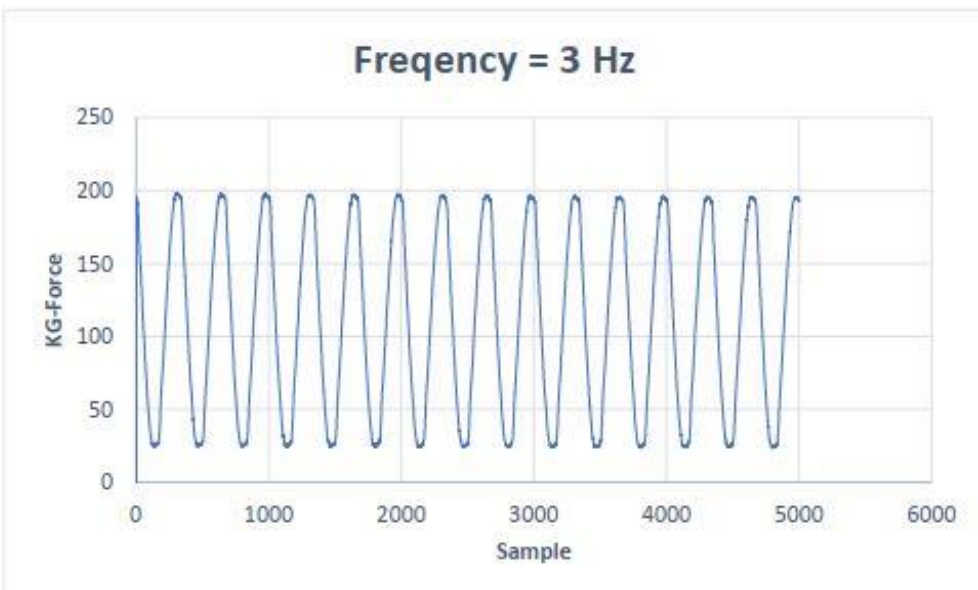

Figure 46 Force at 3Hz Frequency

4.5. Concept 2 Configuration

In Concept 2 configuration front panel of LABVIEW program is

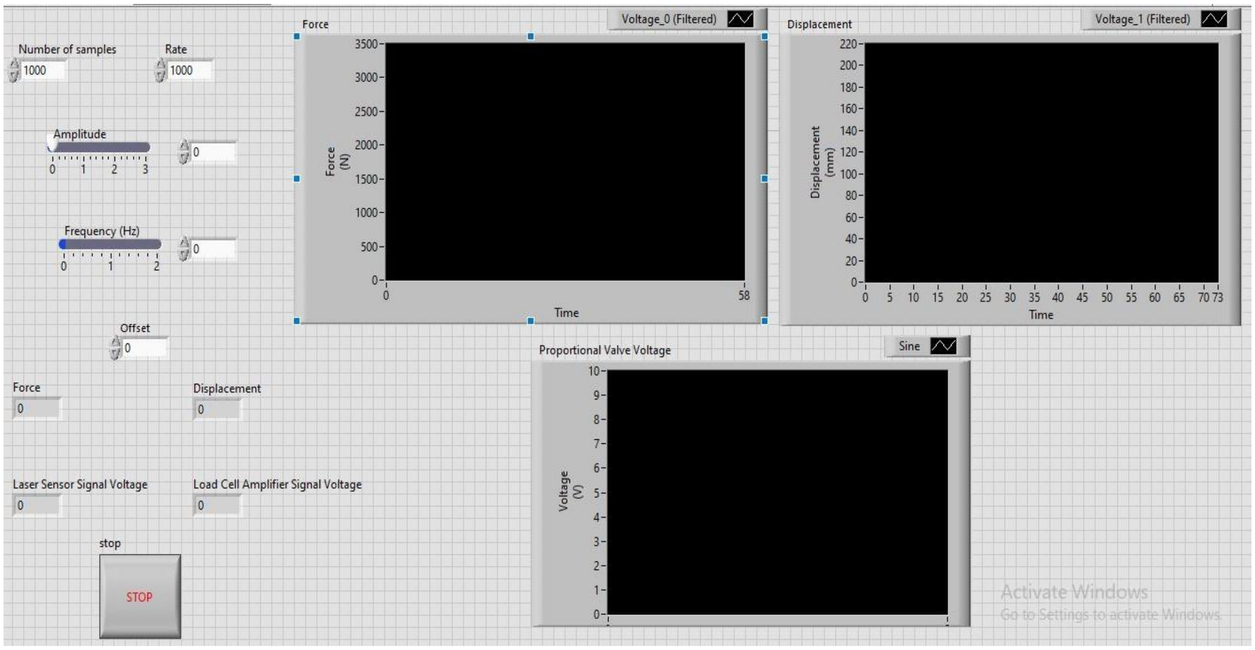

Figure 47 Concept 2 Front Panel

Block diagram of above program is

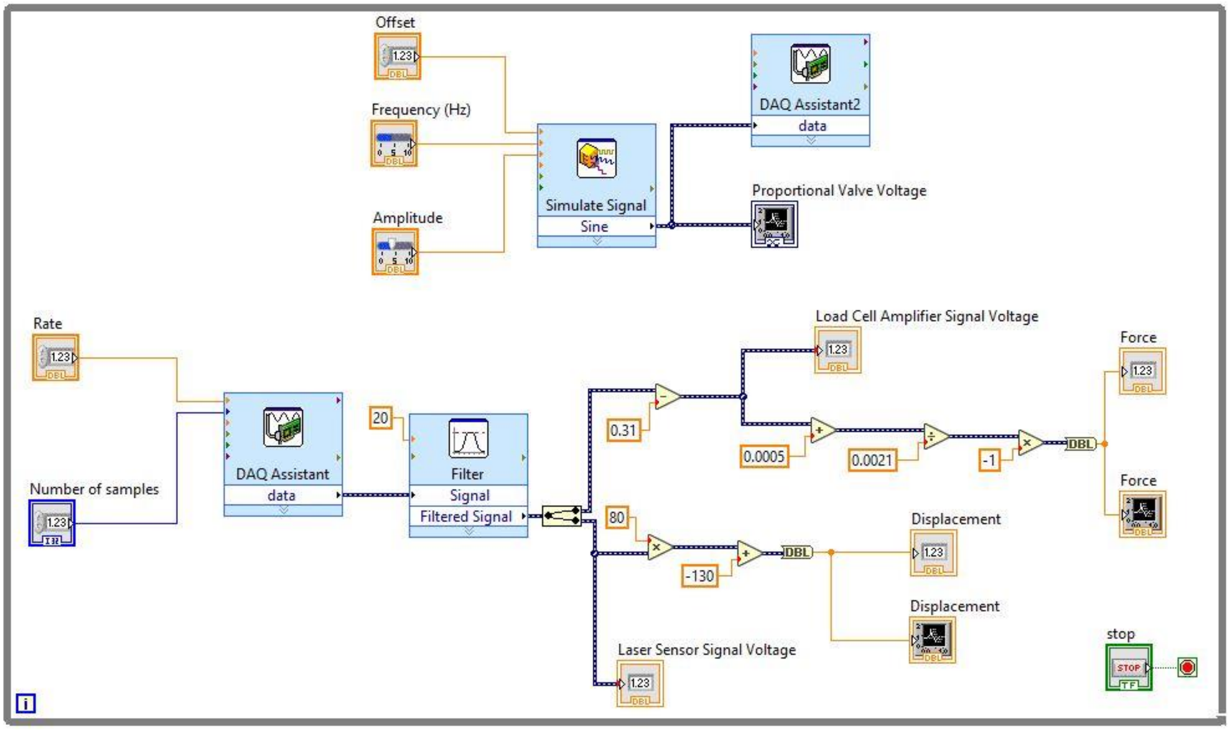

Figure 48 Concept 2 Block Diagram

In Concept 2 configuration compact DAQ NI 9174 having two DAQ cards NI 9215 and NI 9263 is used. NI 9263 generates 0-10 analog voltage output that is provided to proportional valve as set point voltage for its operation. NI 9215 is used to acquire data from Load Cell Amplifier and Laser Distance Sensor. . For NI 9215 Terminal AI0 and AI1 are used to acquire data from load cell amplifier and distance sensor respectively. For NI 9263 Terminal AO0 is used for providing output to proportional valve. Instead of manual controlling by knobs software was used to control the entire operation. Using this configuration continuous loading was applied on Rubber specimen to assess whether machine is able to provide continuous loading or not. Results were quite satisfactory as specimen was kept under continuous loading.

Proportional Valve allows flow from one outlet if voltage is 0V and allows from other one if voltage is 10V. It does not allow flow at 5V. So to open any outlet it must be provided with voltage either greater than 5V or less than 5V. It was provided with analog voltage of 4-6 V continuously to allow to and fro motion of pneumatic actuator. This voltage was provided by NI 9263.

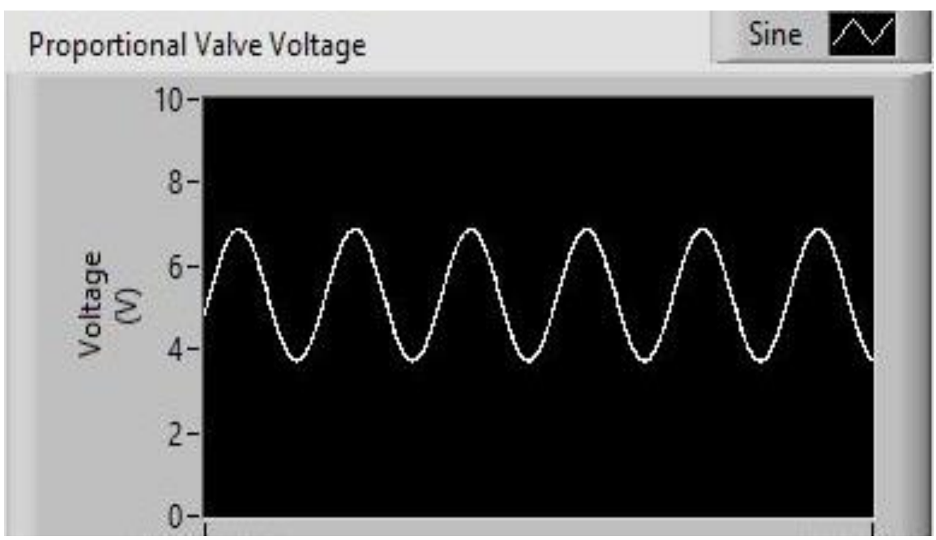

Figure 49 Proportional Valve Set point Voltage 4-6 V

At 4-6V analog voltage given to proportional valve and pressure of 3 bar force of 1400 Newton was generated. This force was measured by DAQ and displayed on front panel of LABVIEW's program.

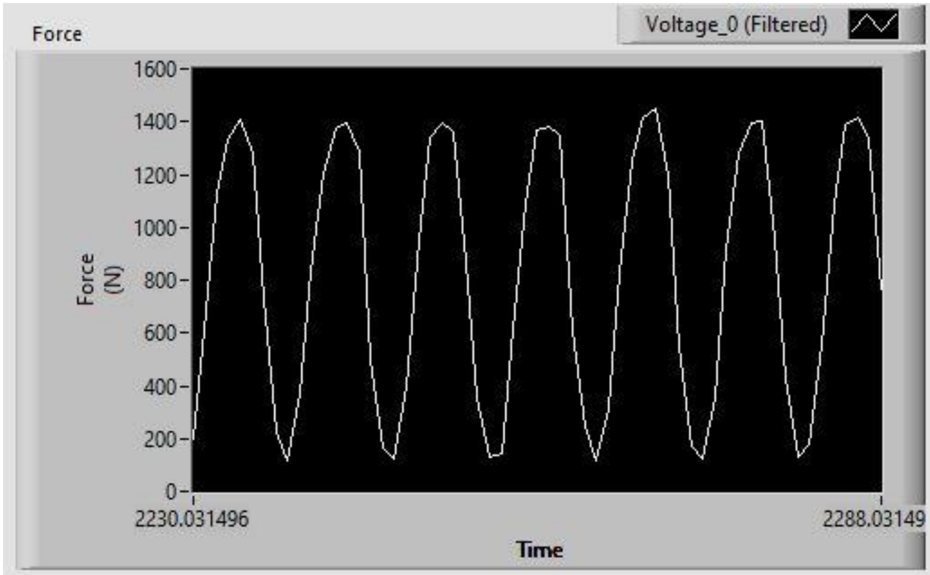

Figure 50 Force for continuous loading

Results of Laser Distance Sensor were also quite satisfactory as it had shown exact position of Pneumatic actuator.

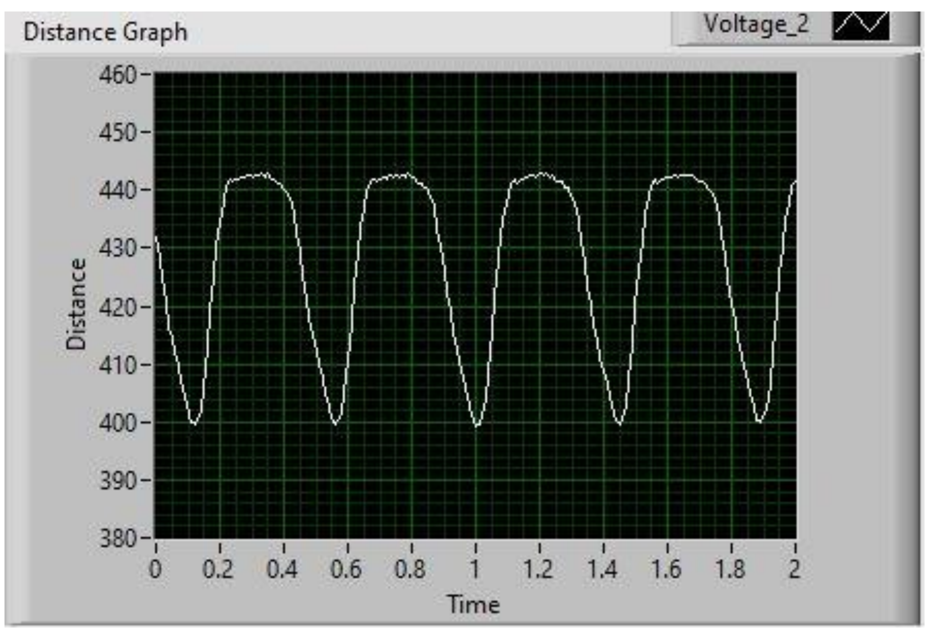

Figure 51 Pneumatic Cylinder Position Graph

5. Conclusion

Main goal of this project was designing and development of pneumatic fatigue testing system for rubber material parts. Numerous industries especially automobile sector opt rubber parts that are either customized or non-customized. With passage of time fatigue is induced in rubber parts due to continuous loading. Ultimately they can fail and cause great amount of destruction. So it is compulsory to know fatigue life of components/parts. So this machine is much vital in areas where rubber parts are used. For this machine careful assessment of force that can be controlled is needed to match the force that will occur in real life scenario and will cause fatigue.

Multiple feasible approaches for development of fatigue testing system for required force were studied at initial phase of this project. Finally a most feasible and practical system was decided and then designed for desired specifications. 3D Modelling of this project was done on SolidWorks. Individual parts were designed and manufactured individually and then all were assembled in form of single unit. Design of mechanical base structure was carried out keeping in mind high amount of forces that will be experienced by it. This machine has customized design i.e. it means parts of suitable size range can be placed in it do testing. 350 mm length of stroke allows this feature to work. Stroke length can be controlled by variation in set point voltage of proportional valve. Software's interface is used to do such action. Signal generator is capable to be tuned at multiple values for adjustment of required length of stroke according to rubber part specification. Number of cycles provided can also be varied by the frequency control of signal generator. This machine is able to operate at varied pressures ranges, frequencies and flow rates. This system is able to generate a force of 3kN at multiple frequencies. Desired force can be generated by this system by varying pressure supplied. This machine combines electrical and mechanical setup. Distance moved by pneumatic actuator is accurately measured and known due to laser distance sensor attached to system. Software Interface allows user to specify number of cycles and rate at which samples are taken. Force that is produced by pneumatic actuator can be analyzed by Force graphs plotted on software interface. Also graphs were plotted for signal sent to proportional valve, load cell amplifier's signal and distance sensor's signal.

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Fatigue Testing of Rubber Component with Hybrid Control of Force and Displacement

by Mian Ashfaq Ali

Fatigue Testing of Rubber Component with Hybrid Control of Force and Displacement

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