Develop a technique for the inspection of piston profile and measure piston skirt diameter

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Abstract

The purpose of this project is to design and fabricate a Piston Inspection Machine. It serves as a proof of concept for later versions to be designed for Tractor OEM. The machine will be able to evaluate the piston profile and measure Diameter of Piston Skirt. The profile is measured by Holding the piston using a U-block mechanism that takes the readings over defined intervals. The LVDT sensor is utilized to take the readings with an accuracy of in microns. The accuracy and precision requirements are specified by the manufacturing drawings providedby the OEM. The design of machine components is dictated by the dimensional constraints rather than stress and loading conditions since most components are stationary and have light in weight components to hold. The design is optimized to take readings along the length of the skirt to measure its profile by evaluating the diameter at specific points. It is mainly due to innovative arrangement that allows point contact at the length of piston skirt surface and has not been seen in precision measurement industry

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Abbreviations

- ✓ ADC Analogue to Digital Converter
- ✓ AI Analogue Input
- ✓ CMM Coordinate Measuring Machine
- ✓ CPR Cycles Per Revolution
- ✓ DAQ Data Acquisition
- ✓ DIO Digital Input/output
- ✓ LabVIEW Laboratory Virtual Instrumentation Engineering workbench
- ✓ OEM Original Equipment Manufacturer
- ✓ PPR Pulses per Revolution
- ✓ RPM Revolutions Per Minute
- ✓ VI Virtual Instrument

Chapter 1
Introduction

1.1 Background and motivation:

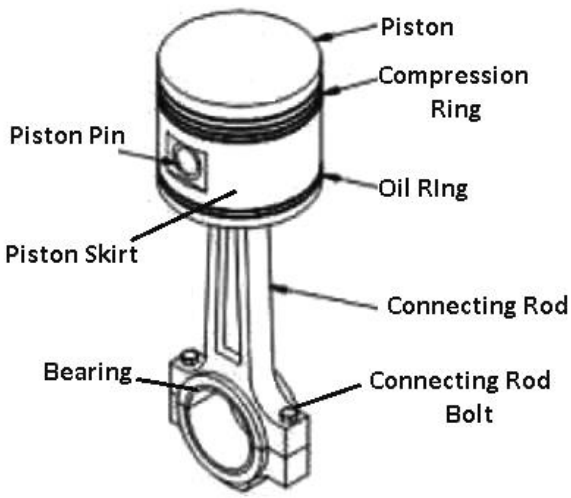
An engine's piston is a cylinder-shaped component that oscillates inside the engine's cylinder. The piston's main job is to carry force from the cylinder's expanding gases to the crankshaft, which then transforms the piston's linear motion into rotating motion. This rotational motion is then used to power the vehicle or machinery.

The piston is connected to the crankshaft through a connecting rod, and its movement is controlled by the engine's valves, which regulate the intake and exhaust of air and fuel. The combustion chamber is additionally sealed by the piston, preventing combustion gases from leaking into the crankcase

In addition to its basic function, the piston plays an important role in the engine's efficiency and performance. Modern engines use precision-machined pistons with carefully designed crowns, skirts, and ring grooves to optimize the compression ratio, reduce friction, and improve durability. The heat energy is transformed into mechanical work via a piston. Pistons are a crucial part of heat engines as a result. Its function is to transmit the force generated by the expanding gas in the cylinder to the crankshaft, which then transmits that rotational momentum to the flywheel.

The main components of piston are follows;

1) Crown
2) Skirt
3) Piston Pin
4) Piston Ring
5) Compression Rings
6) Oil Rings
7) Grooves



To design and fabricate a machine, capable of precise measurement, for automotive industry. In the global market, precision engineering and measuring techniques are available, and we intend to introduce this advancement in Pakistan at a much cheaper cost, which might be very advantageous for the industry. Its International alternative is the CMM machine which can cost from **$30,000** to**$1,000,000** depending upon the specifications.

1.2 Problem Statement:

The task is to develop an Inspection machine that can measure diameter of piston skirt and evaluate the piston profile. The diameter is to be measured within 15 microns of accuracy.

1.3 Objectives and deliverables:

Main objectives of the project are:

1) Inspecting machine for industry that can measure diameter of piston skirt.
2) The accuracy is kept to be around 1 micron (μm)
3) Providing a compact design that is economical, durable and easy to be used.

The deliverables of the project are:

1) CAD Model of finalized mechanism.
2) Fabrication of components.
3) Assembly of the components to finalize the machine.
4) Data Acquisition (Signal Processing to generate data from sensor).
5) Diameter measurement readings of piston skirt with an accuracy and repeatability of 1 micron.

Figure 1: Piston

<u>**Chapter # 2**</u>

<u>**Literature review**</u>

2.1 Piston profile:

There are two main characteristics of piston design that are piston profile and ovality. When we look piston, we conclude that it is perfectly round, but in reality, it's not completely round it's like oval shape. As when we roll the piston on the flat surface, you will see it doesn't roll in a straight a line. Now we have to observe the profile of the piston. It is because of aluminum conducts so much heat so it is designed with a taper.

The top of the piston is smaller diameter than bottom of the piston near the skirt. Basically, skirt is designed in the barrel shape as shown in figure below. This have a big reason that is temperature near the dome vary from the temperature at the skirt of the piston that results the different level of expansion.

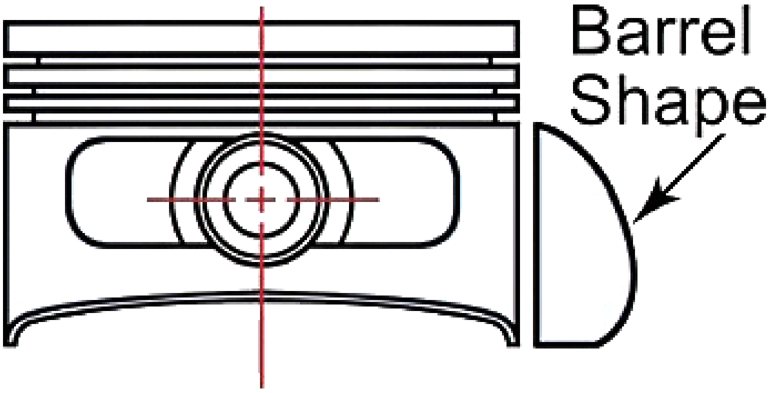


Figure 2: Barrel shape of piston skirt

The tapered shape of skirt allows the piston to expand when heat is applied so the piston does not tie with the cylinder bore, higher the temperature more will be the piston expand. So, in designing the degree of taper must be calculating, too tight clearance causes the seizure from heat expansion and too lose also cause the noise from piston rock.

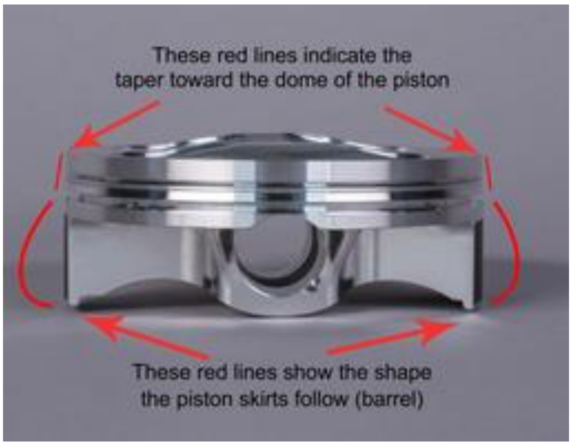


Figure 3: Piston skirts shape

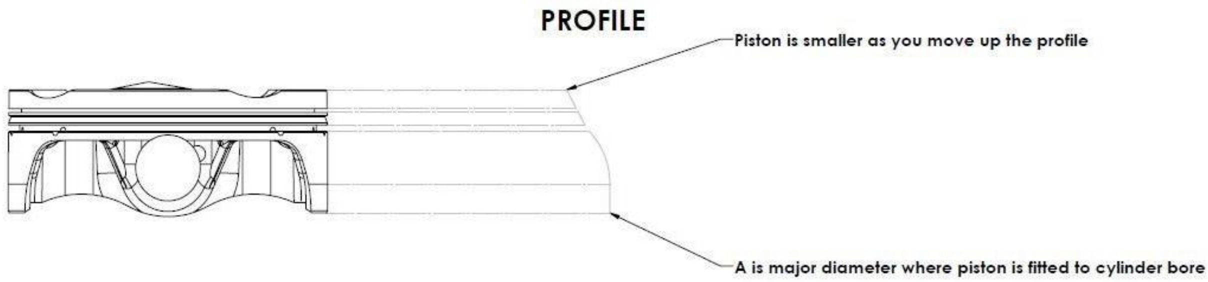


Figure 4: Piston Profile

Because of this piston profile barrel; and tapper shape diameter on skirt is larger than the diameter near the dome.

2.2 Ovality of Piston:

As we know that the piston rising and falling in the motion like a wheel that has flat spot, this is basically known as ovality. In simple words piston is smallest in line with the pin bore. By applying ovality piston is free to move up and down as needed.

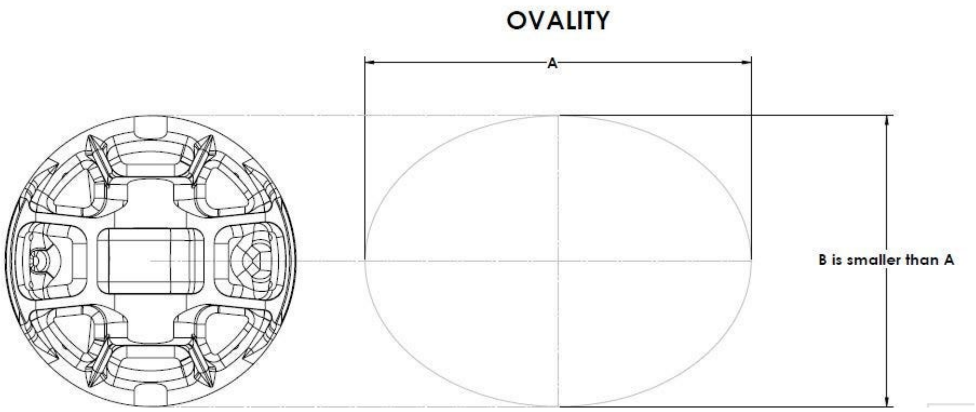


Figure 5:Ovality of piston

2.3 Measurement of piston Ovality:

There is hand on method previously used is the measurement taken by the micrometer. It is the key detail to remember when measuring the piston size. The piston must be measured at skirt or 90-degrees to the pin axis where the major diameter of piston skirt or maximum diameter of piston lies. The measurements are taken by the Outside diameter micrometers. The measurements are taken when the micrometer is placed 90 degrees to the pin hole or pin axis, there will be the maximum diameter of skirt, for some accuracy repeat one or more times and took readings of the diameter.
It is totally depending upon the user or worker who is taking the measurements because the small movement of his hand will change or deviate the readings from the actual value. This is the reason, there will be large possibilities of Human error.

Figure 6: Ovality measurement through Micrometer

There will be the possibility of human error and another limitation of this method is very difficult to determine the profile of piston skirt (i.e. Where would be the maximum and minimum diameter of the piston skirt). By this method we can't measure the waviness of piston or profile of the like how diameter changes along the piston skirt because at each point the skirt diameter changes or variations occur as shown in the figure 7.
So, this method is need to be improved or have to go for the method where we will get the pistons profile and diameters at different points of skirt. So, This is the limitation.

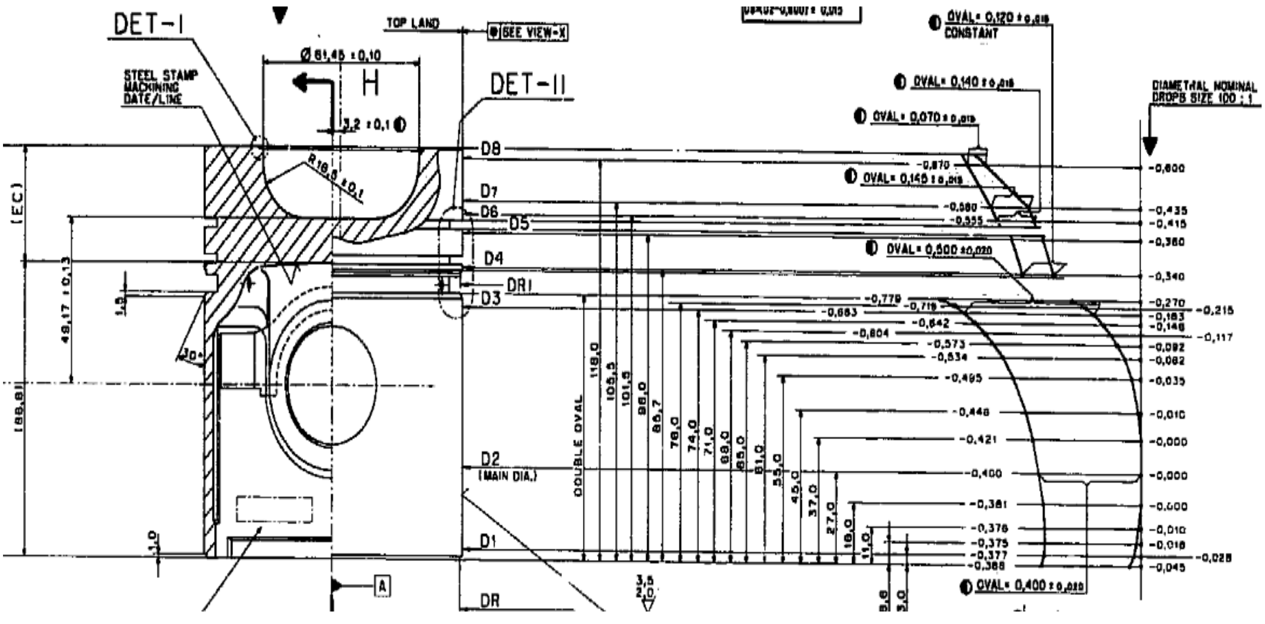


Figure 7: Profile Data

2.4 Piston profile measurement by CMM:

Ovality of piston is measured with a precision 3D Coordinate Measuring Machine (CMM). For the inspection of the ovality of a piston a 3D Coordinate Measuring Machine with continuous scanning capability is required. The measurement is done without a rotary table, therefore pistons can be mounted on a pallet and measured with maximum throughput in one go. It is the good technique to measure the ovality but CMM is not a cost effective and not easily available in small industries, for this main reason of the cost there is a need of same precise measurement and but must be a cost effective, so in this research we have to develop a technique to measure the piston profile or ovality but it must be a cost effective, precise, fast and easily available.

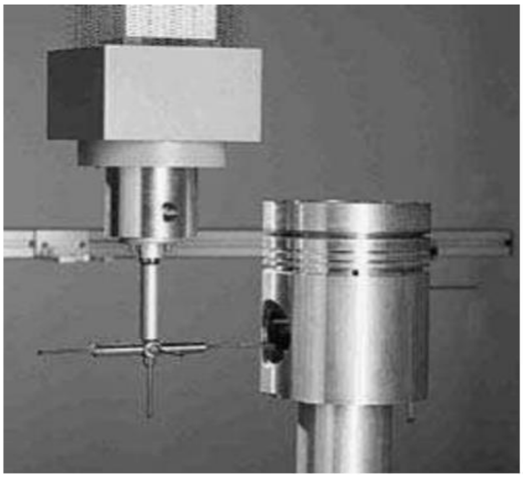


Figure 8: Piston Profile measurement through CMM

2.5 Technique for piston ovality (Profile) measurement:

- Ovality is an unknown thing, a lot of people think by just visualizing the piston is that it is round and with naked eye mostly it seen like a round shape. But when roll on the straight table it will be roll unevenly. It shows the piston have waviness profile at the skirt that is basically known as ovality.
- Ovality basically lies on the thrust axis or perpendicular to the pin axis from where the major diameter of piston is to be measured. In this research we deal with the line axis of piston skirt where the major diameter available or at highest point on skirt.

Why it necessary that piston must have ovality?

It is because when the piston is moving up and down in the cylinder bore, crankshaft and connecting rod forces piston upward but combustion forces piston downward, here ovality helps the piston to move without binding in round cylinder bore (or engine will not seizure). The overview of proposed technique is, firstly we have to hold the piston in such a way that the thrust axis of piston is free and pin axis is perpendicular to ensure the thrust axis is 90-degrees to pin axis.

How to hold the piston?

U- Shaped or v-shaped blocks are used to hold the work piece in cylindrical form for inspection. So, placed the piston on the u-shaped block and pin ensures it constrain its axial movement as well as angular movement. The thrust axis is now freely available for inspection.

2.6 Sensors:

The design and production of high precision gauging probes and other related instrumentation are now led by **SOLARTRON**. It offers a variety of sensors and probes, primarily pencil probes and specialized probes, for linear measurements.

To determine the position of the probe tip, each probe has an inductive sensor. Sensors are available in half-bridge or linear variable differential transformer types. There are various applications, including:

1. Measurements of angles and flatness with high resolution, great linearity, and repeatability
2. Automatic gauging with mechanical contacts and pneumatic probes.
3. Using two side-load-resistant probes to measure the outside diameter.
4. Using miniature probes to gauge the inner diameter of a hole.
5. The TIR measurement, which is determined by the difference of peak readings.
6. A linear variable differential transformer (LVDT) is a type of electrical transformer used for measuring linear displacement or position.

LVDTs are commonly used in industrial applications, such as in process control and machine tooling, where precise measurements of position and displacement are required. They are known for their high accuracy, linearity, and robustness, making them suitable for use in harsh industrial environments. They are also immune to electrical noise and can operate over a wide temperature range, making them well suited for use in temperature-controlled environments.

Figure 9: LVDT Sensor

2.6.1 Principle of LVDT:

In order to create an LVDT inductive displacement sensor, a static transformer's primary winding and two more winding. The primary coil's magnetic flux, which is created when AC current flows through it, is connected to the secondary coil through the core. The output of the transducer is the difference between the voltages of coils A and B, which have an opposite phase. Over its calibrated range, an LVDT's output essentially has a linear displacement function; however, once this range is exceeded, the output is non-linear. The probes can be spring-loaded, pneumatically propelled, or vacuum-retracted. When used horizontally, these feather touch pneumatic probes exert only 0.18N of force as opposed to 0.7N for conventional probes.

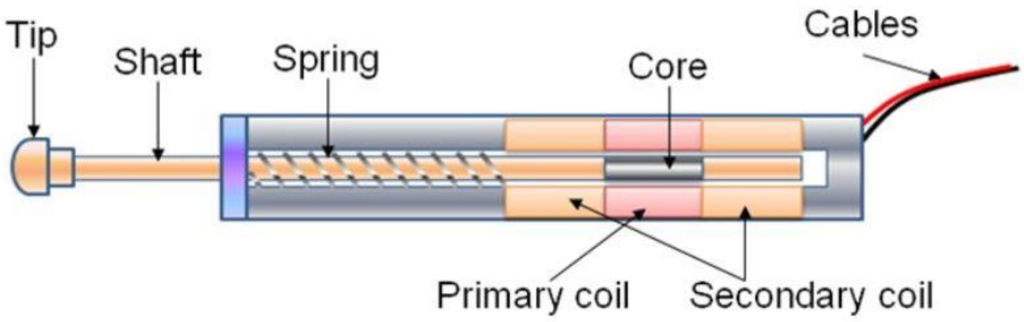


Figure 10: Working Principle of LVDT

2.6.2 Why not optical solution?

Over the years, the optical industry has made significant advancements, which have inspired engineers to create and improve optical measurement methods. Although they lack the reliability of direct piston inspection equipment, their prices are skyrocketing to remain competitive in the market. Additionally, the industrial environment's electromagnetic pollution interferes with the operation of the optical sensors they use, preventing them from performing as well as they should.
After researching this device, we concluded that optical sensors are a bad option for a multipurpose crankshaft inspection machine. In a lab context, however, where full isolation from electromagnetic noise can be offered, optical sensors do have an advantage.

2.7 Electric Sliders:

In the logistics, automation, and precision industries, electric sliders are commonly used. These are preferable than pneumatic sliders because they are actuated by ball screws in conjunction with a feedback stepper motor, which makes them exceptionally dependable and accurate for placement at the micron level.

2.8 Stepper motor:

Since stepper motors can synchronize or align themselves with the output pulse from the controller to the driver, they are frequently employed for precise positioning and speed control. Stepper motors convert electrical energy into rotational motion. One can drive a stepper motor using either a constant current drive or a constant voltage drive. Torque becomes more difficult to obtain relative to greater speeds in constant voltage drive. Constant current drives, on the other hand, are practical and frequently utilized because they can easily provide torque even at greater speeds.

A stepper motor can be excited in three different ways: half-step, full-step, and micro-stepping. One can select the excitation mode by considering the torque and positional accuracy for a particular application. The stepper motor transforms following the application of the pulse. Stepper motor Section 21 in Figure 10 progressively. A 1.8-degree resolution stepper motor would require 200 pulses to complete one full rotation of a shaft.
A stepper motor's two main components are the stator and the rotor. The permanent magnet, rotor 1, and rotor 2 make up the remainder of the rotor assembly. Rotors are axially magnetized, thus if one is magnetized in the south, the next rotor will also be magnetized in that direction. Each pole winding is connected to the opposite pole winding in order to magnetize both poles

in the same direction as current flows through the winding. So, two poles make up a pair that is also known as a phase. A stepper motor can be single phase, 2-phase, or 5-phase depending on the kind. Small teeth surround each rotor, and as previously noted, these teeth are mechanically offset from one another. While resisting the south polarized teeth of rotor 2, phase A's south polarized poles will attract the north polarized teeth of rotor 2 when phase A is energized. The link between the rotor and stator will be revealed by the phase B poles' teeth becoming out of alignment with rotor 2's teeth, which are polarized south by an offset angle.

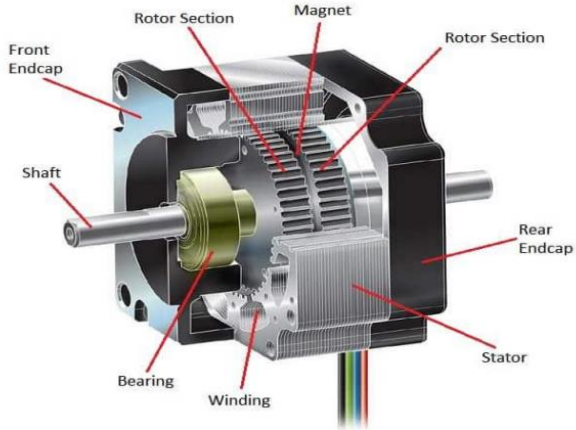


Figure 11:Stepper Motor

2.8.1 Speed-torque:

These characteristics are indicated by the type of driver and motor. Maximum holding torque indicates the maximum torque when the motor is not in rotation Pullout torque indicate the maximum torque that can be achieved at a given speed Maximum starting frequency indicates the maximum pulse speed at which the motor can stop or start instantaneously provided it doesn't accelerate or decelerate, assuming zero friction and inertial loads.

2.8.2 Maximum response frequency:

When motor gradually accelerates or decelerates, it indicates the maximum pulse speed.

2.8.3 Inertial load – starting frequency characteristics:

Stepper motors (having inertia) have incorporate certain lags or advances during instant actuation or when the motor stops, and these characteristics show the changes in initial frequency subjected to inertial load.

2.8.4 Vibration characteristics:

These characteristics indicate the rotation of motor when a pulse is applied and it accelerates, or when it is about to stop, it overshoots the angle.

2.9 DAQ

DAQ is categorized into three units

1. Sensors
2. Conditioning unit
3. DAQ NI Card/module

2.9.1 Sensor:

An instrument that detects a physical quantity and converts its value to an electrical signal is referred to as a sensor (also known as a transducer). We had a linear variable in our situation differential transducer (LVDT), which adjusts electrical voltage in response to physical variations in length. The term length gauge also applies to LVDT. Our crankshaft inspection machine's principal sensor was chosen to be the Solartron LVDT model AT/5/p, which has a resolution of 0.5 m and a repeatability of 0.05 m.

Figure 12:Linear Variable Differential Transformer

2.9.2 Conditioning Unit:

In a data collection system, a conditioning unit's goal is to clean up, enhance, or attenuate the noisy signal originating from the system's installed sensors. The signal that the sensor produces after taking a physical measurement is typically quite noisy as a result of interference from electrical, optical, or mechanical sources. In other cases, like in our situation, the sensor's output signal is minuscule in comparison to the physical quantity. A conditioning unit is therefore employed to enhance and clean the signal in order to overcome both issues. A boxed in-line conditioning module (BICM), which operates on a bipolar DC supply of approximately 15 volts, is the conditioning unit used with our sensor. An LVDT sensor for calibration is included with the BICM.

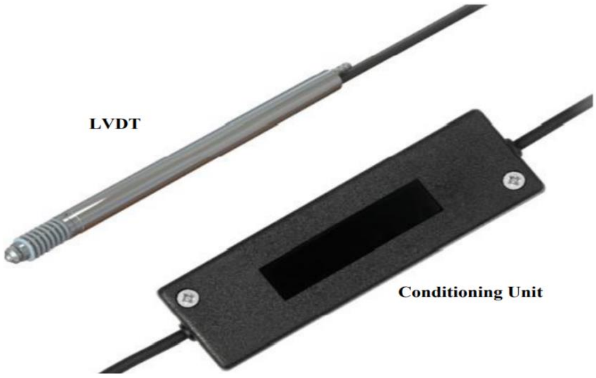


Figure 13: LVDT & Conditioning Unit

2.10 DAQ NI Card/Module:

The employed NI USB-6009 is cost effective and have variety of functions that provides basic input and output, digital input and output. To analyze data from the sensor signals, programming environment is needed. In this case LABVIEW is employed and through USB Card is connected to the computer.

Card specifications are listed in Table 1;

Table 10: DAQ NI 6009 Specifications

Description	Numbers	Bit	Frequency
Analog Input	8	14	48 Hz
Analog Output	2	-	150 H
Digital Input	8	14	1 MHz
Digital Output	8	14	1MHz

Card is powered by the USB Connection for Data acquisition and control applications. This device incorporates software drivers and APIs for LABVIEW, C/C^{++} etc.

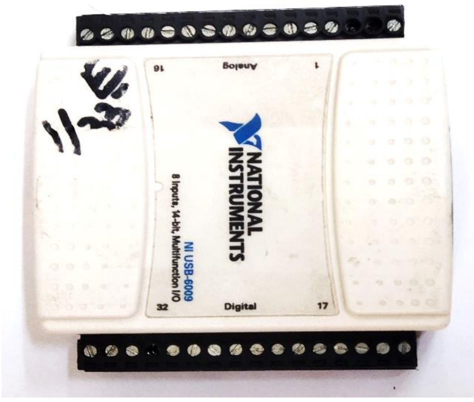


Figure 14: DAQ NI 6009

2.11 Stepper driver:

It is basically an electronic device that employed to control the stepper motor speed, direction, and motion. To control the motion of a stepper it is a basic need. What it can be done? Basically, it is accountable for the transfiguring the digital signal from controller (i.e. DAQ NI Card / Arduino) into series of suitable signals that will drive stepper motor to move.

2.11.1 Key Feature of Stepper Driver:

Stepper driver have many key features are listed below.

Table 11: Key Features of Stepper motor driver

Features	Description
Micro stepping	Allows to move in smaller increments, which leads to smoother motion
Current Control	Controls current to prevent overheating and damage
Direction Control	Can change the direction of motor

Chapter #3
Methodology

In this chapter, design requirements/parameters and selection criteria of different components and reasoning for selected parts have been discussed in detail.

3.1 Design Approach:

Piston and manufacturing drawing where all dimensions and their respective tolerances were mentioned is provided at the start of project.
The design goals are follows:

1.Design a machine such that it is able to measure the diameter of piston skirt.
- Piston profile
- Piston diameter

2.Dimensional constraints must be kept in mind for the accuracy.
3. Machine is Easily scalable for some variations in length of piston.
4. Diameter measurement has an accuracy of 1 micron.
5. Diameter reading is taken at 90-degrees to the pin axis.
6. Take measurements through the length of skirt (90 degrees to pin axis).

The measurement assembly is mounted over base plate with table. This structure is supported by an electric slider. These sliders are high precision and high accuracy. U-Shaped or v-shaped blocks are designed to hold the work piece in cylindrical form for inspection. So, placed the piston on the u-shaped block and pin ensures it constrain its axial movement as well as angular movement. The thrust axis is now freely available for inspection. LVDT sensor is used for inspection and DAQ also been analyzed to acquire data. LVDT hold by the shaft holder of respective diameter.

The detailed description of designed method and installation of machine will be discussed in this chapter.

3.1.1 Parameters under consideration:

As mentioned in earlier section piston is under consideration. Following design parameters are mentioned in the manufacturing drawings of the piston.

3.2 Piston Skirt:

The diameter of piston skirt varies along the length. As per manufacturing design variations in diameters are very small with the specified tolerances. The major diameter of piston skirt is 101.010 mm with tolerance ±0.020 mm. There are also some variations in the tolerances mentioned in the manufacturing drawing of piston.

3.3 Piston pin:

The diameter of pin hole of piston is specified at 34.834 mm. The specified tolerance for the pin is based on the slide fit with the piston which is 34.809-34.825 mm or deviation is 0 to -19 µm. This designing tolerance is acquired according to ISO system of fits and tolerances. The length of piston pin is 110 mm.

3.3.1 Accuracy and repeatability of measurement:

The above-mentioned tolerances are of order 10^{-3}mm. This shows that the measuring instrument be of sub-micron resolution and has repeatability of same order.

3.4 Selected Components:

This section goes into detail on the components chosen for local or international market purchases. Also, each part's selection criteria are described.

3.4.1 Linear Electric Slider:

Electric linear sliders of the ball screw type are frequently employed in the logistics, automation, and precision manufacturing sectors. International vendors offer a range of precision ratings. The current design demands positional repeatability and micron level accuracy ratings. HS100 electric slider is used. The stroke length is 800mm. It is a high precision slider with load carrying capacities given as:

Table 12: Linear Electric slider properties.

Load Description	Load Capacities
Vertical Loading	80kg
Horizontal Loading	40kg
Ball screw Pitch	5mm
Positional repeatability	0.020mm (20micron)
Ball Screw accuracy	C7
Max moving speed	250mm/s

Figure 15: Linear Electric Slider

3.4.2 LVDT:

LVDTs are extremely precise tools with very specific applications. Although the LVDT market is relatively diversified, there are few possibilities for very accurate, highly repeatable, and precise LVDTs. Metrology with SOLARTRON is the best choice. Their LVDTs are repeatable and accurate to sub-micron levels. Omron and The Connectivity are additional key rivals. Yet they fall short of SOLARTRON in terms of resolution and precision. Moreover, the needed measurement range is not available with the same resolution and accuracy. SOLARTRON metrology's **AT/5/P LVDT** probe has been chosen. It is a feather touch probe with spring push and pneumatic push as two possibilities.

Figure 16: AT/5/P LVDT

Other specifications

Some other specifications are listed in Table 4.

Table 13: Specifications of LVDT

Description	Specification
Signal type	Analogue
Body Diameter	φ9.5mm
Body Length	96mm
Measurement range	±5mm
Accuracy	0.25µm or 0.50% of reading (whichever is greater)
Max Repeatability	0.1µm (0.05µm typical).

3.4.3 Selection of sensor tip:

This component selection is most important for profile measurement of piston skirt. In this case there is need of point contact between the piston skirt and the sensor tip or head but there is need of point contact must be at the Centre line of piston skirt or major diameter line (i.e. the contact point is must be 90 degrees to pin axis).

Figure 17: Sensor Head

For this reason, the selection of sensor tip has too much importance. The selection is totally based on contact between solid surfaces. So, the sensor head is decided in form of semi-cylindrical shape and inserted in the front of LVDT sensor.

3.4.4 Stepper motor:

Stepper motor is used to operate the electric slider as it runs in the steps according to our requirement, 4 wire stepper motor is used to operate the system, because as it revolves the lead screw the holder portion having sensor translates in the direction parallel to the skirt axis. Because of this reason we need a stepper motor to operate the whole system.

Figure 18: Stepper Motor

3.4.5 Sensor Holder:

Sensor is the cylindrical form with diameter 9.5 mm so purchased the shaft holder with diameter 10mm (SK10mm).

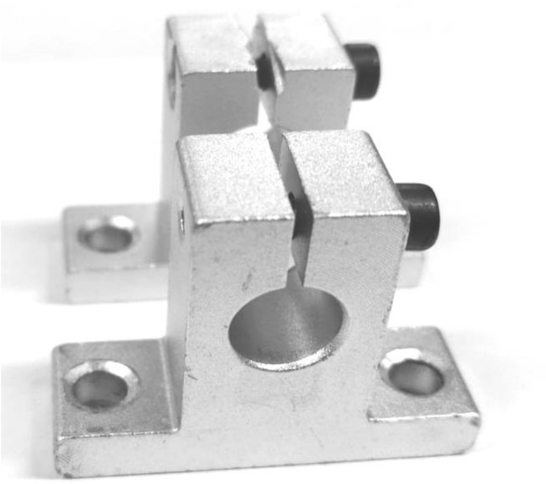


Figure 19: Sensor Holder

3.4.6 DAQ NI Card 6009:

Now move towards the data acquisition, that can be done by employing the DAQ NI 6009, The electrical signal initiated by the sensor and conditioning unit transfigure to the digital one which can easily read by the computer or system. The signals are basically converted from analog to digital because DAQ Card or module have built-in analog to the digital converter, so the analog signals like current, voltage is converted to the digital signal. The employed NI USB-6009 is cost effective and have variety of functions that provides basic input and output, digital input and output. To analyze data from the sensor signals, programming environment is needed. In this case LABVIEW is employed and through USB Card is connected to the computer.

Card specifications are listed in Table 5.

Table 14: DAQ NI 6009 Specifications

Description	Numbers	Bit	Frequency
Analog Input	8	14	48 Hz
Analog Output	2	-	150 H
Digital Input	8	14	1 MHz
Digital Output	8	14	1MHz

Card is powered by the USB Connection for Data acquisition and control applications. This device incorporates software drivers and APIs for LABVIEW, C/C^{++} etc.

Figure 20: DAQ NI 6009

3.4.7 Stepper Driver TB6600:

According to the variety of features and performance, a lot of stepper drivers are available in market. But there is need to be select the right one. So, question raised which parameters must kept under consideration for the right selection of Stepper driver?

Following are the factors that depend:

- Required Torque
- Speed
- Precision
- Available power Supply
- Control Circuitry

TB6600 is a stepper motor driver to control the motor in variety of applications. To control bipolar and unipolar stepper motor TB6600 is employed.it is operated on voltage 9V-42 V DC and provide 4.5 A current to each coil of motor.

Functions of TB6600 Stepper motor driver are follows;

Table 15: Functions of TB-6600

Function	Description
Micro stepping	It can handle the micro stepping, for smooth running and precise motion
Pulse	It controls pulse, that determines the step size and speed of motor
Direction	It controls the direction

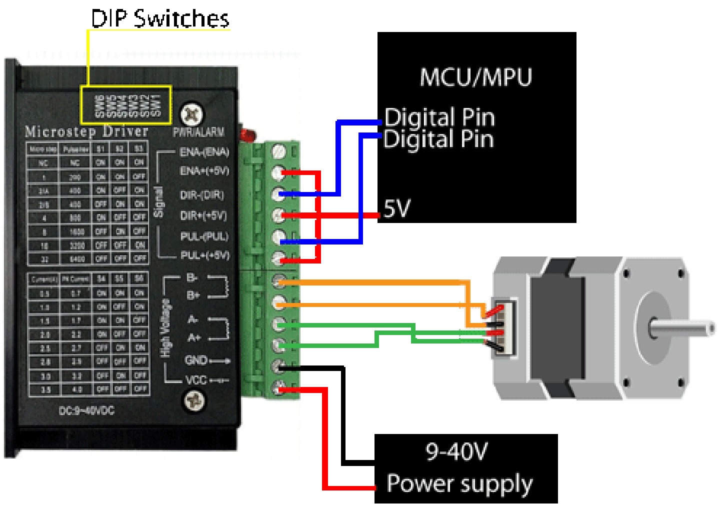


Figure 21: TB-6600 With Wiring Scheme

Specifications of TB6600

Following are the specifications listed below in the Table 7.

Table 16: Specifications of TB-6600

Specifications	Description
Input Current	0~5A
Output Current	0.5~4.0A
Control Signal	3.3~24V
Power (MAX)	160W
Micro Step	1, 2/A, 2/B, 4, 8, 16, 32
Temperature	-10～45℃

Chapter # 4
CAD-Designing

The design of manufactured components has also been discussed and final designs has been presented this chapter.

4.1 3D-Desisgn of manufactured parts/Components:

The remaining parts need to be manufactured with particular care after the carefully chosen components, keeping in mind that we have access to local vendors. These components cannot be transferred to foreign vendors for fabrication since the cost would multiply tenfold and the process would take a very long time. Hence, taking into mind the technological constraints of local suppliers/vendors, the parts have been designed to be manufactured here. The following components have been manufactured and put together/assembled to ensure that the machine operates properly:

- Base Plate
- U-Shape Block
- Piston Pin
- Circular Spacer
- Plate for sensor holding/mounting
- Calibrator
- Head for sensor or sensor tip

After this manufacturing the selected components and Purchased items need to assembled for the proper functioning of machine.

4.1.1 Base Plate:

Base plate is 12 mm thick and have 3 sets of holes

Table 8: Base Plate Properties

Description	Specification	Quantity
Bench mounting holes	M6 through	8
Electric slider holes	M5 through	10
U-block Mounting Hole	M8 through	2

4.1.2 U-Shaped block:

This component is the backbone of the machine, so it has too much importance for this technique. So, during designing must keep in mind its designing parameters importance and the critical parameters need to be accurate. Material used: Mild steel.

Why and Which parameters are important?

The design of u-shaped block has its own importance, actually this block is designed to hold the piston for the testing or inspection of ovality of skirt. Basically, we need to hold the piston in such a way that is piston skirt is completely free so LVDT can easily touch its skirt surface during translating the sensor, which results in the form of skirt profile. But during designing the issue faced is that how to ensure the pin allows the piston to sit on u-block, means to ensure the Centre of u-block and pin are 100% aligned. This is the main parameter of block designing. This can be easily done by Highly accurate CNC Milling machine, but for this case we can't have access to that highly accurate machine. So apart from the 3d model of block, during manufacturing using two ways firstly slot or u-shape block is machined by manual milling and go for the CNC work for Centre hole for the piston pin which ensures the pin and piston hole Center is aligned.

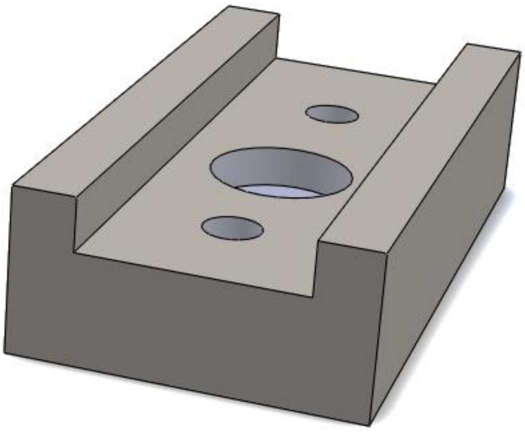


Figure 22: U-Shaped Block

4.1.3 Piston Pin:

There is need to design and manufacture a pin for piston to hold it properly and limits its axial movement. when piston is placed on the u-shaped block and pin ensures it to constrain its axial movement as well as angular movement. The thrust axis is now freely available for inspection.

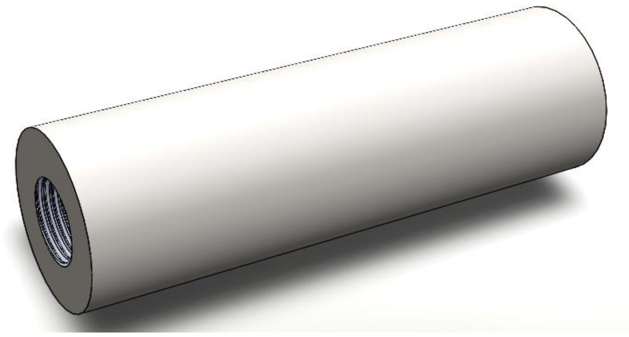


Figure 23: Piston Pin

Material Used: Stainless steel (To prevent it from rusting). One thing we need to consider during the designing of piston pin, it must be the slide fit to the hole of piston according to the ISO standards of fits and tolerances.

4.1.4 Circular Spacer:

Circular spacer is used at the base of u-shaped block to move up or hold up from base plate to make sure the contact between the sensor head and skirt of piston is near to the Centre line of skirt or major diametrical line. Material used: Mild Steel.

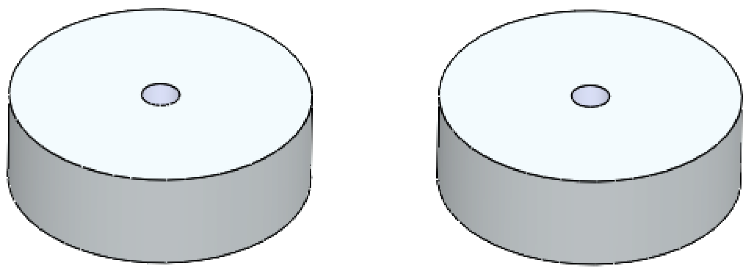


Figure 22: Circular Spacer

4.1.5 Head of Sensor/Sensor Tip:

As discussed in previous section the necessity of the head of sensor in semi-cylindrical shape is discussed, so for this reason it is designed and manufactured. Material used: Stainless steel.

Figure 23: Sensor Head

4.1.6 Plate for sensor holding/mounting:

Base plate is 10 mm thick and have 2 sets of holes. The material used is Mild Steel (MS)

Table 17: Sensor holding Plate specifications

Description	Specification	Quantity
Slider mounting holes	M6 through	6
Sensor holdings holes	M5 through	4

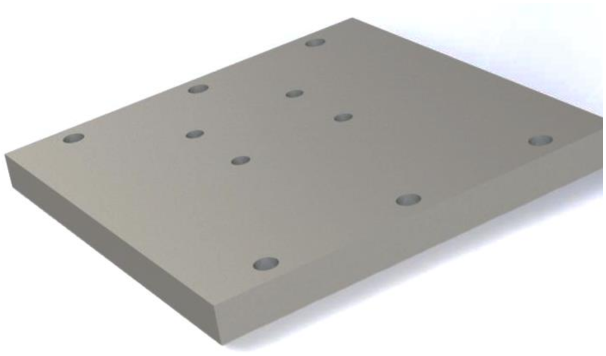


Figure 24: Plate for sensor holdings

4.1.7 Calibrator:

The process of calibrating an instrument involves setting it up such that it can produce results for samples that are within a reasonable range. A key component of instrumentation design is eliminating or reducing conditions that lead to faulty measurements. The manufacturing of calibrator is necessary for maximum possibility of assembling the parts in the reasonable range, because in this case the calibrator is simple circular cylinder of length same to the piston so when the sensor heads touches the circular cylinder of the straight line is acquired through the DAQ system and according to this the block is fixed on base plate.

Figure 25: Calibrator

Chapter # 5
Installation and Assembly

In this chapter, the purchased and manufactured components are installed and assembled to finalize the machine.

Assembly is categorized into 3 portions.

1. Sensor holdings Assembly
2. Block pin Assembly
3. Final Assembly

5.1 Sensor Holding Assembly:

Sensor holdings contains 3 parts.

- Plate base for sensor holder
- Sensor holder
- LVDT sensor

In this portion, Placed the sensor holder on the plate, then fix it. After this fit the sensor into the sensor holder as shown in the picture below.

Parameters under consideration:

- Ensure the distance between the sensor holders manually as much we can fix them properly.
- Plate on the electric slider is fixed, but ensure its accuracy as much decided by the CAD-Software.
- Fix the sensor head to LVDT by removing the initially probe head in the LVDT.

5.2 Block pin Assembly:

This assembly contains 3 parts.

- U-shaped Block
- Piston pin
- Circular Spacer

In this portion, Placed the circular spacer on the base plate in such a way that the distance from the Electric slider should maintain. After this place the u-shaped on the spacer and fix by using bolts. Now fix the pin into the specified hole at U-shaped Block.

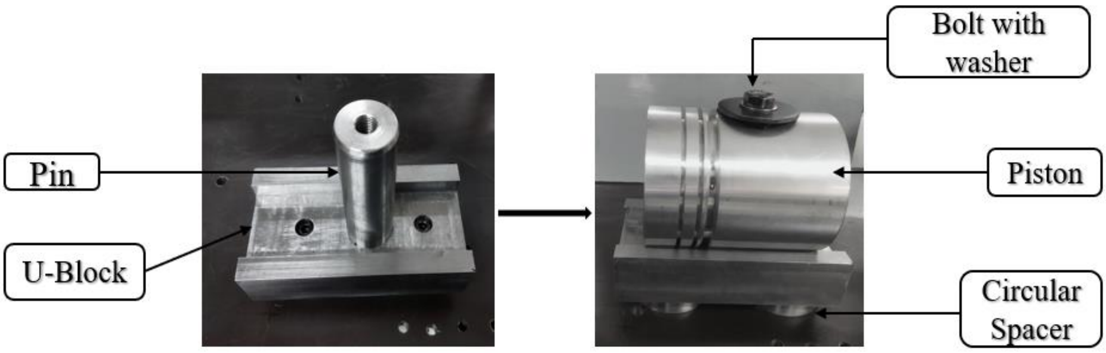


Figure 26: Pin Block Assembly

Parameters Under Consideration:

- Ensure the distance between the Electric slider and Block pin assembly must be specified as per requirement.
- Ensure the block is 180-deg to the slider.
- Align the block by using the Dial gauge.

Figure 27: Alignment of Block using dial gauge

5.3 Final Assembly:

In this portion, the final assembled machine is displayed which contains both block pin assembly, Sensor holdings Assembly, Wiring for Sensor (LVDT) and Wiring of Stepper motor through Tb6600 with the DAQ NI 6009.

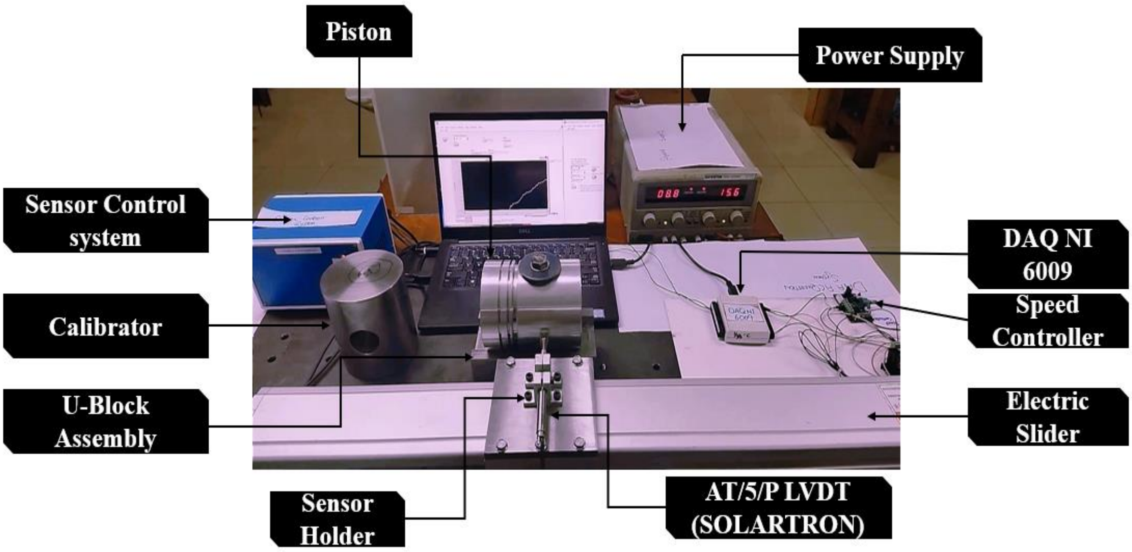


Figure 28: Piston Inspection Machine

Chapter #6
DATA Acquisition and LAB-VIEW coding

In this chapter, Data acquisition and LabVIEW programming for control of stepper motor is discussed. It includes two programs.

1) Data Acquisition
2) Stepper Motor control

6.1 Data Acquisition:

Data acquisition system consists of following units;

1) Sensor
2) Conditioning Unit
3) DAQ Card/Module

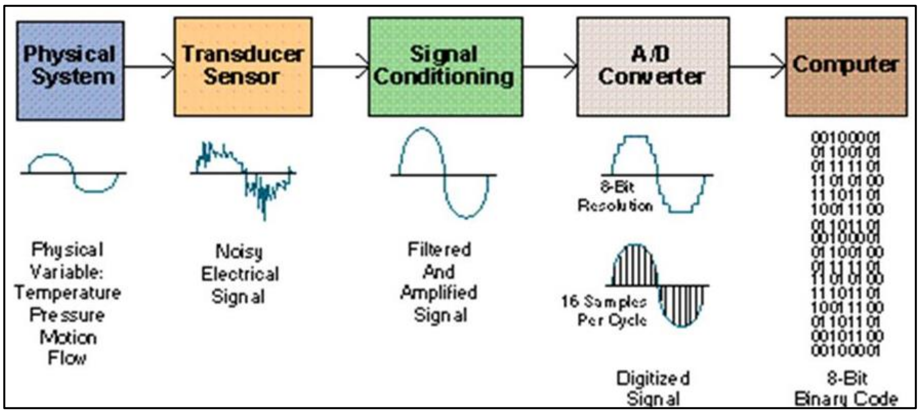


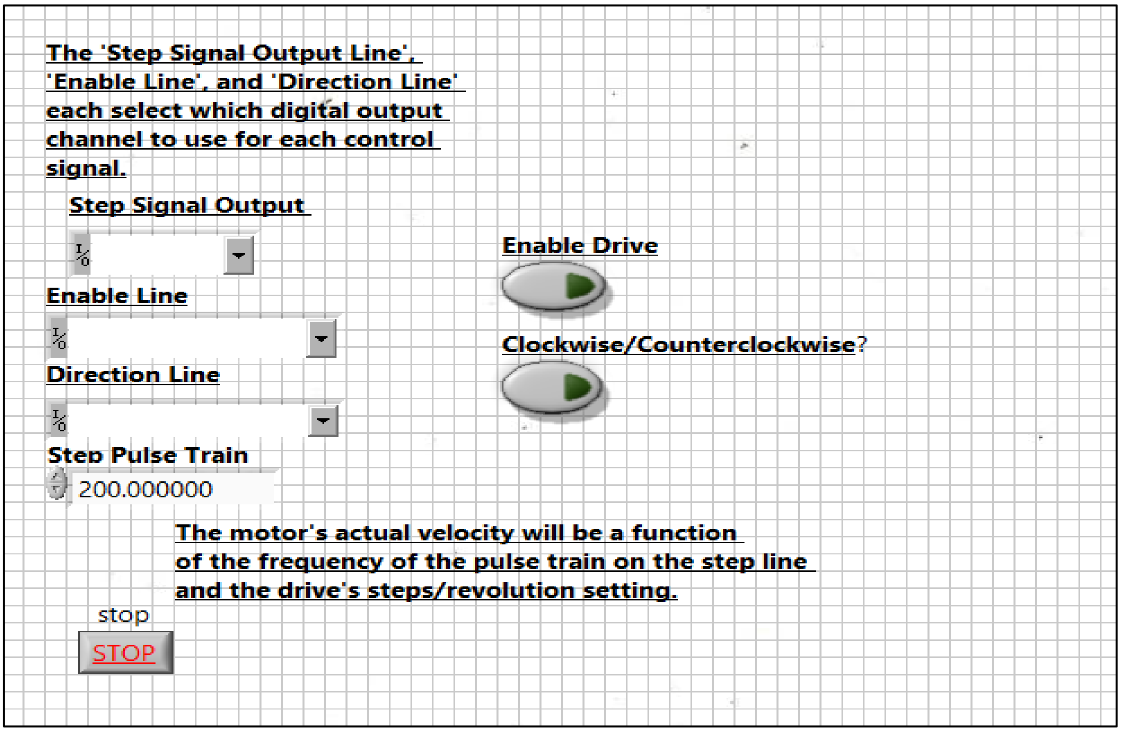
Figure 29: DAQ Process

6.1.1 LAB-VIEW:

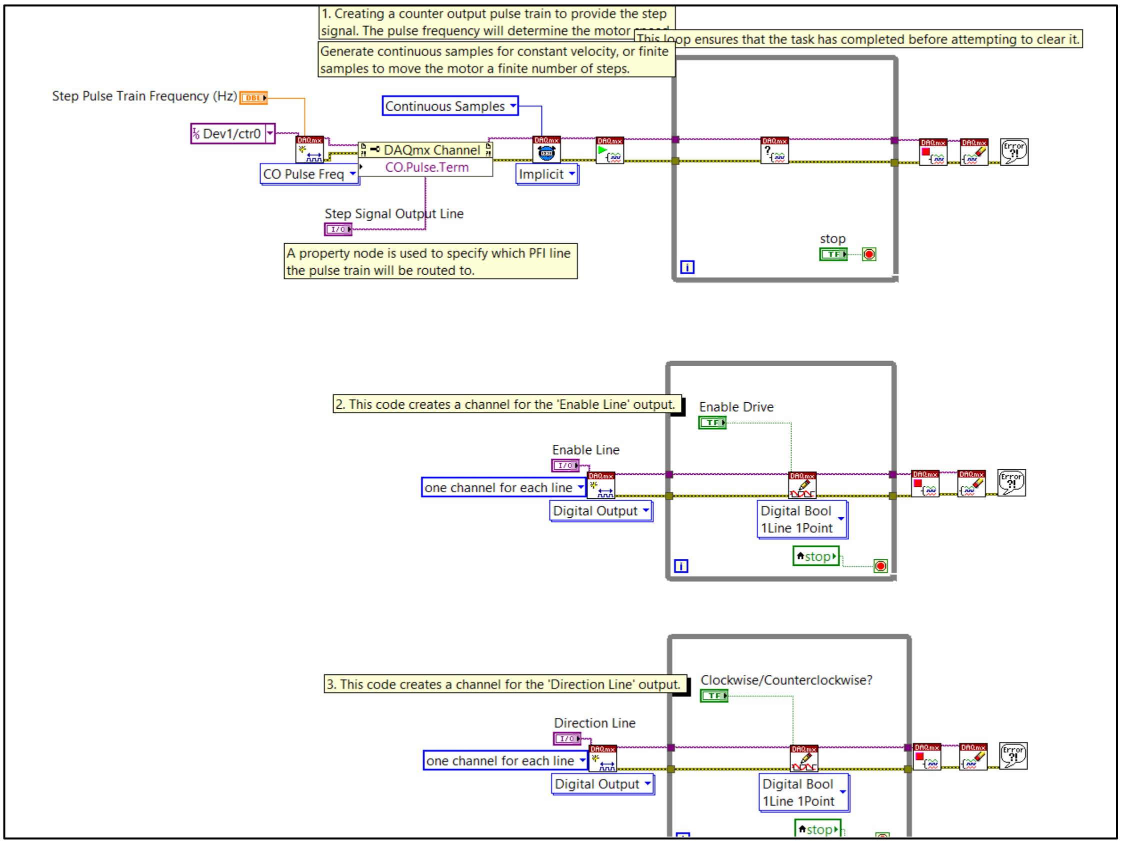
LabVIEW (short for Laboratory Virtual Instrument Engineering Workbench) is a system design and development platform developed by National Instruments that enables scientists and engineers to develop measurement and control systems through a graphical programming language. LabVIEW provides an intuitive and easy-to-use environment for creating virtual instruments, which are software representations of hardware devices used for data acquisition, analysis, and presentation. LabVIEW uses a graphical programming language called "G", where code is represented as a series of interconnected blocks, or nodes, that visually represent dataflow. This approach simplifies the development process and makes it easier for non-programmers to understand and create complex applications. LabVIEW is commonly used in a variety of applications, including industrial automation, academic research, and scientific experimentation.

6.2 Stepper Motor Control:

By using the Lab-view the program is generated to control the speed, On/Off and direction of the stepper motor. The front panel and Block diagram of the program is displayed below in the figure 30.



(a): Front Panel (Stepper Motor Control)

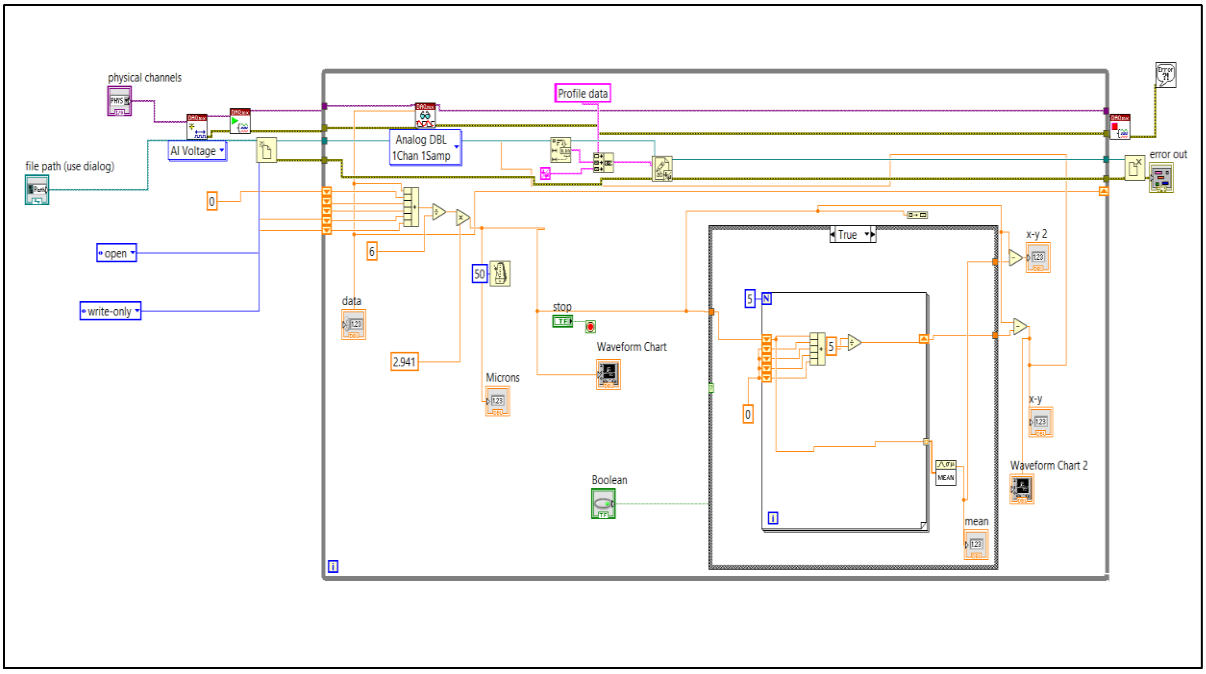


(b): Block Diagram (Stepper Motor Control)

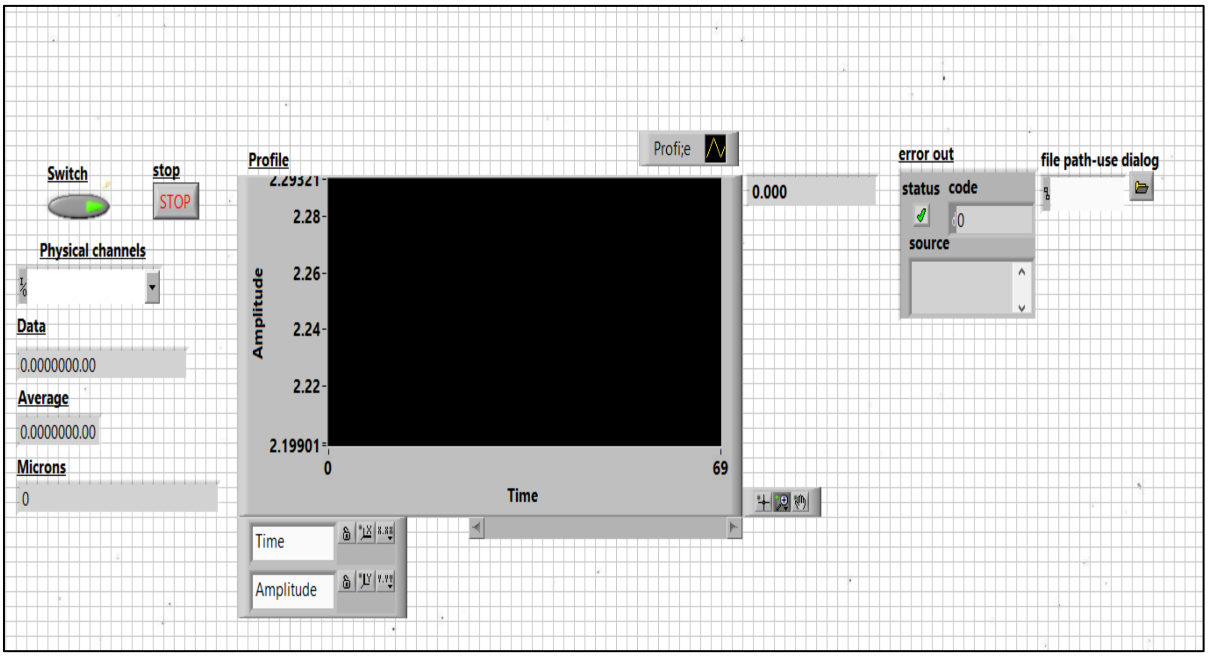
Figure 30 (a): Front Panel (Stepper Motor Control) (b): Block Diagram (Stepper Motor Control)

6.3 Data logger:

The next step is to acquire the incoming data from the LVDT sensor and analyze it for the results. Lab-view is employed to build a program to acquire data from sensor the block diagram of program is displayed below in the figure The Data acquired discussed in the next chapter.



(a): Front Panel (Data logger)



(b): Block Diagram (Data logger)

Figure 31 (a): Front Panel (Data logger) (b): Block Diagram (Data logger)

Chapter # 7
Results and Discussion

This chapter presents on overview of testing setup and test results. The OEM specified parameters and their tolerances are compared with the measurements taken by the machine. The results and performance of the machine is discussed.

7.1 Testing:

The test output is highly dependent upon the test design. It is necessary to ensure that design intent and the user needs are aligned. This process involves following steps:

7.1.1 Design Verification:

Design verification means that the product performs as intended by the designer. For example, the inspection machine is designed such that it measures the diameter. The accuracy and repeatability should be less than or equal to 0.015mm. If the results cannot be verified, the design process is iterated until the design is verified.

7.1.2 Design Validation:

A successful design verification is followed by design validation. Design validation is further evaluation of verified results. It ensures that the customer needs are met successfully. If design cannot be validated, the test controls are varied until an agreement is made between validation and verification. If the design is still not validated, then the design process is reiterated until the verification and validation are successful.

7.1.3 Test design:

For the design of test for piston inspection machine, the accuracy and repeatability are of most importance. The test should run repeatedly and the results should still remain same. For current test of piston, it is hold in the U-block, then sensor translates parallel to piston skirt and sensor head touches the piston skirt while translating. The final step is to save the data acquired from the sensor.

7.1.4 LabVIEW Block Diagram AND Front Panel:

As shown in the figure, the individual probe readings (mV) are amplified by multiplying with the sensitivity/gain and the variation of these readings are added together with the nominal diameter value

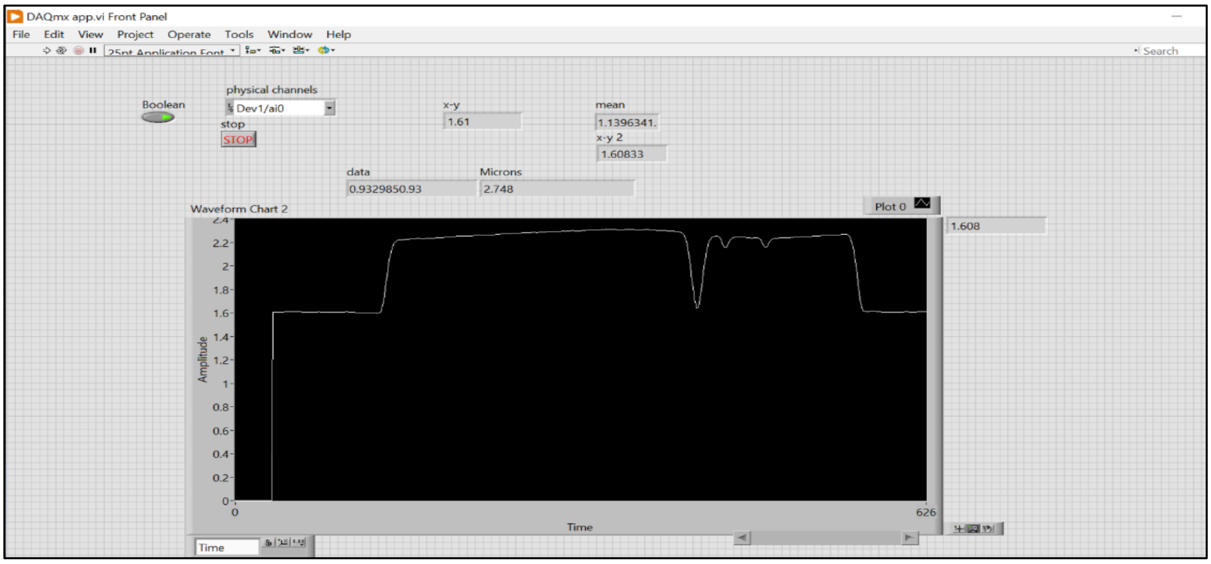


Figure 32: Piston inspection results

Acquired Results:

Firstly, Tested the Calibrator that is a cylindrical shape to ensure how much accurate the installed setup is, because when we aligned the U-block that might not be 100% aligned, so to check the systematic error firstly the calibrator is tested and attained the following results. The test for Calibrator done 3 times on base of repeatability to reduce error and plot the average to achieve maximum accuracy. The results for the calibrator displayed in the figure 33. Here in graph it clearly shows that there was 15 microns difference in the profile of the calibrator, that shows the systematic error but this difference has 2 factors.

1. Calibrator is not properly machined like through CNC Lathe
2. The U-Block is not perfectly 100% aligned which is because of the outer surface of block is not 100% machined.

After the calibrator results, the piston outcome will be discussed below.

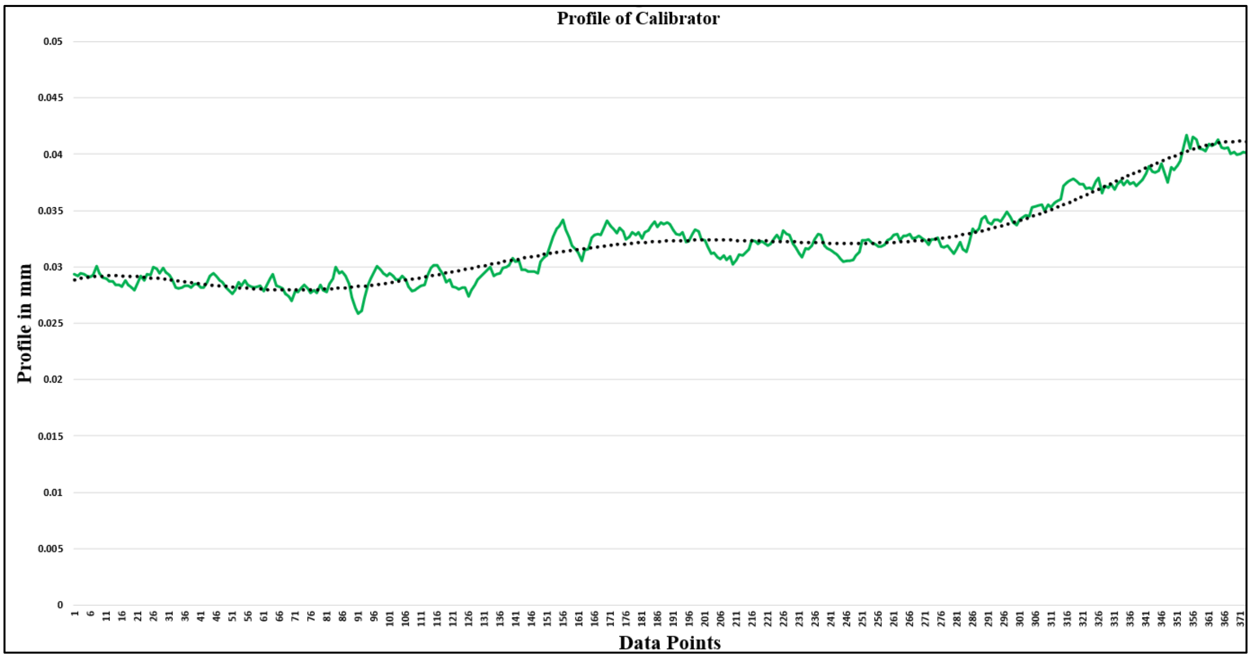


Figure 33: Piston skirt Results

Piston Outcomes

Piton is tested 2 times throughout its length and 2 times only skirt length is being tested, and then analyze the results. Following are the results for piston skirt diameter and profile displayed in the figure 34.

- Series 1 shows the 1st test of piston
- Series 2 shows the 2nd test of piston

The graph shows how piston profile changes as the sensor moves the changes are in microns.

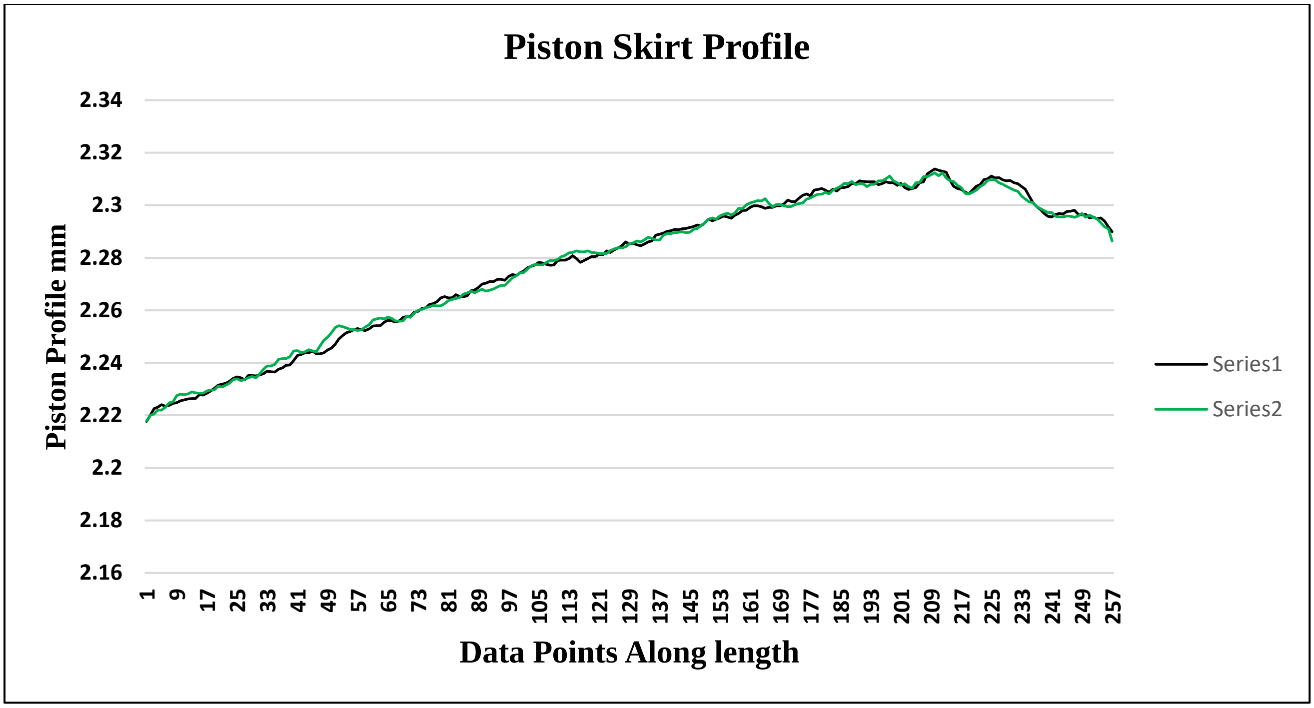
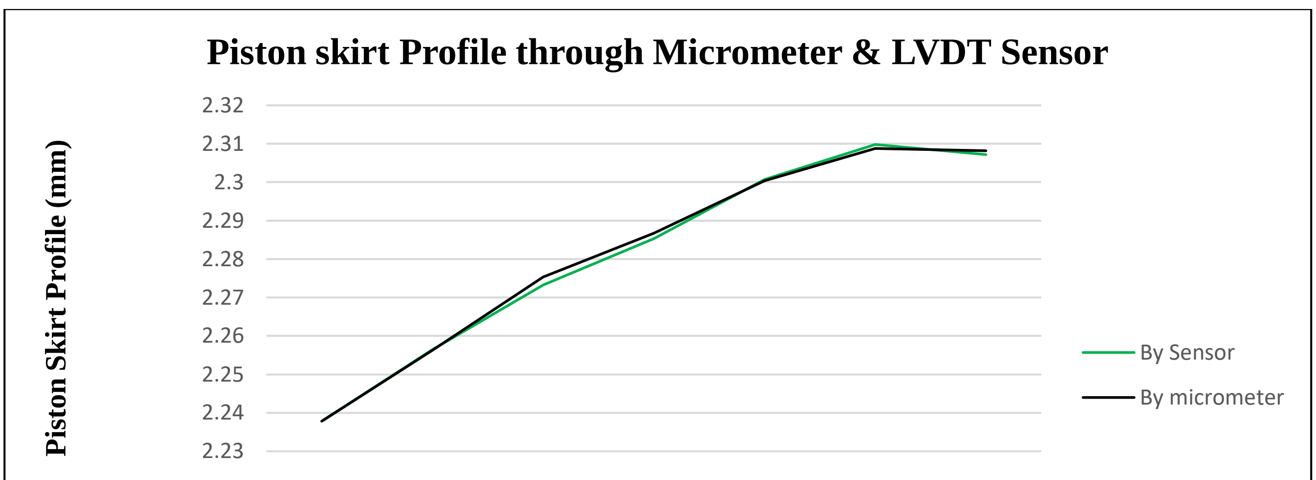


Figure 34: Profile of piston

Results through micrometer and LVDT Sensor:

The readings were taken at each centimeter throughout the piston skirt length and then compared with the results taken from LVDT sensor as shown in a figure35. This graph shows the actual profile of piston and profile behaviour how it was changing along the skirt's length.



	1	2	3	4	5	6	7
By Sensor	2.237823	2.256432	2.273216	2.285348	2.300673	2.309794	2.307149
By micrometer	2.237823	2.256323	2.275323	2.286723	2.300323	2.308764	2.308147

Figure 35: Piston skirt Profile through Micrometer & LVDT Sensor

Factors Under consideration During testing:

Following are the factors that must keep in mind when testing is carried out

1. Test must be done at the low speed to get more data points that leads to more accuracy.
2. Starting point must be the base of skirt.
3. Save the data acquired from sensor in text file.

Diameter results through Sensor and Micrometer:

The diameter at each centimeter along the length of piston skirt displayed in the Table 10.

Table 18: Comparison of results.

Data Points	Diameter measured through LVDT	Diameter measured through micrometer
0 cm	100.385 mm	100.385 mm
1 cm	100.930 mm	100.930 mm
2 cm	101.013 mm	101.015 mm
3 cm	101.979 mm	100.980 mm
4 cm	100.935 mm	100.935 mm
5 cm	100.921 mm	100.920 mm
6 cm	100.449 mm	100.450 mm

According to the results at 2cm the maximum diameter of piston is obtained which is perpendicular to pin axis or 90-deg to pin axis major diameter occurred.

Chapter# 8
Conclusion and Recommendations

This chapter contains a comprehensive conclusion drawn from the result. Recommendations about the future projects of similar nature and improvement that can be done in this machine will also be mentioned.

8.1 Conclusion

After countless design iterations and testing, a working Piston inspection machine wasdeveloped and assembled. The parts selected and manufactured for the piston inspection machine performed exceptionally. Data acquisition system was challenging to develop but it gave clean output signal and worked fine. Multiple readings were taken but the same output was obtained. The data was collected and output remained same depicting the industrial grade durability and the repeatability of the machine. The machine was tested to check any discrepancies in its output and there was none. Overall,the project was a success yet as for every other project, room for improved remains.

8.1.1 Recommendations

8.1.2 Functional Improvements

The following improvements are proposed for future iterations of the prototype:

- This prototype provides a groundwork for many products for automotive OEM. It can be scaled to full scale industrial product. The modular nature allows easier retro-fitting for the previously mentioned measurements.

- The machine can be automated for industrial use, increasing the productivity.

8.1.3 Design Improvements

Following design improvements are suggested for future iterations of the prototype:

- The U-Block can be improved to be more accurate and the results may improve towards more and more accuracy.

- Many design improvements in holding piston needed and improve thr results towards more accuracy.

Chapter# 9
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