To develop a technique to measure the diameter of crankshaft journal using three point contact.

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Masters Research Report

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NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment of the Requirements for the Degree of Masters of Mechanical Engineering

By

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july , 2023

FORM TH-4

National University of Sciences & Technology

MASTER THESIS WORK

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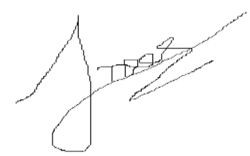

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Acknowledgment

First of all, I am grateful to Allah almighty for blessing us with the motivation and persistence to complete this research project. I am also very thankful to our parents and family for their continued support throughout this project, and we are very thankful to the administration and staff of school of mechanical and manufacturing engineering for given us the opportunity to learn.

We are also thankful to our project supervisor Dr. Riaz Ahmad Mufti and co-supervisor Dr. Jawad Aslam for their continuous technical and moral support towards us over the course of the project. Their motivating behavior and patient attitude enabled us to learn more eagerly. The respect they showed to us was a lesson that we learnt and intend to reflect it at our workplaces and towards our juniors.

Abstract

The purpose of this project is to design and manufacture the crankshaft inspection machine. This machine will be able to measure the diameter of crankshaft journal using three-point contact for both 3 cylinder and 4 cylinders. The measurement is done using three LVDT sensors with an accuracy of +_1 micron which are pointed towards the center of the crankshaft journal. The sensors are attached with the C type block mechanism that takes the readings over defined intervals. Two centers, Head stock and pneumatic tail stock are used to hold the crankshaft in place while inspection. Sensors are stationary and the crankshaft rotates by the means of stepper motor attached via belt. Three-point measurement is done by calculating the coordinates of all three points and then by using the least square approximation method, the radii is calculated by simultaneously solving the circle equations. The accuracy and precision is specified by the drawings provided by OEM. The design is optimized to take readings for the journals in such a way that radial alignments of probes become irrelevant. It is mainly due to innovative arrangement that allows point contact to the journal surface and has not been seen in precision measurement industry.

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Chapter 1

Introduction

1.1 Crank shaft and its main parts

A crankshaft is a mechanical part of an engine that converts the reciprocating motion of the piston into rotary motion. The crankshaft has a set of crankpins which are offset from each other along the axis of the shaft. Every crankpin is connected to the connecting rod which in turn connected to the piston. As the piston moves up and down, it pushes and pull the connecting rod and as a result, crankshaft rotates. This rotational motion is then used to power the vehicle or machines. The main parts of crankshaft are

- Crankshaft journal
- Crankpin
- Main bearing
- Counter weights
- Oil passages

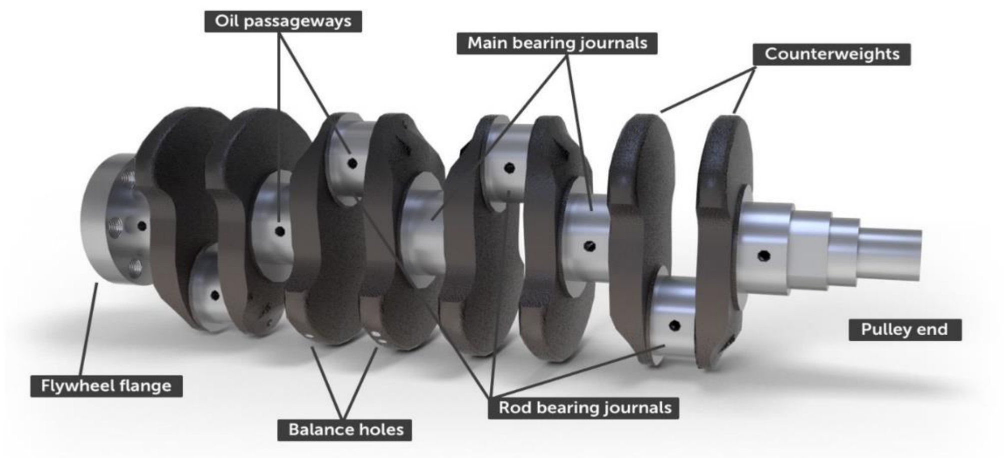


Figure 1 Crank shaft and its main parts

1.2 Motivation and background

As the major part of an automobile engine, the diameter of crankshaft journal have a direct impact on the engine parts, precision of fit, running noise and vibration. Therefore it is crucial to identify crankshaft journal errors.

There are few techniques available in international market to measure the diameter of crankshaft journal. The most accurate one is through CMM which can cost from 32000$ to 120000$ depending upon the nature of measurement. We intend to bring the advancement of measuring the diameter of crankshaft in Pakistan rather than sending crankshaft to international market for the inspection. Our motive is to design and fabricate a prototype technique to measure the diameter of crankshaft journal that can be able to do precise measurement. The wear and tear can be improved inside the engine as crankshaft is subjected to high dynamic loading, if the desired dimensions are achieved.

A crankshaft's precision is essential to an engine's functionality, toughness, and dependability. Precision machining techniques enable extremely high levels of accuracy and consistency, and modern manufacturing processes and quality control procedures guarantee that crankshafts are built to very tight tolerances.

Straightness, roundness, and surface finish are all aspects of accuracy. Any deviation from straightness might result in imbalance and vibration, thus the crankshaft must be straight and devoid of bends or twists. The crankshaft's roundness is also crucial since any irregularity can result in more friction and bearing wear. Finally, the journals' surface finish needs to be flawless and free of flaws because any roughness or flaws can increase friction and wear on the bearings.

1.3 Problem statement

The task is to develop a technique to measure the diameter of crankshaft journal using three point contact. We can able to measure the diameter of both 3-cylinder and 4-cylinder engine. We will be measuring the diameter of crankshaft with an accuracy of +-1 microns.

1.4 Objectives

The main objectives are

- Making the prototype that can be able to measure the diameter of crank shaft journal using three-point contact.
- The prototype can able to measure the diameter of both 3-cylinder and 4-cylinder crankshaft with an accuracy within 1 micron
- Making a prototype unique, durable, economical and easy to use.

1.4.1 Deliverables

- CAD model of the prototype
- Manufacturing and fabrication of prototype.
- Signal processing using LAB VEIW
- Diameter measurement readings of crankshaft journal.

Chapter 2

Literature review

In this chapter we will study different techniques that are available in the market for measuring the diameter of crankshaft and selection criteria and comparison with the technique which we have made.

2.1 Purpose and functioning of crankshaft

crankshaft is a critical component of any internal combustion engine. It enables the engine to produce power by converting linear motion into rotational motion. Additionally, the crankshaft has counterweights to balance the rotating assembly's weight and lessen vibrations. The main bearing and rod bearings on the crankshaft also support the spinning assembly and lessen friction.

Connecting rods, pistons, and the crankshaft itself make up the crank mechanism. The crankshaft's secondary function is to distribute power to various engine parts, such as the oil pump, air conditioning compressor, alternator, valve timing, and so on. The crankshaft is held in place by the main bearings, which also make sure that it revolves freely inside the engine block. Piston connecting rods are fastened to the pin journals, also referred to as conrod journals. To compensate for external moments, reduce internal moments, reduce bearing loads, and reduce vibration amplitudes, counterweights are placed on the opposing sides of pin journals.

2.2 Techniques to measure roundness/ diameter of crankshaft

In essence, roundness is a measurement of how closely a part's particular geometry resembles a mathematically perfect circle. Roundness is measured or inspected using rotational procedures by measuring radial deviations from a fixed rotating datum (reference). To assess roundness, one needs a datum as a reference. To fully evaluate a roundness profile, there are a variety of measures, such as run-out measurement, diameter measurement, cylindricity measurement, etc. Any roundness parameter measurement method primarily uses two approaches. Either the transducer or sensor is fixed while the crankshaft is rotated, or the sensor is rotated to measure the fixed crankshaft.

There are various methods for measuring a crankshaft's diameter, depending on the degree of precision needed and available equipment's. Here are a few typical methods.

2.2.1 Measurement through guage/One point method

To measure the diameter of crankshaft using micrometer is an old method although it is being used in many places. It is one point method. In this technique, the object is rotated around its axis while the sensor is kept still. Runout is the name of this measurement. By using this method, the diameter cannot be estimated. Additionally, this approach is unable to distinguish between profile measurements and spindle errors.

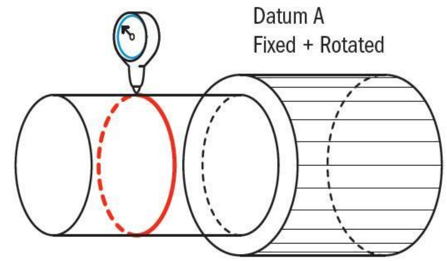


Figure 2 One point method to measure the diameter

2.2.2Optical measurement system

An optical measurement system takes photos of the crankshaft and measures its dimensions using high-resolution cameras and sophisticated software. The diameter and other dimensions of the crankshaft can be measured with high accuracy using this non-contact method.

Dual Camera Measurement System:

Telecentric vision systems and pinhole vision systems are the two most popular types for two-dimensional machine vision measuring systems. The object's image size remains constant inside the depth of field because of the unique mechanical construction of the telecentric lens, and as a result, the measurement precision of the telecentric vision system typically reaches the micron level .However, in the telecentric vision measurement system, only light that is perpendicular to the primary optical axis can be photosensitive. As a result, the telecentric vision system's field of view is smaller than that of a pinhole camera.

Figure depicts the large-scale precision measurement method suggested in this paper. Two high-resolution CCD cameras, two telecentric lenses, and two double telecentric lenses make up this system.

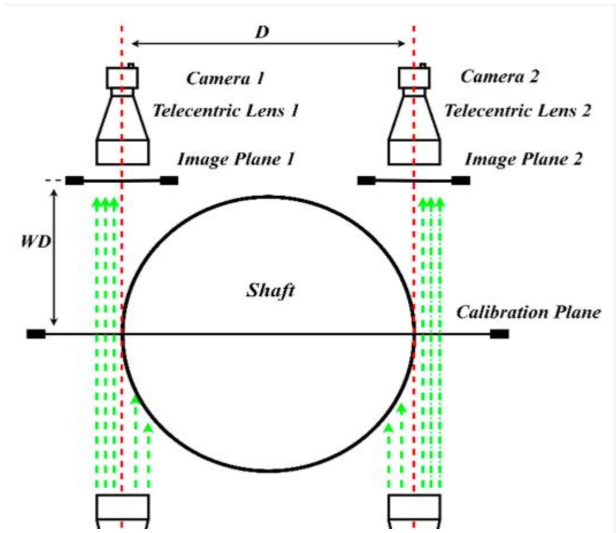


Figure 3 Measurement of diameter using optical system

2.2.3Two point method

Using two probes, this technique measures an angle at one of two places on a cylindrical workpiece as well as displacements at the other two sites. The spindle error is eliminated by the differential output of the probes, and the correct roundness error is produced by deconvolution of the differential data. This technique is mostly used to measure cylinder diameters. Both probes are simultaneously pushed outward when one moves in. We can calculate the diameter by summing the displacements of the two probes and using the correct calibration. Each rotation of the workpiece results in the production of two diameter values.

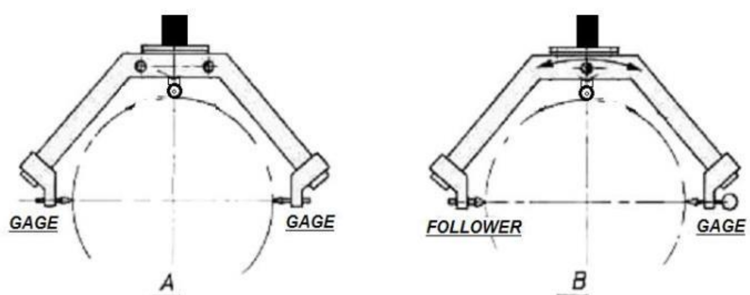


Figure 4 Modified saddle-type roll calipers for two-point measurement. A) With fixed arms. B) With swing arms

2.2.4 Three-Point Method:

The three-point method is the most common method for measuring the roundness profile of a rotating machined workpiece accurately. In this method, three LVDT probes are employed around the workpiece to simultaneously detect the roundness profile as well as the two-dimensional spindle error components. With the help of calculations, spindle errors can be canceled in the output of the probes and the correct roundness profile is generated from the data. The basic Three-point method could be further classified into three types:

1. Sequential three-point method
2. Generalized three-point method
3. Combined three-point method

2.2.4.1 Sequential three-point method

For sequential three-point method, the probe interval and sampling period are equal. It can measure a discrete roundness profile without data processing errors. However, due to the lesser number of data points it cannot express stepwise variations of the profile accurately.

2.2.4.2 Generalized three-point method

The generalized three-point method has a sampling period far shorter than the probe interval and it yields high accuracy in the long wavelength range and provides more information of the profile. Even in this method, however, profiles including stepwise variations cannot be expressed correctly. The roundness profile is evaluated from the differential output of the probes through integration calculation or discrete Fourier analysis. In the integration-type generalized three-point method, stepwise variations are smoothed by the integration. While in the Discrete Fourier Transform type generalized three-point method, stepwise variations cannot be treated correctly by the Fourier analysis.

2.2.4.3 Combined three-point method

By combining the Sequential three-point method and the Generalized three-point method we get the Combined three-point method which utilizes the advantages of both these methods to overcome their shortcomings. This method can accurately express the stepwise variations of the roundness profile and can completely cancel the two-dimensional spindle error components. For the calculation purposes an interpolation technique is used in the discrete Fourier transform type generalized three-point method to avoid the influence of stepwise variations. To get a continuous differential output curve, the part of stepwisevariations in the differential output is interpolated with the least-squares approximation method. This method cannot be applied to the roundness measurement directly because this method is based on the two-point method and the two-dimensional spindle error component cannot be canceled completely. Three-probe method of roundness measurement is subjected to the trouble of harmonic suppression, which is also mathematically complicated due to complex transformation processing. The harmonic suppression leads to the loss of several crucial values and induces uncertainty in the results.

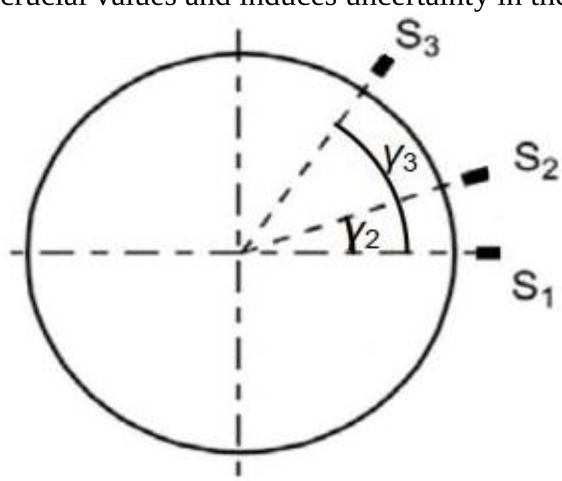


Figure 5 Diameter measurement using three point

2.2.4Four-Point Method

In this method, four probes are used to carry out the roundness measurement, it is a slight advancement over three-point method, since it uses three-point method for roundness measurement and sequential two-point method for the straightness measurement. Three probes are placed in one plane while the fourth one is placed orthogonally in plane with the middle probe. By rotating the workpiece, the signals from the first three probes are used to accurately measure the roundness of the specimen by removing the two-dimensional components of spindle error from their differential output. While the signals of the other two, in-plane, probes are used to determine the straightness of the specimen. The signal from the middle probe is used twice, once for roundness measurement and later for straightness evaluation. The system is mathematically described and was later experimentally verified as well. Even though this system has a well laid out mathematical model for calculating roundness and parallelism, it still has certain limitations. This model is not suitable for detecting all the harmonics of a roundness profile; hence a vast amount of crucial data is lost during the operation which resultantly limits the credibility of this system. Detecting a particular 10harmonic component depends on the positions and angles of the probes relative to each other. This method is currently the most accurate method for the roundness measurement of large cylinders. The method accuracy has not been sufficiently determined due to the scarcity of similar precision test rigs for large cylinders in the local market. However, during measurements the repeatability of determination of a roundness deviation, which was 1micron, with the value measured being 10micron. The method uncertainty assessed statistically was about 19%, compared to the highly accurate radial method. The system's inability to detect several harmonics is its major drawback.

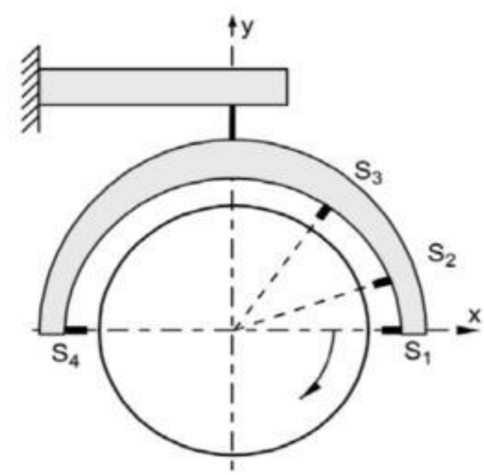


Figure 6 Four point measuring system

2.3 LabVIEW

LabVIEW is a graphical programming language and development environment used for data acquisition, instrument control and industrial automation. It was launched by the national instruments and is first releasedin 1986.
LabVIEW is used to create programs by dragging and dropping graphical elements called nodes onto the graphic user interface(GUI). Functions, input, output and all the data types are represented by the nodes. These nodes are represented by the wires which transmit data and control signals between the nodes.
LabVIEW consist of block diagram and front panel window. All the connections and integrations are done in the block diagram while all the inputs, outputs and graphs are displayed on the front panel window.

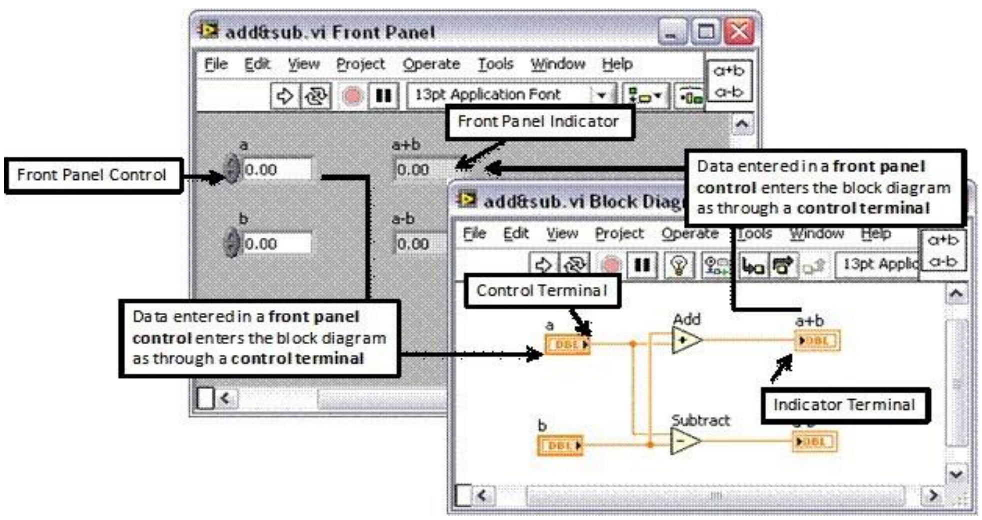


Figure 7 lab view interface

- <u>Data communication</u>

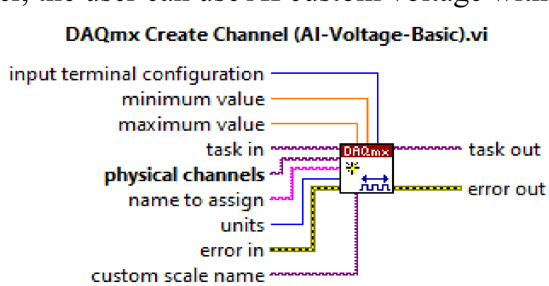
Data communication Vis are used to exchange the data between different applications.

- <u>Signal processing:</u>

It is used to perform the signal synthesis, data windowing, digital filtering and spectrum analysis. Following functions are used for the interpretation of signals.

2.3.1 DAQ create channel (AI-voltage-Basic):

This function is used to measure the measure the voltage. We can use it for the excitation to scale the voltage. Moreover, the user can use AI custom voltage with excitation.



2.3.2 DAQmx Timing (Sample Clock):

This function is used to set the criteria of the sample clock which is

- ➢ the source of the Sample Clock
- ➢ the rate of the Sam
- ➢ the number of sam

Figure 8 DAQ Create channel

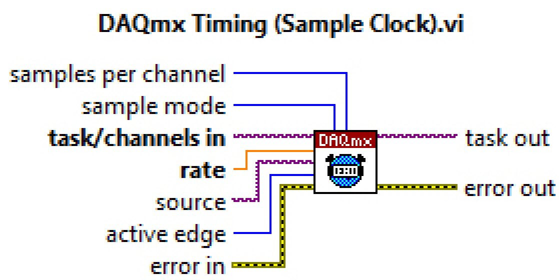


Figure 9 DAQmx timing

2.3.3Property Node:

This function is used for reading or writing the properties of a particular reference. It is basically used to get the properties and methods on local and remote applications instances. Vis and objects. This function is also used to access the private data of LabVIEW.

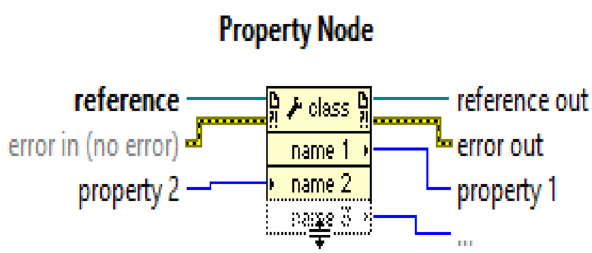
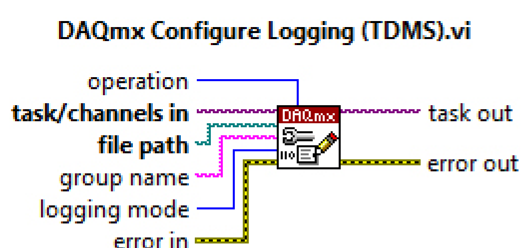


Figure 10 property node

2.3.4DAQmx Configure Logging

(TDMS) :

This function arranges or compose the TDMS file logging for a required task.
for the task. TDMS files don't need interrogation or defragmentation as this function stores the scaling information and raw data individually so that to reduce the file size and for the improvement of performance.



2.3.5 DAQmx Start Task:

This function shifts the specified task to running condition to initialize the measurement. Few applications require it while for other, its optional.

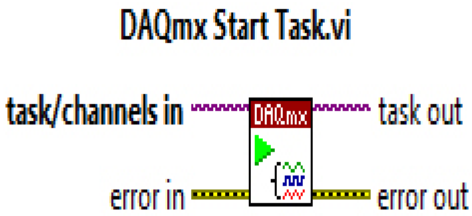


Figure 12 DAQ start task

2.3.6 DAQmx Read (Analog 2D):

DBL NChan N Samp) :

This function is used to read one or more the one floating point samples from a specified task, which may comprise of one or more analog input channels.

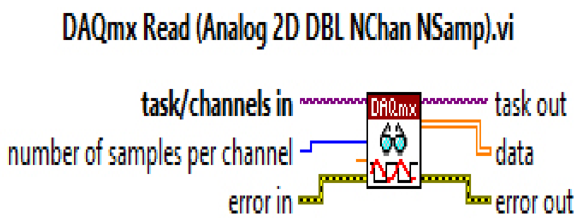


Figure 13DAQmx Read

2.3.7 DAQmx Stop Task:

This function is specifically used to terminate the running task and return it to the state of task was in before the DAQmx Start Task VI ran or the DAQmx Write VI ran with the auto-start input set to TRUE.

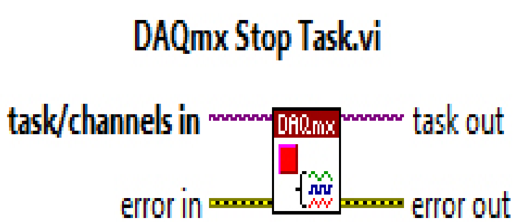


Figure 14 DAQmx stop task

2.3.8 DAQmx Clear Task:

This function is used to clear and also terminate the task, and also aborts the task if necessary. It releases any resources the task reserved if necessary. You can't use a task after you clear it unless you recreate the task.

Figure 15 DAQmx clear task

2.3.9 Simple Error Handler:

This function is used to find and indicate the error occurred. A dialog box is displayed with the nature and description of an error written on it.

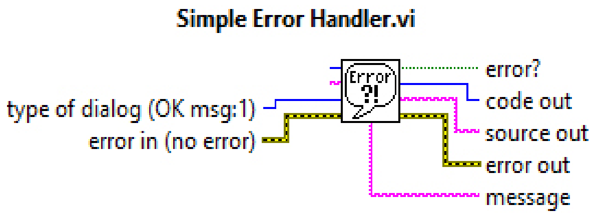


Figure 16 Simple error handler

2.3.10 Butterworth Filter:

This function uses the butterworth coefficient VI for generating a digital butterworth filter. It basically connect the data to X input so that we can manually select the instance or can determine the polymeric instance to use.

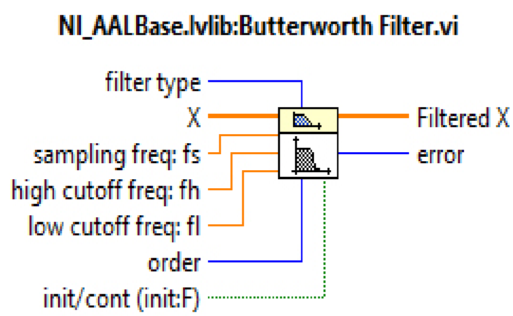


Figure 17 Butterworth filter

2.3.11 Index Array:

This function is used for resizing the array and to display the required index input for each dimension. It returns the element of n dimension array at the index.

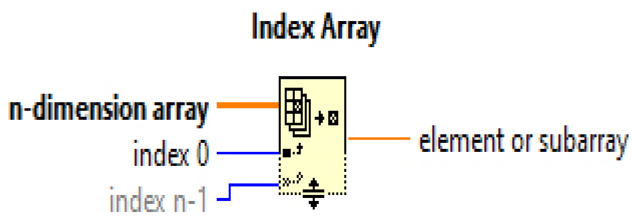


Figure 18 Index array

2.3.12 Build Array:

This function is used to an n dimensional array.

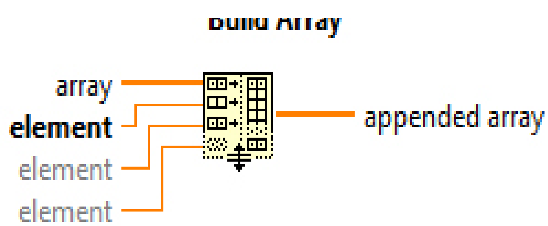


Figure 19 Build array

2.3.13Array Max and Min:

This function is used to indicate the maximum and minimum values with their index in a particular array.

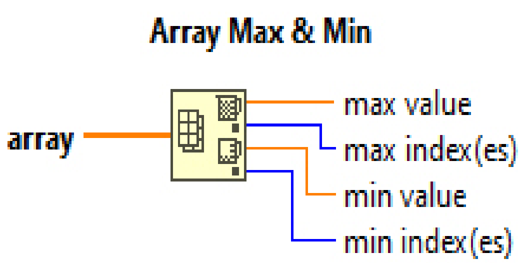


Figure 20 Array max and min

2.3.14Compound Arithmetic:

This function is used to performs arithmetic on one or more numeric, array, cluster or Boolean inputs. Arithmetic function can be selected by right clicking the function and select the change mood from the shortcut menu. Add is the default mode when you select the function from numeric palette. OR is the default mode when you select the function from the Boolean palette.

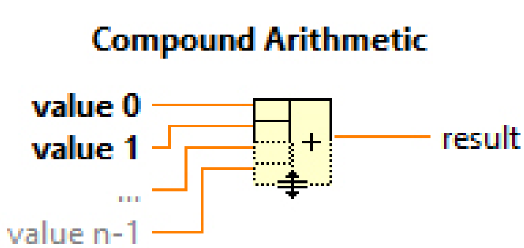


Figure 21 Compound Arithmetic

2.4 LVDT Sensor

An LVDT is an electromechanical sensor that measures displacement by converting mechanical motion into a changeable electrical output (current or voltage). They serve as mechanical motion sensors in measuring technologies or actuators for automatic control systems.

The Linear Variable Differential Transformer (LVDT) and half bridge displacement sensors in the A6G family are only 6 mm in diameter, but they operate just as well as ordinary 8 mm diameter displacement transducers. This makes it possible to cram these contact sensors close together for precise measurement of tiny features which are:

- 6mm diameter LVDT displacement transducer (gauge probe)
- ± 1mm displacement transducer measuring ranges
- Linearity better than 0.5% of precision measurement
- Repeatability precision better than 0.05 µm
- Standard contact sensor tip force of 0.7N (options available)
- Range of contact sensor tips available
- Spring actuation
- IP65 sealing
- Inductive sensors with excellent sideload capability
- Linear Variable Differential Transformer (LVDT) or Half Bridge options.

Figure 22 LVDT Sensor

Chapter 3
Methodology

In this chapter, design requirements and selection criteria of different components and reasoning for selected components have been discussed in detail. The design of manufactured components has also been discussed and final design has been presented at the end of the chapter.

3.1 Technique for measuring the diameter:

For measuring the diameter of crankshaft journal. Two probes are aligned along horizontal axis and third one is positioned at 35 degrees to the horizontal axis.

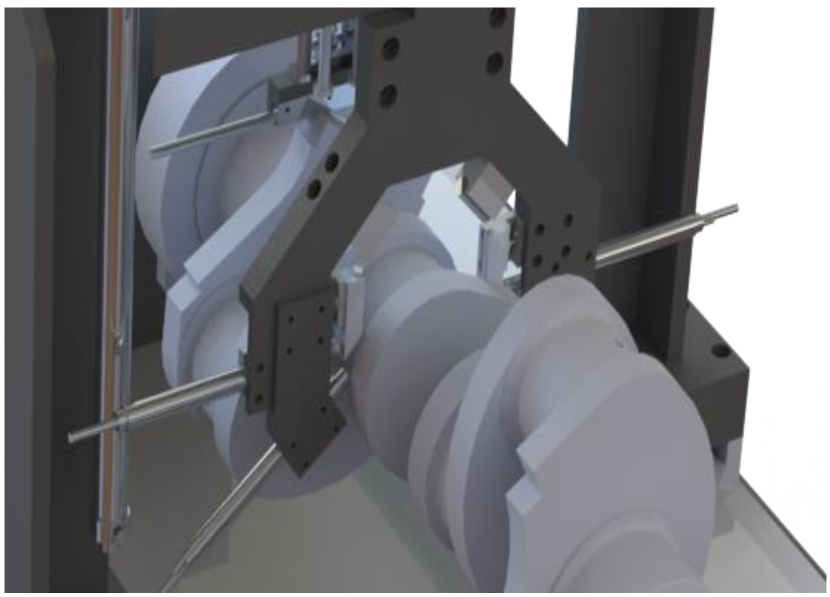


Figure 23 3-Point technique

The raw data coming from the all three probes are in volts. This raw data is converted into microns by multiplying it with the gain which is calculated through the calibration. For the calibration, calibrator is manufactured with the known journal sizes. As there are two sizes of journals for 3-cylinder and 4-cylinder having difference of around 10mm.

For the known diameter of calibrator, Voltages of all three LVDT probes have been noted and then accordingly linear relationship is developed for smooth measuring of diameter using three-point contact.

All three sensors are giving variation of surface roughness in microns. Micrometer was used for measuring the journal diameter and the variation that is coming from the sensors have been added or subtracted from it to get the actual size of the diameter.

he machine satisfies both the designer and user intended functions. It performs inspection for both 3- and 4-cylinder, can effectively measure diameter of and main journals alike.

<u>For post processing Lab Veiw is used:</u>

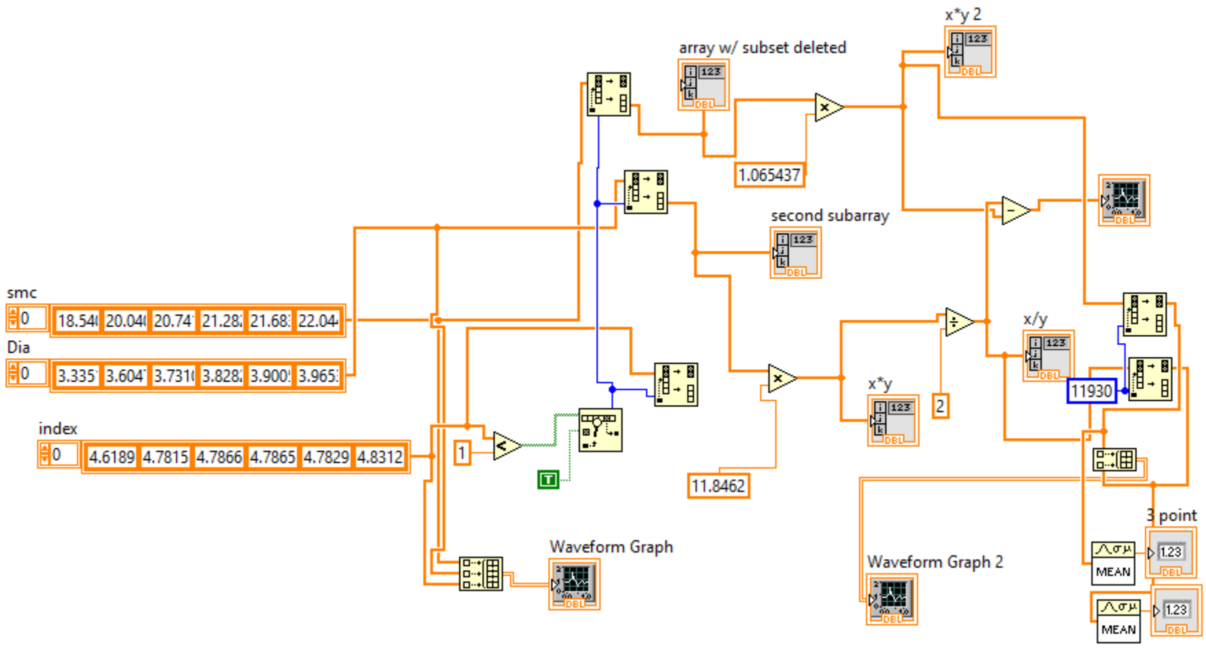


Figure 24 Data code for post processing

3.2 Design Approach:

Two crankshafts were provided by the OEM at the start of project. One is of a 3-cylinder engine and the other is for their 4-cylinder engine. They also provided us with the manufacturing drawings of these crankshafts where all the dimensions and their respectivetolerances were mentioned. This provided us with the deliverables and the constraints to start this project. The design goals are as follows:

Design the machine such that it is able to measure the diameters of both:

- Main Journals
- Pin Journals

Also, it can measure the phase angle between crank pins of both crank shafts

- ➢ Dimensional constraints vary for main and pin journal:
- ➢ For main journal, the length of journal is 32mm.

- Pin journal is 35 mm long.
- Machine is Easily scalable for both 3- and 4-cylinder crankshaft.
- Diameter measurement has an accuracy of 1 micron.
- Diameter reading is taken at 0.5°
- Take measurements at two locations along each journal given that there is an 8mmhole at the middle section of each journal. this leaves even lesser space to work forthe measurement assembly (12mm on each side of the hole).

The measurement assembly is mounted over a bridge like structure. This structure is supported by an electric slider and a freely sliding rail. These sliders are high precision andhigh accuracy. There is another slider mounted on this bridge to which a pin is attached. This pin joint is used to attach the C-Block assembly which is a C-like shape incorporatingtwo-point measurement method and V-block error separation technique. Two pneumatic actuators are used to lift or lower the C-block assembly.

3.2.1 Parameters under consideration

As mentioned in earlier section that there are two crankshafts under consideration. Following design parameters are mentioned in the manufacturing drawings of the crankshafts provided by the OEM.

Main journal:

The diameter of Main journal of Three-cylinder crank shaft is specified at 69.83mm. The specified tolerance in the drawing for main journal diameter is 8µm unidirectional i.e., 69.83^{+0} mm. The total runout specification is 0.010mm (10micron). However, the runout measurement is irrelevant to our project. The length of journal is 31mm.

Pin journal**:**

The diameter of Pin journal is specified at 57.130mm. The specified tolerance in the drawing for main journal diameter is 10 µm unidirectional i.e., 57.130^{+0}mm. The totalrunout specification is 0.030mm (30micron). The length of journal is 39mm. -0.010

Accuracy and repeatability of measurement:

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

Scalability between 3- and 4-cylinder crankshafts:

The length of 3-cylinder crankshaft is 488 mm. This means that distance between tailstock should be adjustable with a difference of 115mm.

3.3 Selected components

The components selected for purchase from market, either local or international, are discussed in detail in this section. The selection criterion for each part is also mentioned.

3.3.1 Linear Electric Sliders (Ball screw):

Ball screw type linear electric sliders are widely used in logistics, automation and precision manufacturing industries. Variety of precision ratings are available at international vendors. The current design requires micron level accuracy rating and positional repeatability. The required stroke length for normal working of the machine is 530mm for3-cylinder crankshaft and 645mm for 4-cylinder crankshaft. An additional 100-150mm stroke length is required to bring the measurement assembly to a rest position.

Given the above-mentioned constraints, HS100 electric slider is used. The stroke length is 800mm. It is a high precision slider with load carrying capacities given as:

Table 1 Electric Slider

1. Vertical Loading:	80kg
2. Horizontal Loading:	40kg
3. Ball screw Pitch:	5mm
4. Positional repeatability:	0.020mm (20micron)
5. Ball Screw accuracy:	C7
6. Max moving speed:	250mm

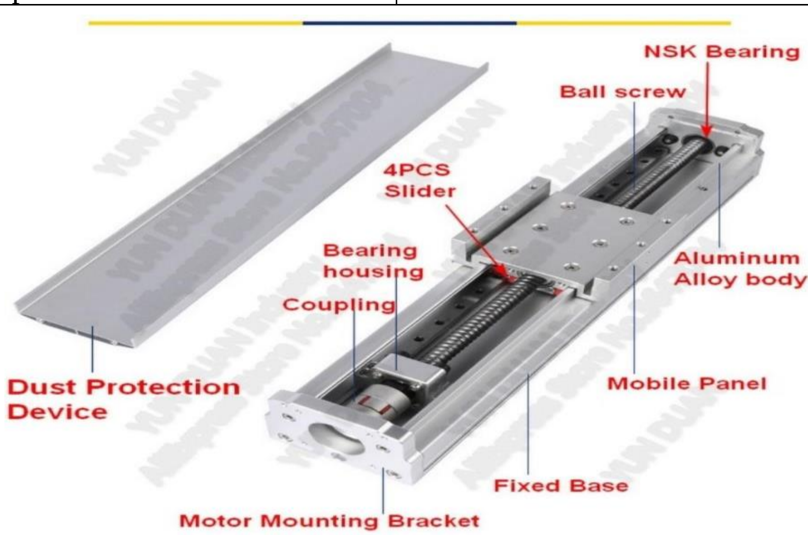


Figure 25 HS100 electric slider and its components

3.3.2 Linear Sliding Block and Rail

Hiwin is recognized for producing high precision guide rails and linear bearings with highloading capacities. It is easily available in international as well as local market for use in automation, robotics and precision manufacturing industries. There are two HIWIN rails used in the machine, one as a free slider for supporting the whole assembly and the other is used for the attaching the C-Block assembly.

<u>HGW30:</u>

Rail width is 30mm. This slider has rail length of 900mm, the running parallelism is 2 microns. The block is flange type for allowing a more rigid mounting of assembly.

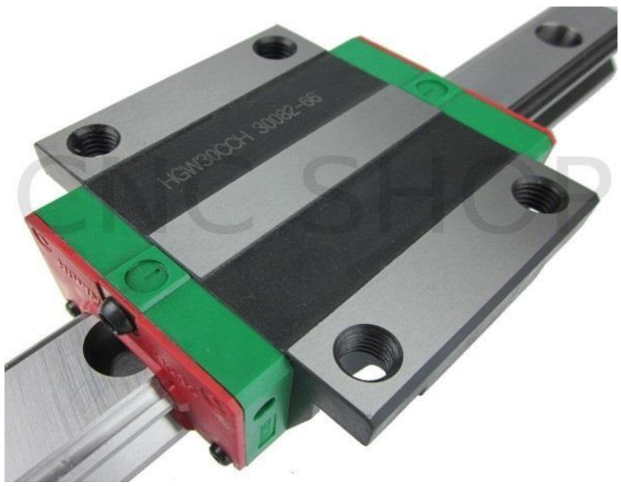


Figure 26 HGW30 Rail

<u>HGW20</u>

Rail width is 20mm. This slider has rail length of 400mm, the running parallelism is 2microns. The block is flange type for allowing a more rigid mounting of assembly.

Figure 27 HGW20 Rail

3.3.3 LVDTs:

LVDTs are very precise instruments with very specific applications. The LVDT industry is very diverse but there are not a lot of options for high precision, highly repeatable and accurate LVDTs. The best option is SOLARTRON metrology. Their LVDTs have sub- micron accuracy and repeatability. Other significant competitors are Omron and TEConnectivity. But their resolution and accuracy are not up to par with SOLARTRON. Also, with same resolution and accuracy, the required measurement range is not available.

The selected LVDT probe is AT/5/P by SOLARTRON metrology. It is a feather touch probe with two options: spring push and pneumatic push. The Tip is spherical Tungsten Carbide of φ6.35mm. Other dimensions are:

Table 2 LVDT

Signal type	Analogue
Body diameter	9.5mm
Body length	96mm
Measurement range	+5 to -5mm
Accuracy	0.25μm or 0.50% of reading (whichever is greater)
Max Repeatability	0.1μm (0.05μm typical)

Although there are blade type tips available for diameter measurement applications, our specific application requires a much larger tangent line (at least 13mm long) to be able to measure both main and pin journal diameters. That’s why we have used spherical tungsten carbide tip.

3.3.4 DAQ system(NI PCLe NI card):

Analogue input, digital I/O, and four 32-bit counters/timers for PWM, encoder, frequency, event counting, and other applications are provided by the PCIe-6320. The device's high-throughput PCI Express bus and multicore-optimized driver and application software are used to deliver high-performance functionality. Advanced timing functionality is delivered by onboard NISTC3 timing and synchronisation technology, comprising independent analogue and digital timing engines and retriggerable measurement tasks. From simple data logging to control and test automation, the PCIe6320 is perfectly suited for a variety of applications. The NI-DAQmx driver and configuration tool that are included make configuration and measurement easier.

It consist of following aspects:

Table 3 DAQ Card

Number of channels	16 analog and 24 digital I/O.
Resolution	16-bit
Voltage	-10 to +10
Sample rate	250KS/s

Figure 28 DAQ- NI Card

3.3.5 Actuators

Pneumatic actuators have been usedfor lifting and lowering the measurement assembly. SMC is a well-known manufacturer of pneumatic actuators and available in both local and international markets.

Actuators are available by the manufacturer depending upon the load, size and operating speed. CJ2 series is selected due to its compact size and load capacity. Here, two pneumatic actuators have been used which are:

CJ2M16-200Z:

Table 4 Pneumatic Actuator 1

Series	CJ2M16-200Z
Stroke length	200mm
Bore diameter	16mm
Operating pressure	1-10 bar

Figure 29 Actuator 200Z

<u>CJ2M10-100Z:</u>

Table 5 pneumatic Actuator 2

Series	CJ2M10-100Z
Stroke length	100mm
Bore diameter	10mm
Operating pressure	0.6-10 bar

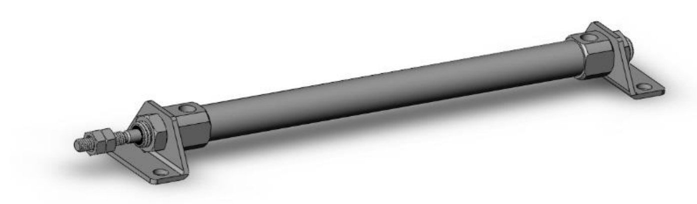


Figure 30 Actuator 100Z

3.3.6 Sliding Tables:

Sliding tables are highly precise components used for actuation of heavy components or to move components with minimum running parallelism. These have been used in the machine for the tangent contact of sensor. Two types of SMC sliding tables have been used.

<u>**MXQ12-100:**</u>

Table 6 Sliding table 1

Material	Stainless steel
Stroke	100mm
Max load	2kg
Cylinder diameter	12mm

Figure 31 Sliding Table 100mm

<u>SMC MXJ4-10N:</u>

Table 7 Sliding Table 2

Material	Stainless steel
Stroke	10mm
Cylinder Diameter	4mm

Figure 32 Sliding table 10mm

3.3.7 Hollow shaft encoder:

A rotary encoder measures the angular position and motion of a rotating shaft. This component is incorporated in driving mechanism for crankshaft to be able return accurate position of the crankshaft. This design saves space by eliminating the need for a coupler and allows for a simple mounting

Following are the specifications of hollow shaft encoder

Table 8 Encoder

Series	Incremental type
Hollow shaft diameter	30mm
Resolution	12000PPR
External diameter	100mm
Thickness	38mm
Supply voltage	DC8-30V
Top response frequency	300KHz
Shaft material	Stainless steel
Net weight	About 600g

Figure 33 Hollow shaft Rotary encoder

3.3.8 Carbide Rods

Tungsten Carbide rods are used for making V-block contacts and to make the probe tip tangent contact with the surface under measurement. Two different rod diameters have been used:

φ5mm x 21mm: for tangent contacts of probe tip to the journal.

Φ8mm x 28mm: For v block arrangement

3.3.9 Nema 23 Motor:

The NEMA 23 hybrid bipolar stepper motor has a 2.3*2.3 inch faceplate and a high torque output. With 200 steps per revolution and a step angle of 1.8 degrees, this motor will rotate once every 1.8°. It **consists** of following general specifications.

Table 9 Nema 23 motor specs

Phase	2
Step angle	1.8 degrees
Voltage	12-24v
Current	3A
Resistance	0.90Ω
Holding torque	1.2Nm
Shaft diameter	8mm

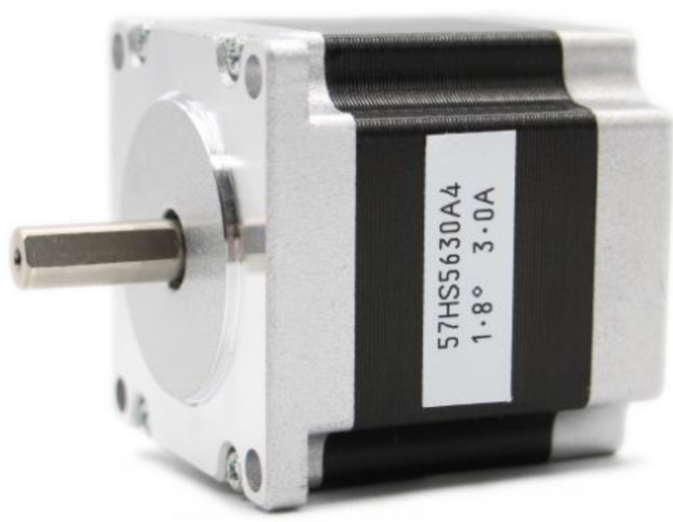


Figure 34 Nema 23 motor

3.3.10 Nema 34 DC motor:

A Nema 34 stepper motor has a faceplate that measures 3.4 by 3.4 inches (86 × 86 mm). Nema 34 high torque stepper motors provide excellent pricing without compromising on quality. These motors are designed to deliver the most torque while reducing audible noise and vibration. The motors can be customised to match the needs of your machine or are easily available in a wide range of winding and stack length configurations. It consist of following aspects**.**

Table 10 Nema 34 motor specs

Phase	2
Step angle	1.8 deg
Holding torque	12Nm
Current	6A
Number of lead	4
Weight	5.1kg

Figure 35 Nema 34 motor

3.4 Design of manufactured parts:

After careful selection of the components, the remaining parts have to be designed with extra care considering that we have to local manufacturing vendors. These parts cannot be sent to international vendors for manufacturing because that would increase theprice ten folds and the process would be very time consuming. Therefore, the parts have been designed for manufacturability at local vendors, taking account their technicallimitations.

Following parts have been manufactured and assembled for the proper functioning of the machine:

- Base plate
- Crank mounting assembly
- Hs100 tower

- Hg30 tower
- Hg20 base plate
- 5204 bearing pin
- C-block mounting 350
- C-block body
- Mounting for φ8mm carbide rods
- Mounting for φ5mm carbide rods
- Clamps for SOLARTRON at/5/p

3.4.1 Base Plate

The base plate is a 15mm thick mild steel plate. It has four sets of holes:

Table 11 Hole table for base plate

	Description	Designation	Qty.
1	Drive mechanism and tailstock mounting holes	M8x1.25 thru	4
2	Pneumatic tailstock mounting holes	M8x1.25 thru	4
3	Electric slider mounting holes	Φ6.0mm thru	8
4	Slider rail mounting holes	M8x1.25 thru	4

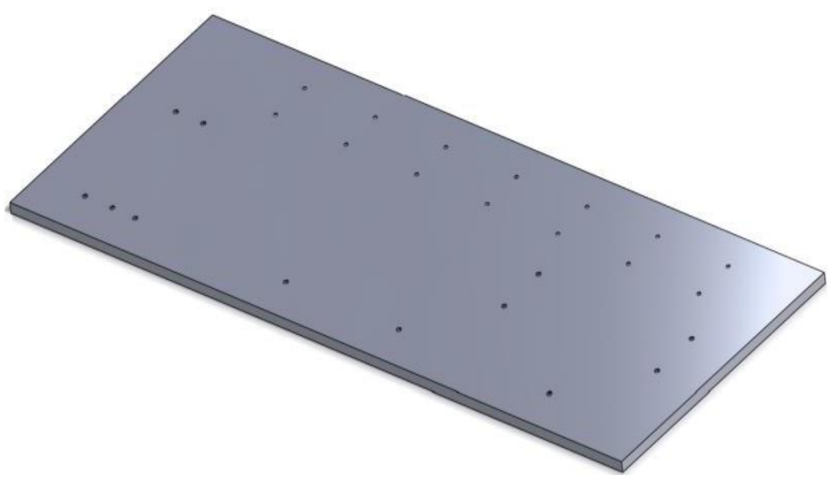


Figure 36 Base plate

3.4.2 Crank driving assembly:

one is fixed and other is pneumatic. after the crankshaft is put in between these tailstocks, the pneumatics are engaged and the crankshaft is held in between the tailstocks. the crank driving mechanism is mounted on the fixed tailstock. It rotates the crankshaft with constant RPM

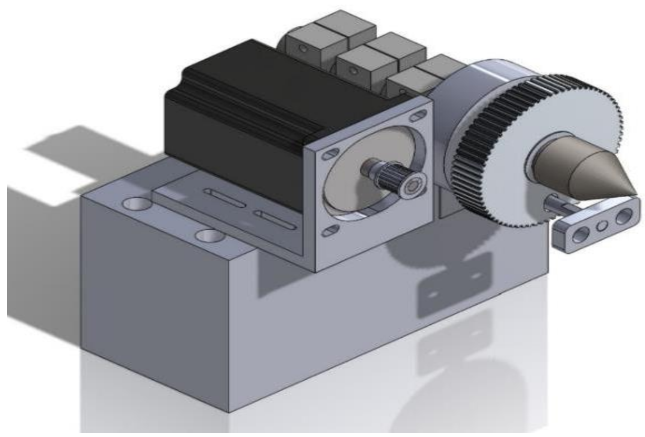


Figure 37 Crank driving assembly

3.4.3 Driving assembly section veiw:

A timing pulley is mounted on this shaft using bearings. This timing pulley is further attached to the crankshaft using a pin such that when the crankshaft is mounted, the pin is inserted in place. The section view is as follows:

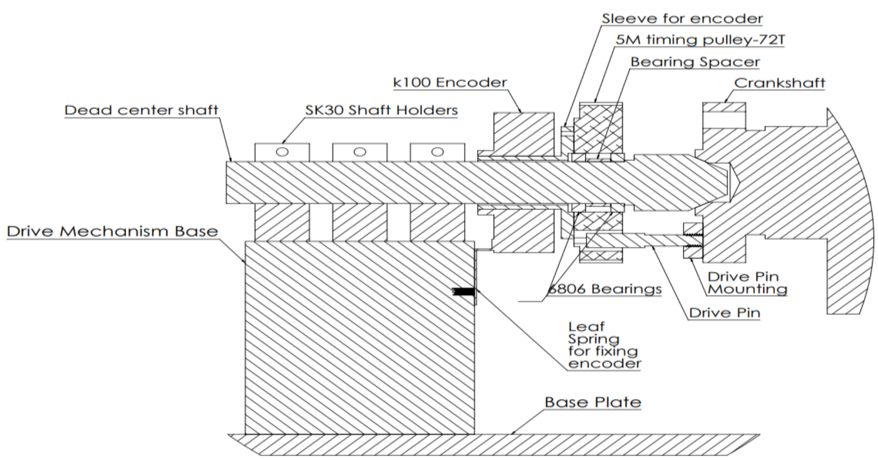


Figure 38 Section veiw

The height of the dead center axis is 180mm. A NEMA-34 stepper motor is used to drive the crank through timing belt. The rotary encoder is mounted with the timing pulley and fixed by leaf spring to the base of tailstock. This way, the dead center is fixed, the pulley and encoder are rotating with the crankshaft during operation.

3.4.4 Pneumatic Tailstock Block:

The pneumatic tailstock consists of a base with two sets of holes. There are two sets of holes for mounting the pneumatic tailstock at two different positions on this base. The distance between these sets of holes is 121mm.There is a dead center mounted in the pneumatic tailstock. The stroke of the pneumatic tailstock is 45mm.

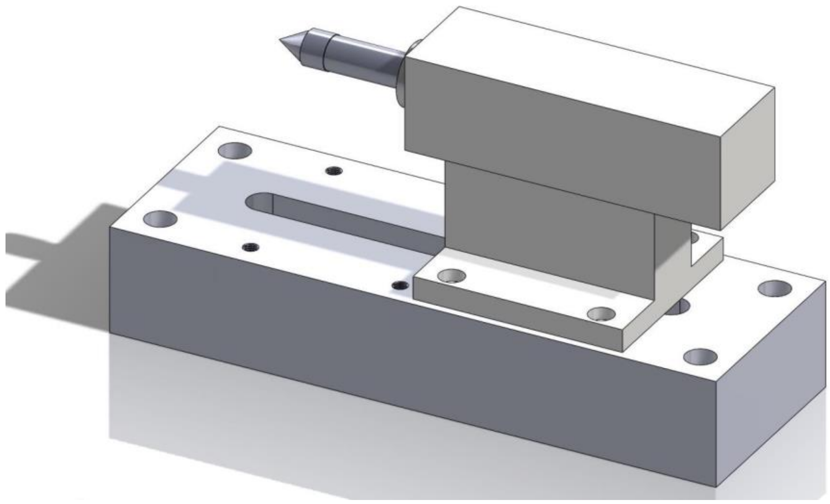


Figure 39 Pneumatic tailstock

3.4.5 HS100 & HG 30 Towers:

This tower is mounted on the electric slider i.e., HS100. It is designed such that the most mass is in its base. Its design has been through multiple iterations but most significant aretwo shown below. The difference, as you can see, is between the rib length. In initial design, the rib was simple and small but the due to large height of the tower, the rib designwas revised and the final design is shown

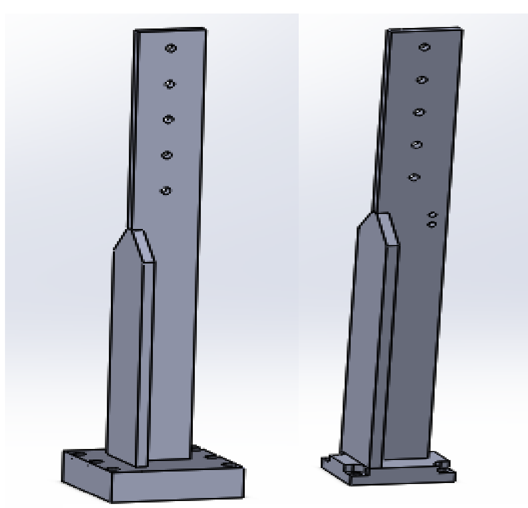


Figure 40 left(HG100) Right(HG30) towers

3.4.6 5204-Bearing Pin:

This pin is mounted on the HG20 block at its base. A 5204 NTN bearing is press fitted on it which is inserted into C-blockmounting 350.

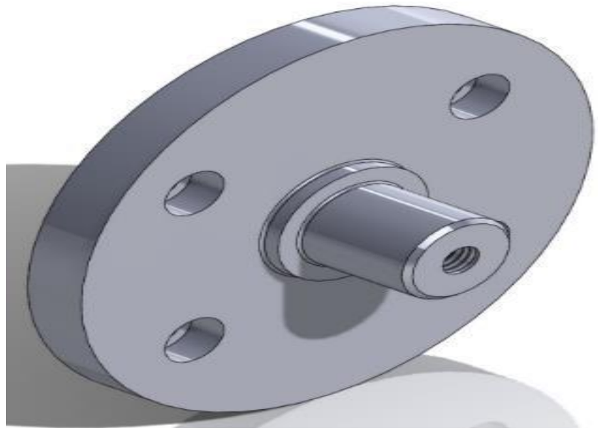


Figure 41 5204-Bearing Pin

3.4.7 C-Block Mounting 350:

This component has 5204 bearing press fitted into it. The C-block body (3.4.8) has to be attached at 4 counter bored holes at its lower end. It is designed such that the distance from the bearing axis to the crank axis is 350mm when the assembly is measuring diameter of main journal. this distance was initially 250mm but it was increased during revision. The reason is that a smaller mounting makes a larger angle with thevertical while measuring the pin journals which may cause imbalance and result in faulty readings.

Figure 42 C-Block Mounting

This is one of the most crucial parts of this machine. Its design has been iterated and revised several times before reaching an optimumdesign. It is mounted at the lower end of C-block mounting

The major constraints for this component are

- Small Space Available for Taking Measurement
- The length of journals is only 32mm for main journal and 35 mm for pin journal. there is also φ8mm hole at the midpoint of each journal. This leaves only 14mm for measurement.

3.4.8 Diameter Measurement of Both Main and Pin Journal:

The ability to measure diameter of both journals requires that measuring assembly can somehow actuate between 60mm-80mm diameters.

3.4.8.1 Design

To overcome these problems C-block is designed to have a tangent contact with the journal surface. The difference between two diameters is 16.066mm. Since two probes are being used with ±5mm measurement range, the probes can be accurately positioned to achieve an optimum working range. This is done by clamping the probes at roughly 1mm extended position when main journal is being measured.

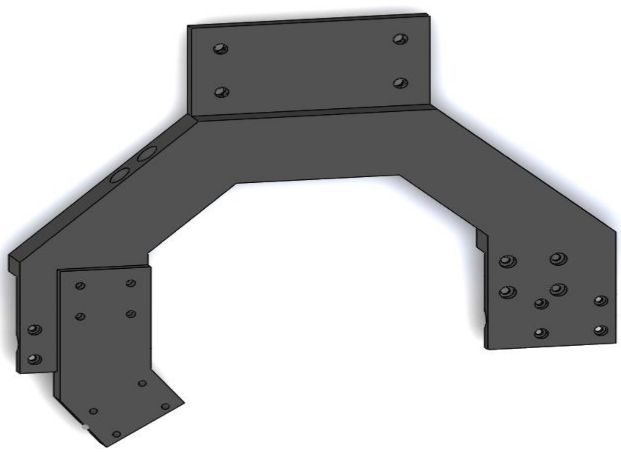


Figure 43 Mounting for carbide rods and sensors

ϕ8mm carbide rods are used for tangent contacts of V-block. The mounting is simplewith two tapped holes to fix it with the C-block and a groove for holding the carbide rods.

3.4.9 Clamps for SOLARTRON AT/5/P:

These clamps are simple strips with clamping holes. It has a groove for holding the LVDT.

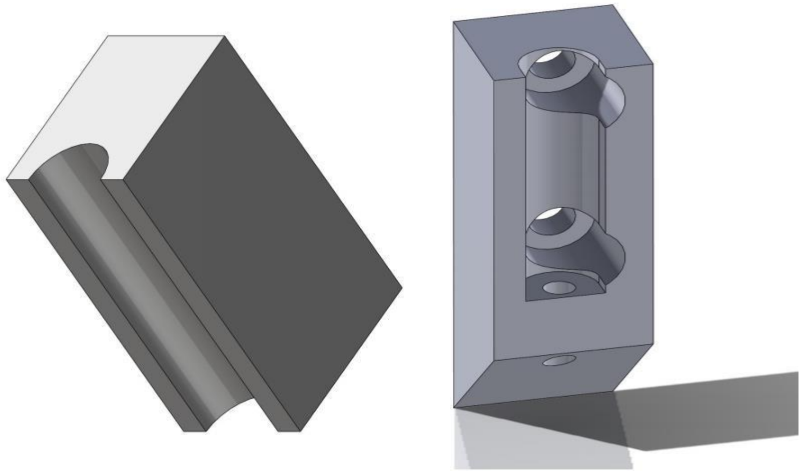


Figure 44 Left) 8mm rod mounting, Right) 5mm rod mounting

3.4.10 Mountings for Pneumatic Actuators

Pneumatic actuators are used for lifting lowering of the measurement assembly. These are mounted one on each tower; the HS100 tower and HG30 tower.

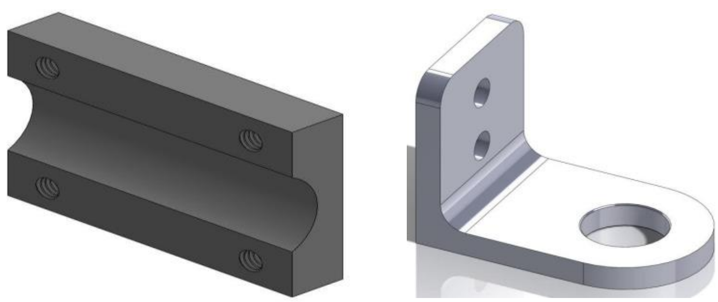


Figure 45 Left)Mounting for the sensor, Right) Clamp for pneumetic actuator

3.4.11 Assembled C-Block

The assembled C-Block has following components:

1. C-block body

2. MXJ4-10N sliders
3. φ5mm Carbide rod mountings
4. φ5mm Carbide rods
5. φ8mm Carbide rod mountings
6. φ8mm Carbide rods
7. AT/5/P feather touch, spring push LVDTs
8. Clamps

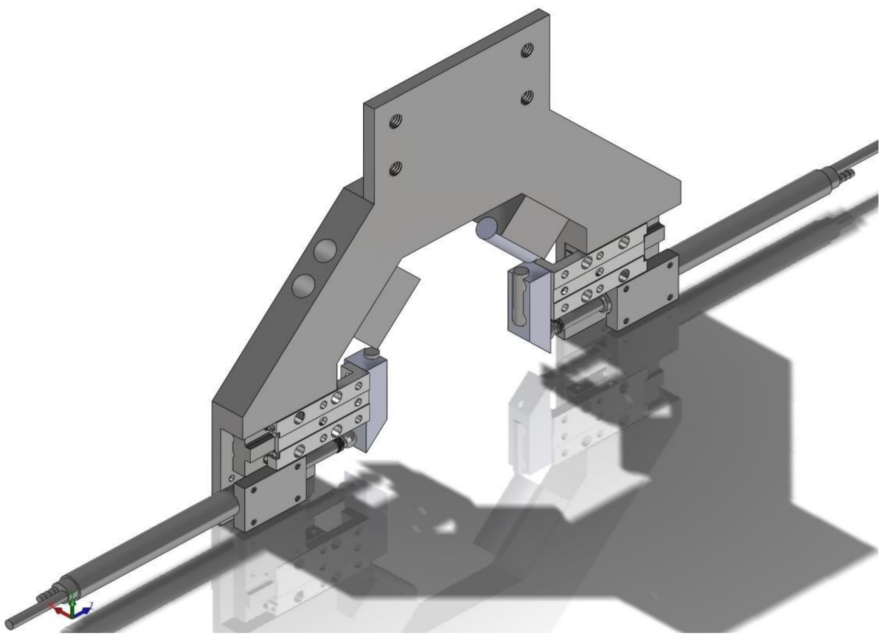


Figure 46 C Block Assembly

3.4.12 Assembled Measurement Mechanism:

The complete measurement assembly has following components and subassemblies:

- HG30 Slider
- HG30 Tower
- HS100 Slider

- HS100 Tower
- HG20 Base Plate
- HG20 Slider
- 5204 Bearing Pin
- NTN 5204 Bearing
- C-Block Mounting 350
- C-Block Assembly

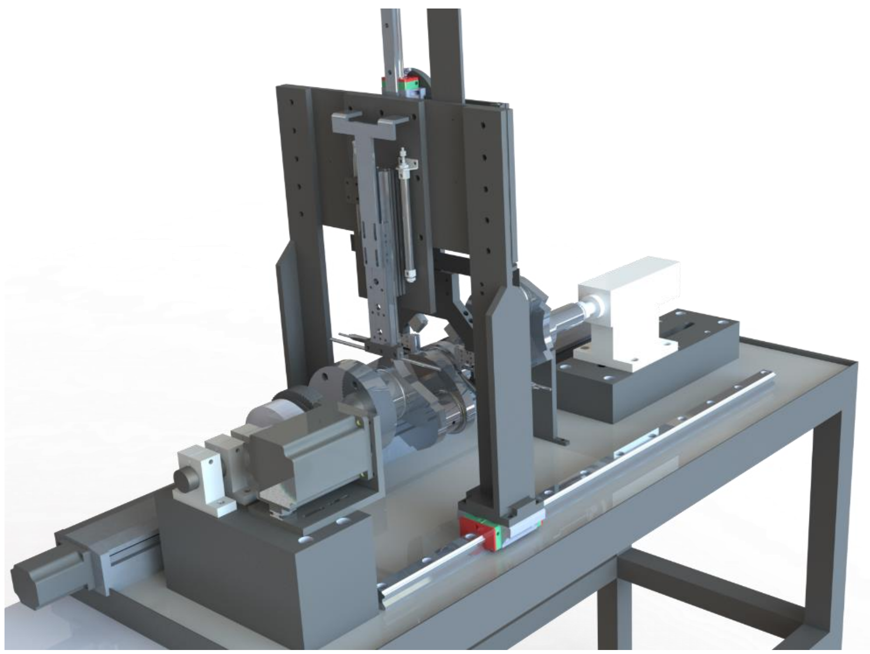


Figure 47 Assembled measuring mechanism

3.4 Fully Assembled Machine

Fully assembled machine has following subassemblies:

- Measurement Mechanism
- Crankshaft Mounting and Driving Mechanism

The measurement assembly can travel 800mm, enabling measurement of both 3- and 4-cylinder crankshafts and then coming to a rest position at one end.

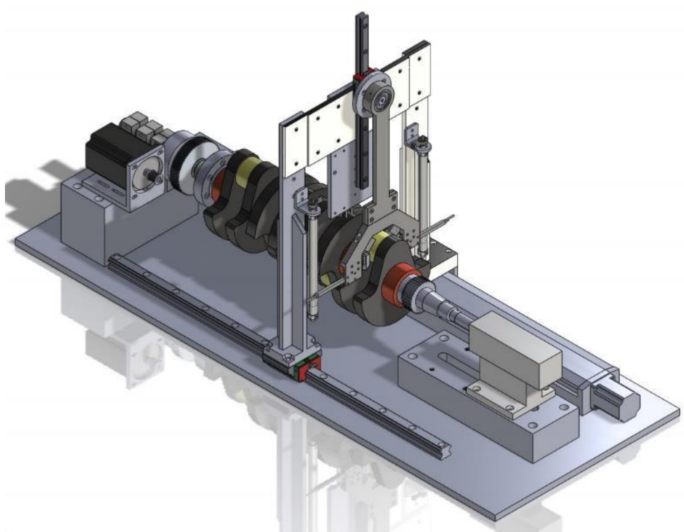


Figure 48 Fully Assembled machine

Chapter 4
Results and discussion

An overview of testing setup and test outcomes is provided in this chapter. The measurements made by the machine are contrasted with the OEM defined parameters and their tolerances. The machine's performance and outcomes are discussed.

4.1 Design Verification:

Verification of the design refers to whether the product functions as planned by the creator. As an illustration, the inspection machine is built to measure the diameter and its variation at intervals of less than 0.5°. 12000 readings can be taken each revolution with the current arrangement. This indicates that a reading interval as tiny as 0.03° can be used. However, 6000 samples are taken per revolution for the test setup. This results in a 0.06° interval.

Precision and repeatability is within 0.001mm or less.

4.2 Design Validation:

Design validation, which follows a successful design verification, is an additional assessment of the verified results that ensures the needs of the customer are successfully met. If the design cannot be validated, test controls are changed until an agreement between validation and verification is reached. If the design is still not validated, the design process is repeated until the verification and validation are successful.

4.3 Test Design:

ccuracy and repeatability are crucial factors when designing tests for crankshaft inspection machines. Repeatedly running the test should yield the same results.

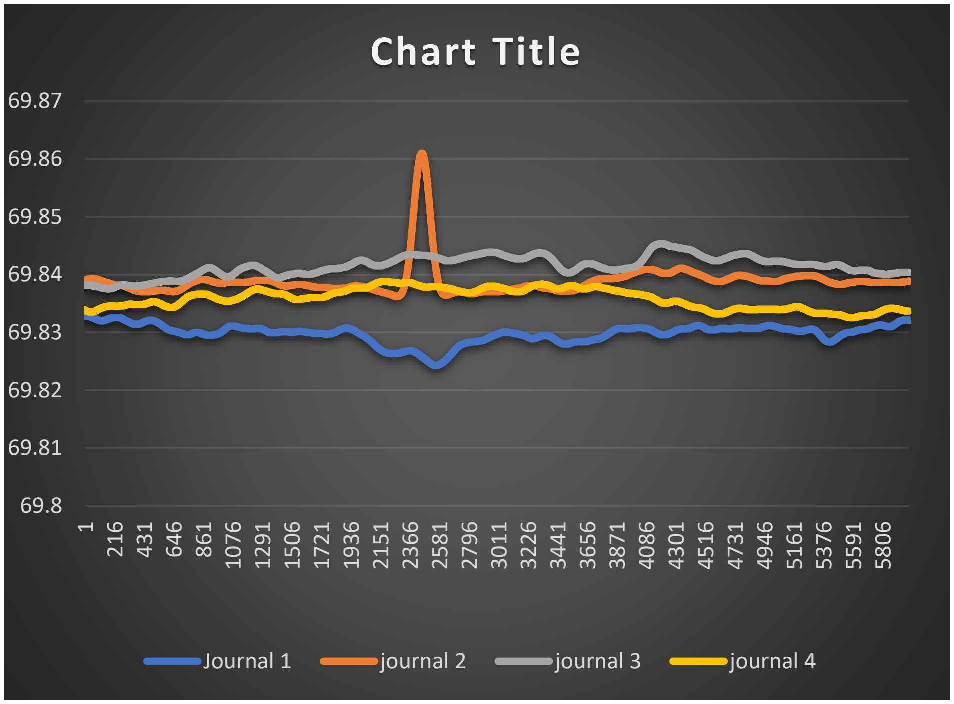
The C-block is lowered onto the main journals in preparation for the crankshaft's current test.

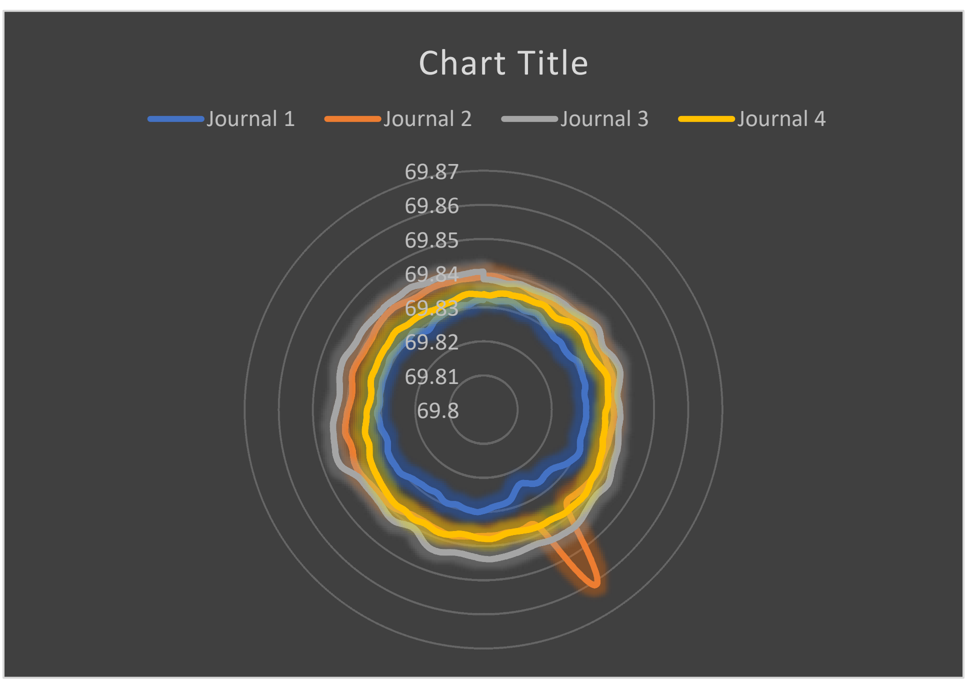
when at least 360 degrees of the crankshaft are turned. Two diameter readings are taken throughout this 360° turn, one during the first half cycle and the other during the second half cycle of crankshaft rotation. This enables comparing the diameter variation values for two cycles simpler.

4.4 Data Processing:

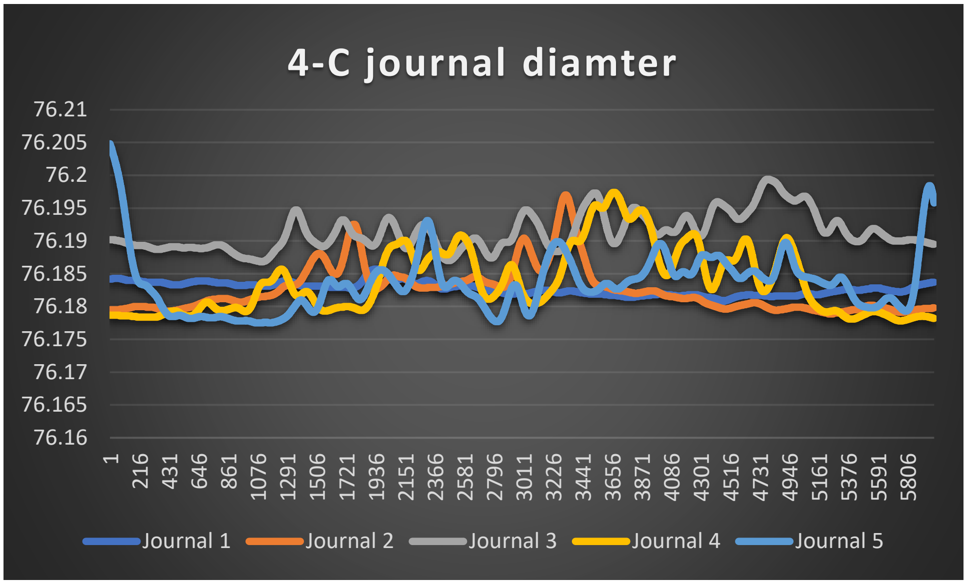
The raw data coming from the all three probes are in volts. This raw data is converted into microns by multiplying it with the gain which is calculated through the calibration. For the calibration, calibrator is manufactured with the known journal sizes. As there are two sizes of journals for 3-cylinder and 4-cylinder having difference of around 10mm. The accuracy and repeatability of data processing is 1 micron i.e 0.001mm.

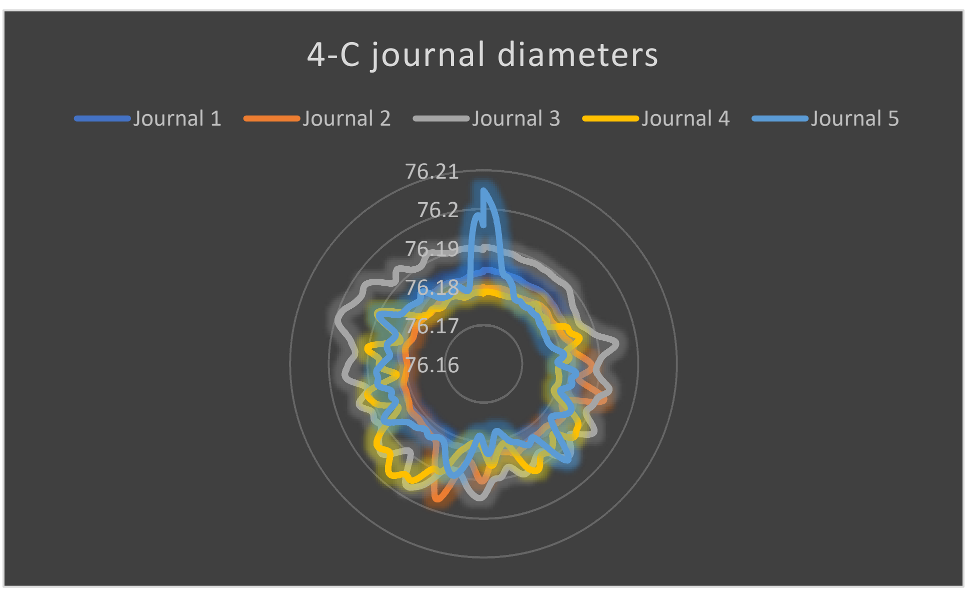
4.5 For 3-Cylinder journal diameter, the results are as following.



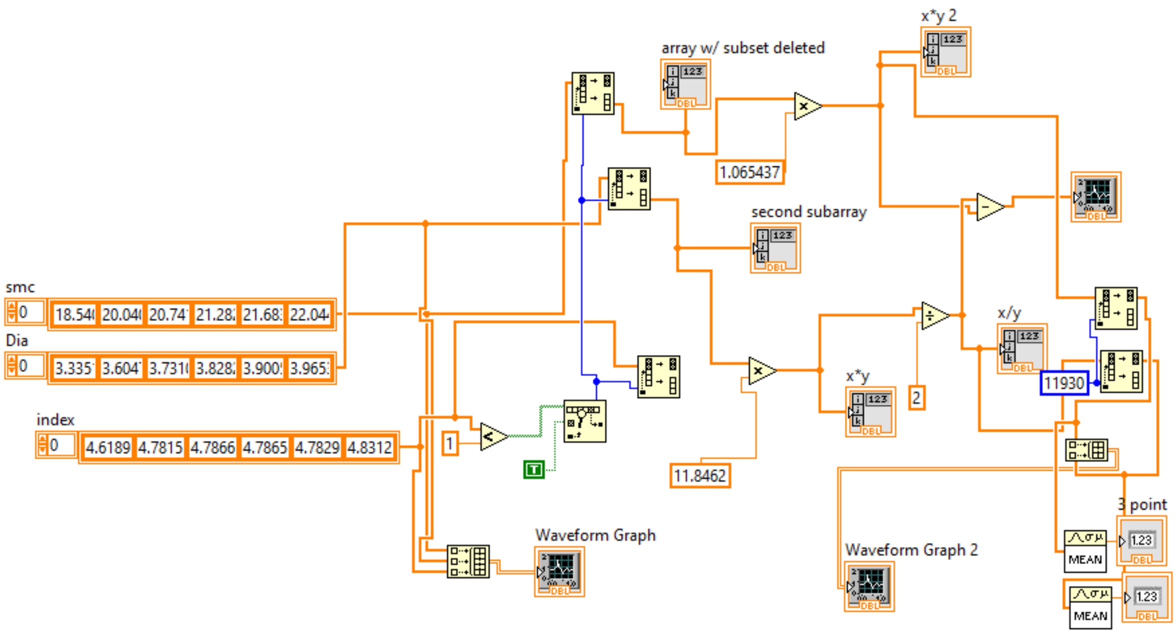


4.6 For 4-Cylinder jounal diameter the results are as follows:





4.7 For three point measurement, the processed data code is as following:



Radii measurements have been calculated by using the above code. Further we find the coordinates of each point as two sensors are places at the horizontal axis with the radii value in x direction. The third point is at 35 degrees to the horizontal axis.

By using the Pythagoras theorem, the coordinates of third point is calculated. Further by using the coordinates of all three points and least square approximation method. the radii is calculated using following maple code.

```
>
> restart;
> Z := ImportData( )
```

Z :=

38.0914	38.0914	38.0914	38.0914	38.0914	38.0914	38.0914	38.0914	38.0914
−38.0914	−38.0914	−38.0914	−38.0914	−38.0914	−38.0914	−38.0914	−38.0914	−38.0914
31.202570310000002	31.202570310000002	31.202570310000002	31.202570310000002	31.202570310000002	31.202570310000002	31.202570310000002	31.202570310000002	31.2025703100000
21.848084298	21.848084298	21.848084298	21.848084298	21.848084298	21.848084298	21.848084298	21.848084298	21.848084298
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.
38.0914	38.0914	38.0914	38.0914	38.0914	38.0914	38.0914	38.0914	38.0914
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

```
> for i from 1 to 6000 do;
  X[1, i] := Z[1, i]; Y[1, i] := Z[2, i];   Z[1, i] := Z[3, i]; Z[2, i] := Z[4, i] :

  end do:
> for n from 1 to 6000 do;
  eq[1, n] := (X[1, n]-h)^2 + (0-k)^2 = r[n]^2
  end do:
```

$$eq_{1,1} := (38.0914 - h)^2 + k^2 = r_1^2$$

$$eq_{1,2} := (38.0914 - h)^2 + k^2 = r_2^2$$

$$eq_{1,3} := (38.0914 - h)^2 + k^2 = r_3^2$$

$$eq_{3,\,6000} := (31.20273414 - h)^2 + (21.848199012000002 - k)^2 = r_{6000}^2$$

```
>
> for q from 1 to 6000 do;
  sys[q] := {eq[1, q], eq[2, q], eq[3, q]} : L_R[q] := fsolve(sys[q]);

  end do:
```

$$sys_1 := \{(-38.0914 - h)^2 + k^2 = r_1^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_1^2, (38.0914 - h)^2 + k^2 = r_1^2\}$$

$$L\_R_1 := \{h = 0., k = -0.0003563797490, r_1 = -38.09140000\}$$

$$sys_2 := \{(-38.0914 - h)^2 + k^2 = r_2^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_2^2, (38.0914 - h)^2 + k^2 = r_2^2\}$$

$$L\_R_2 := \{h = 0., k = -0.0003563797490, r_2 = -38.09140000\}$$

$$sys_3 := \{(-38.0914 - h)^2 + k^2 = r_3^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_3^2, (38.0914 - h)^2 + k^2 = r_3^2\}$$

$$L\_R_3 := \{h = 0., k = -0.0003563797490, r_3 = -38.09140000\}$$

$$sys_4 := \{(-38.0914 - h)^2 + k^2 = r_4^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_4^2, (38.0914 - h)^2 + k^2 = r_4^2\}$$

$$L\_R_4 := \{h = 0., k = -0.0003563797490, r_4 = -38.09140000\}$$

$$sys_5 := \{(-38.0914 - h)^2 + k^2 = r_5^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_5^2, (38.0914 - h)^2 + k^2 = r_5^2\}$$

$$L\_R_5 := \{h = 0., k = -0.0003563797490, r_5 = -38.09140000\}$$

$$sys_6 := \{(-38.0914 - h)^2 + k^2 = r_6^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_6^2, (38.0914 - h)^2 + k^2 = r_6^2\}$$

$$L\_R_6 := \{h = 0., k = -0.0003563797490, r_6 = -38.09140000\}$$

$$sys_7 := \{(-38.0914 - h)^2 + k^2 = r_7^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_7^2, (38.0914 - h)^2 + k^2 = r_7^2\}$$

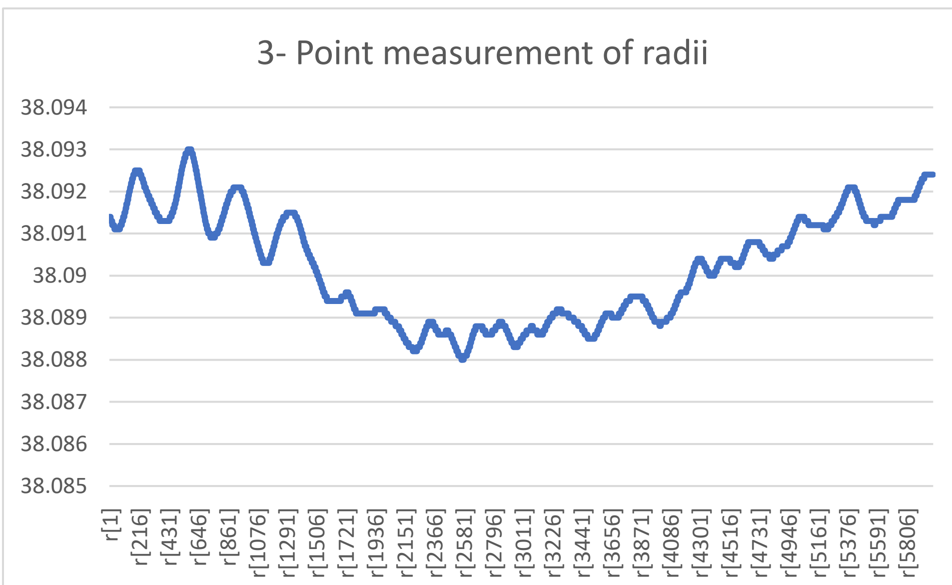
$$L\_R_7 := \{h = 0., k = -0.0003563797490, r_7 = -38.09140000\}$$

$$sys_8 := \{(-38.0914 - h)^2 + k^2 = r_8^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_8^2, (38.0914 - h)^2 + k^2 = r_8^2\}$$

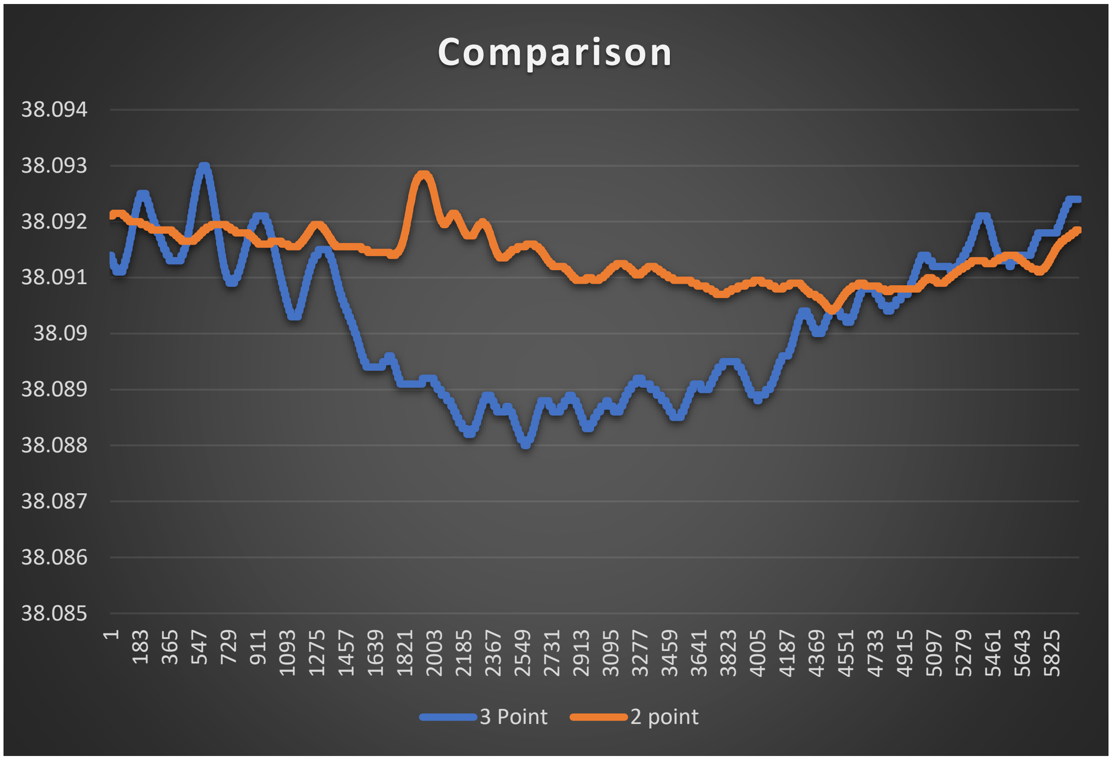
$$L\_R_8 := \{h = 0., k = -0.0003563797490, r_8 = -38.09140000\}$$

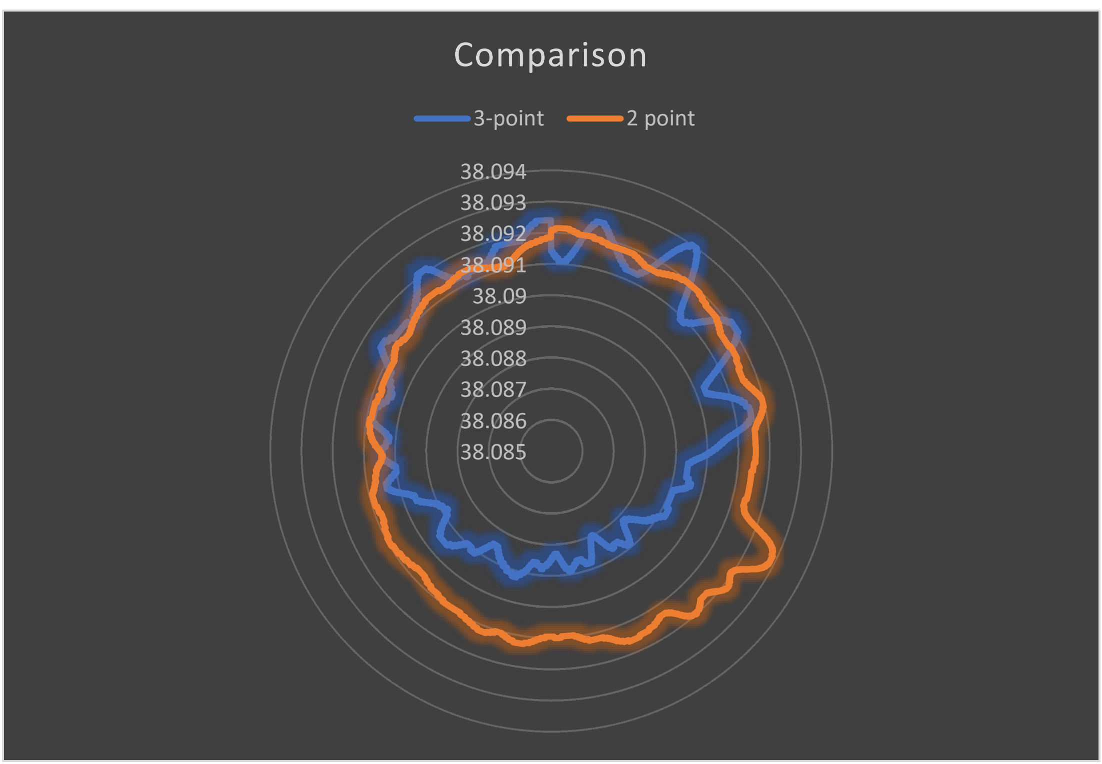
$$sys_9 := \{(-38.0914 - h)^2 + k^2 = r_9^2, (31.202570310000002 - h)^2 + (21.848084298 - k)^2 = r_9^2, (38.0914 - h)^2 + k^2 = r_9^2\}$$

4.8 Final Result of 3 point measurement:



4.9 Comparison between 2 point and 3 point contact:





Chapter 5
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**.**

5.1 Conclusion:

After countless design iterations and testing, a working crankshaft inspection machine was developed and assembled. The parts selected and manufactured for the crankshaft inspection machine performed exceptionally. Data acquisition system was challenging to develop but it gave clean output signal. Multiple readings were taken forboth main and pin journals under varying conditions, the same output was obtained. The data was collected on consecutive days with different settings, yet the 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.

5.2Future Recommendations:

5.2.1 Functional Improvements

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

- As 12000 pulses Incremental encoder is used for angular position so accuracy is limited to 0.03° degrees. If more accuracy is needed in angular position there is encoder available in 24000 and 48000 pulses which can be used for increasing accuracy of phase angle.

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

5.2.2 Design Improvements

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

- The drive mechanism and pneumatic bases are very bulky and heavy. For a finished industrial product, these blocks can be made shell for weight reduction but make sure to prevent vibrations because accuracy is needed in micron.
- The C-Block can be improved to have lesser components and more probes mounted for increased accuracy of measurement such as four-point method.

Chapter 6
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(Adamczak et al., 2011)

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