To develop a technique to measure the phase angle between Crankpins

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I certify that this research titled "To develop a technique to measure the phase angle between crankpins" Is my own work. This work has not been presented elsewhere for assessment. The material that has been used from other sources is properly acknowledged /referred.

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Abstract:

This research paper introduces a new technique designed specifically for measuring the phase angle between off-centred symmetrical circular objects, like crankshafts. The purpose is to improve crankshaft inspection machines, enabling more accurate measurements for increasing engine performance and reliability. Measuring the phase angle between the crankshaft pins has been challenging task. The proposed method utilizes LabVIEW algorithms and advanced sensors like LVDT and Optical Incremental encoder which are capable of detecting and analysing the small variations in the phase angle between pins. This technique measures phase angle between pins by the maximum lift phenomena and deviation in maximum lift of pins results phase angle difference as incremental provides angular position.it enables measurements with a high degree of precision, facilitating the reliable detection of any irregularities or deviation in phase angle that may affect crankshaft performance and reliability. Existing methods measures phase angle with high precisions but they have factors which may lead to inaccuracies, one important parameter is crankshafts should be perfectly horizontal otherwise it will affect accuracy. This proposed technique eliminates this variable and provide easy, economical and accurate solution to OEM. The purpose of this teqnique is to utilize it in crankshaft inspection machine that is designed for Tractor OEM. Crankshafts Manufacturing drawings were provided by OEM on whiich all tolerances were mentioned. For phase angle allowable error is 0.25^{o} from the true value So the sensors used for measuring phase angle upto 0.03^{o}. Overall, this research paper presents a promising advancement in crankshaft inspection by introducing a new technique for measuring the phase angle between off-centred symmetrical circular objects as Crankshafts.

Table of contents

Declaration.......6

Acknowledgements.......7

Abstract:.......8

Introduction.......13

1.1 Background and Motivation.......13

1.2 Problem Statement.......13

1.3 Objectives & Deliverables.......13

Literature Review.......15

2.1 Crankshaft.......15

2.2 Phase angle.......16

2.2.1 CMM.......16

2.2.2 Optical Measurement Systems.......16

2.3 LabVIEW.......17

2.3.1 DAQ create channel (AI-voltage-Basic).......18

2.3.2 DAQmx Timing (Sample Clock).......18

2.3.3 Property Node.......19

2.3.4 DAQmx Configure Logging (TDMS).......19

2.3.5 DAQmx Start Task.......19

2.3.6 DAQmx Read (Analog 2D).......19

2.3.7 DAQmx Stop Task.......20

2.3.8 DAQmx Clear Task.......20

2.3.9 Simple Error Handler.......20

2.3.10 Butterworth Filter.......21

2.3.11 Index Array.......21

2.3.12 Build Array.......21

2.3.13 Array Max and Min.......21

2.3.14 Compound Arithmetic:.......22

Methodology.......23

3.1 Phase angle Technique.......23

3.2 Design Approach.......25

3.3 Parameters under consideration.......26

3.3.1 Main journal.......26

3.3.2 Pin journal.......26

3.3.3 Scalability between 3- and 4-cylinder crankshafts.......26

3.4 Selected components.......26

3.4.1 Linear Electric Sliders (Ball screw).......26

3.4.2 Linear Sliding Block and Rail.......27

3.4.3 LVDTs........28
3.4.4 DAQ Card(NI PCIe 6320 NI card)........29
3.4.5 LabVIEW........30
3.4.6 Actuators........30
3.4.7 Sliding Tables........31
3.4.8 Hollow shaft encoder........31
3.4.9 Carbide Rods........32
3.5 Design of manufactured parts........32
3.5.1 Base Plate........33
3.5.2 Nema 23 Stepper Motor........33
3.5.3 Nema 34 Stepper motor........34
3.5.4 Crank shaft mounting assembly........35
3.5.5 HS100 & HG 30 Towers........36
3.5.6 5204-Bearing Pin........36
3.5.7 C-Block Mounting 350........37
3.5.8 C-Block Body........37
3.5.9 Mounting for φ 8mm and 5mm Carbide Rods........38
3.5.10 Clamps for SOLARTRON AT/5/P........38
3.5.11 Mountings for Pneumatic Actuators........39
3.6 Design of machine........39
3.6.1 Assembled C-Block........39
3.6.2 Assembled Measurement Mechanism........40
3.6.3 Fully Assembled Machine........41
Results and Discussion........42
4.1 Testing........42
4.1.1 Design Verification........42
4.1.2 Design Validation........42
4.1.3 Test design........42
4.2 Phase Angle Post Processing program........42
4.3 Processed Data........44
4.4 Graphical results........44
4.4.1 3-cylinder crankshaft........44
4.4.2 4-Cylinder crankshaft........46
Conclusion and Recommendations........48
5.1 Conclusion........48
5.2 Recommendations........48
5.2.1 Functional Improvements........48
5.2.2 Design Improvements........48

References 49

List of Figures

Figure 1- Typical crankshaft and its components 15
Figure 2- Phase angle using CMM 16
Figure 3- Optical Measurement Systems 17
Figure 4- Lab view interface 18
Figure 5- DAQ Create channel 18
Figure 6- DAQmx timing 18
Figure 7- Property node 19
Figure 8- DAQmx configure logging 19
Figure 9- DAQ start task 19
Figure 10- DAQmx Read 20
Figure 11- DAQmx stop task 20
Figure 12- DAQmx clear task 20
Figure 13- Simple error handler 20
Figure 14- Butterworth filter 21
Figure 15- Index array 21
Figure 16- Build array 21
Figure 17- Array max and min 22
Figure 18- Compound Arithmetic 22
Figure 19- Phase angle measurement 23
Figure 20- Second method phase angle 24
Figure 21- 2nd method for phase angle measurement 24
Figure 22- Front panel for phase angel 25
Figure 23- HS100 electric slider and its components 27
Figure 24- HGW30 Block and Rail 28
Figure 25- HGW20 Block and Rail 28
Figure 26- Solartron AT/5/P LVDT with Signal Conditioning Unit 29
Figure 27- NI PCIe 6320 30
Figure 28- SMC CJ2 M16-200Z Pneumatic Actuator 31
Figure 29- SMC MXJ4-10N 31
Figure 30- K100 Hollow Shaft Rotary Encoder 32
Figure 31- Base plate 33
Figure 32- Nema 23 34
Figure 33- Nema 34 34
Figure 34- Driving Assembly 35
Figure 35- Crank Driving Mechanism Assembly section view 35
Figure 36- Pneumatic Tailstock Assembly 36
Figure 37- Left) HS100 Tower, Right) HG30 Tower 36
Figure 38- 5204-Bearing Pin 37
Figure 39- C-Block Mounting 37
Figure 40- C block 38
Figure 41- 5mm Carbide Rods Mounting 38

Figure 42- 8mm Carbide Rod Mounting 38
Figure 43- Clamp for Solartron AT/5/P 39
Figure 44- Pneumatic Actuator Mounting 39
Figure 45- C-Block Assembly Designed 40
Figure 46- Assembled measurement mechanism........ 41
Figure 47- Assembled Machine Design 41
Figure 48- LabVIEW program Block Diagram 43
Figure 49- LabVIEW program Front Panel 43

List of Tables

Table 1:Linear electric slider specs 26
Table 2- PCIe 6320 specs........ 29
Table 3- K100 Encoder Specs 31
Table 4- Hole Table for Baseplate 33
Table 5- Nema 23 specs 33
Table 6- Nema 34 Specs 34

List of Graphs

Graph 1-Pin 1 phase angle 44
Graph 2-Pin 2 phase angle 44
Graph 3-Pin 3 phase angle 45
Graph 4-phase angle Comparison b/w pins........ 45
Graph 5- Pin 1 phase angle 46
Graph 6-Pin 2 phase angle 46
Graph 7-Pin 3 phase angle 46
Graph 8-Pin 4 Phase angle 47
Graph 9- Phase angle comparison b/w pins 47

Chapter No.1

Introduction

1.1 Background and Motivation

A crankshaft is Necessary component in engine that is serves as driving mechanism for piston, consisting of a series of cranks and crankpins to which the connecting rods of an engine is attached. It is a mechanical part that convert reciprocating motion to rotational motion and vice versa. The function of crankshafts is to give a smoother drive to the vast engine with multi cylinders. Linear motion of the pistons which is changed to rotational motion by thrust of gasses. In the combustion of fuel-air mixture, power is produced. This power is transformed into rotary movement of crankshaft. The linear motion of pistons is converted via the connecting rod into torque. It's then passed to the flywheel. The components of crankshaft include:

- Main journals
- Crank Pins
- Crank Webs
- Counterweights

To design and fabricate a prototype, capable of *precise measurement*, for automotive industry. The techniques of precision engineering and measurement are available in the international market, and we intend to bring forth this advancement in Pakistan but at a much cheaper cost, which can help the industry substantially. Its International alternative is the **CMM** machine which can cost from ***$30,000*** to ***$1,000,000*** depending upon the specifications.

Crankshaft is subject to high variable loading. It is prone to wear and tear. The wear and tear can be substantially improved if the intended dimensions are achieved.

1.2 Problem Statement

The task is to develop a technique and test rig that will calculate the phase angle between pin journals. Final product will be able to test both 3- and 4-cylinder crankshaft

1.3 Objectives & Deliverables

Main objectives of the project are:

1. Making a proof-of-concept prototype for industry that can measure diameter of crankshaft main and pin bearings.
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 and manufactured.

The deliverables of the project are:

1. CAD Model of finalized mechanism
2. Assembly of crankshaft driving mechanism
3. Fabrication of probes mounting mechanism to take reading
4. Signal Processing to generate data from probe sensors
5. Phase angel measurement for 3- and 4-cylinder crankshaft
6. Diameter measurement readings of both main and pin journals with an accuracy and repeatability of 1 micron.

Chapter No.2

Literature Review

In this chapter, the literature studied for the development of this project has been discussed. This includes the techniques involved and details of components to be used. The selection criterion for selection of these parts is also mentioned in the following sections.

2.1 Crankshaft

Crankshaft is indeed the cornerstone of an IC engine, responsible for converting linear motion into rotational motion. Crankshafts are subjected to enormous dynamic loads while engine operates, and it is therefore necessary to ensure high wear and fatigue resistance of this crucial component.

The crankshaft is placed within the engine block, and its main function is to transform linear motion of piston into rotational motion. Pistons are connected to crankshaft through connecting rods.

Hence, the crank mechanism is a combination of connecting rods, pistons and the crankshaft itself. The secondary role of crankshaft is to transfer power to miscellaneous engine components including oil pump, valve timing, alternator, air conditioning compressor, alternator etc. The main bearings are responsible to hold the crankshaft in place, and ensure that it easily rotates within the engine block. The pin journals, also known as conrod journals, have piston connecting rods fixed on them. The counterweights are positioned on the opposite sides of pin journals to make up for outer moments, curtail internal moments, to mitigate the bearing stresses and vibration amplitudes.

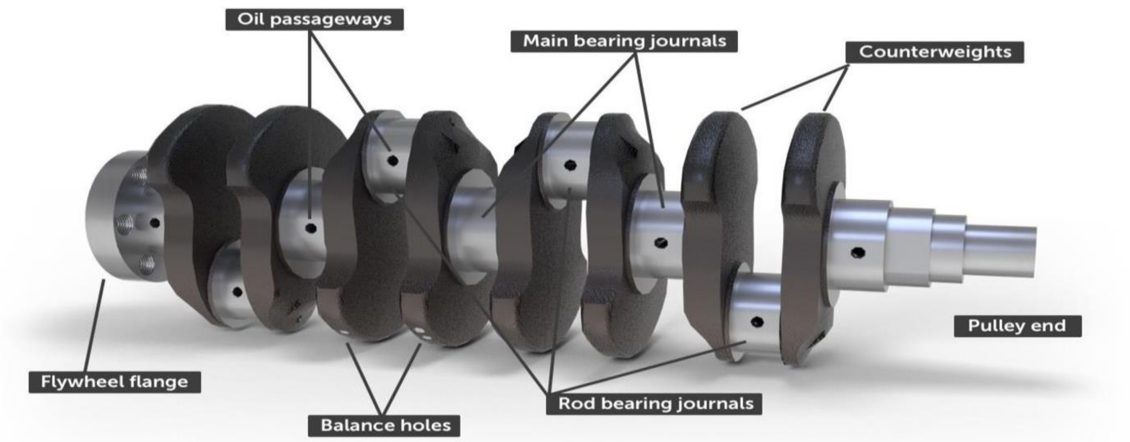


Figure 1- Typical crankshaft and its components

At lower engine RPMs, it is not necessary to provide counter weighting to the rotating mass of crankpin, but considering the fact that the forces exerted by rotating crankpin increase with the square of engine speed and stroke of crankshaft, it is necessary to provide some counter balancing with increasing engine speed. The counter weights ensure a long smooth operating engine. The number of both pin and main journal depend upon the engine type and number of cylinders. There are lubrication orifices on both journals. The flywheel is mounted onto the crankshaft to reduce vibrations and to smooth the engine torque, because the engine torque is discontinuous and is only produced during the expansion cycle of piston.

Now that we have already explained the functions of crankshaft, and since it’s one of the most important components responsible for engine operation and performance, it’s therefore highly important to ensure its accurate and precise manufacturing.

2.2 Phase angle

2.2.1 CMM

Coordinate Measuring Machine (CMM) is a widely used technique for measuring the phase angle or angle between pins in the manufacturing of crankshafts. CMM is a precise measuring device that employs a probe to capture the coordinates of specific points on the crankshaft. In the case of measuring the phase angle between pins, the crankshaft would be mounted on the CMM, and the probe would be positioned to touch the pins of interest. The CMM then moves the probe along the surface of the crankshaft, capturing the coordinates of the pins at multiple positions.

The captured coordinate data is processed using specialized software that calculates the phase angle between the pins based on their positions. This calculation is typically done by determining the angular displacement between the pins, considering the centerline or reference axis of the crankshaft.

It is important to note that the accuracy of CMM measurements is influenced by factors such as machine calibration, probe selection, and environmental conditions. Regular calibration and maintenance of the CMM are necessary to ensure reliable and precise measurements.

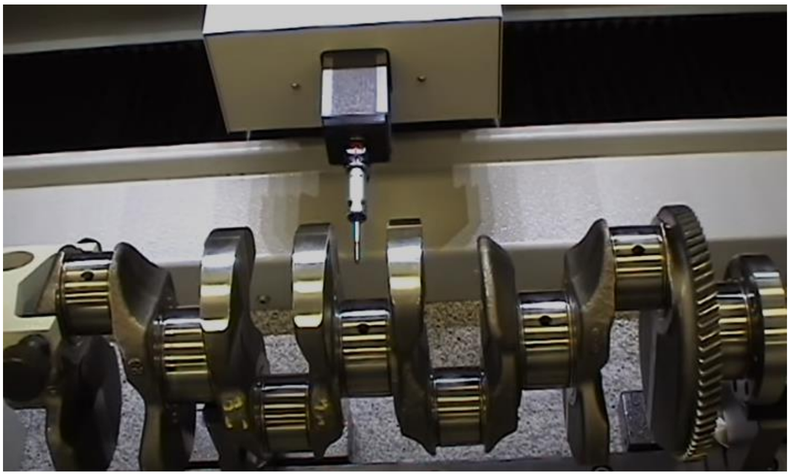


Figure 2- Phase angle using CMM

2.2.2 Optical Measurement Systems

Optical measurement systems are highly accurate and non-contact solutions for measuring phase angles in various applications. These systems utilize cameras, sensors, light sources, and advanced image processing algorithms to capture and analyse patterns or images projected onto the object being measured. To ensure accuracy, calibration is a critical step in optical measurement systems. It involves establishing the relationship between captured image coordinates and the corresponding real-world coordinates. Calibration targets or known reference objects are used, and advanced algorithms calculate the transformation matrix for accurate measurements.

The measurement process begins with system setup and calibration, followed by positioning the object within the measurement field. As the object undergoes motion or rotation, the optical system captures images or patterns. These images are processed using sophisticated algorithms to extract position and movement data. The phase angle is then calculated based on the measured positions. Optical measurement systems offer several advantages. They provide non-contact measurements, eliminating potential interference or distortion. The systems achieve high accuracy and resolution, enabling precise phase angle measurements. Real-time measurements are possible, allowing for dynamic analysis during object motion.

However, certain considerations and challenges must be addressed. Lighting conditions and reflections can impact measurement accuracy, necessitating appropriate light sources and image processing techniques. Complex objects or challenging environments may require advanced algorithms or multi-camera setups to capture comprehensive data.

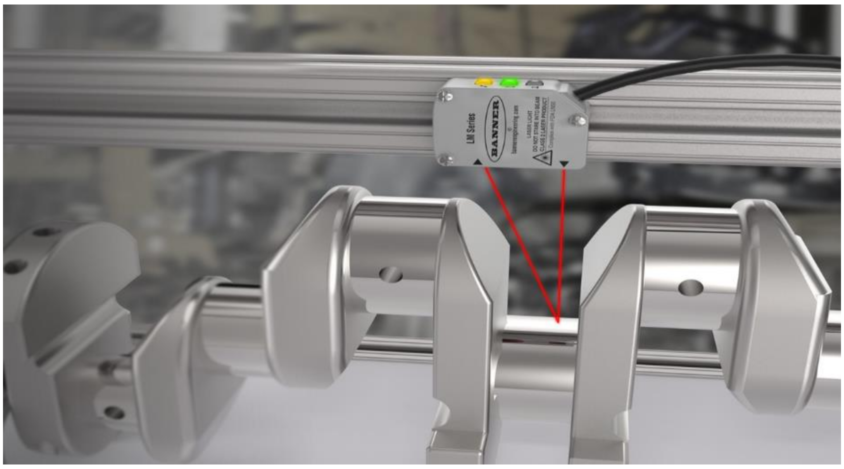


Figure 3- Optical Measurement Systems

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 release in 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.

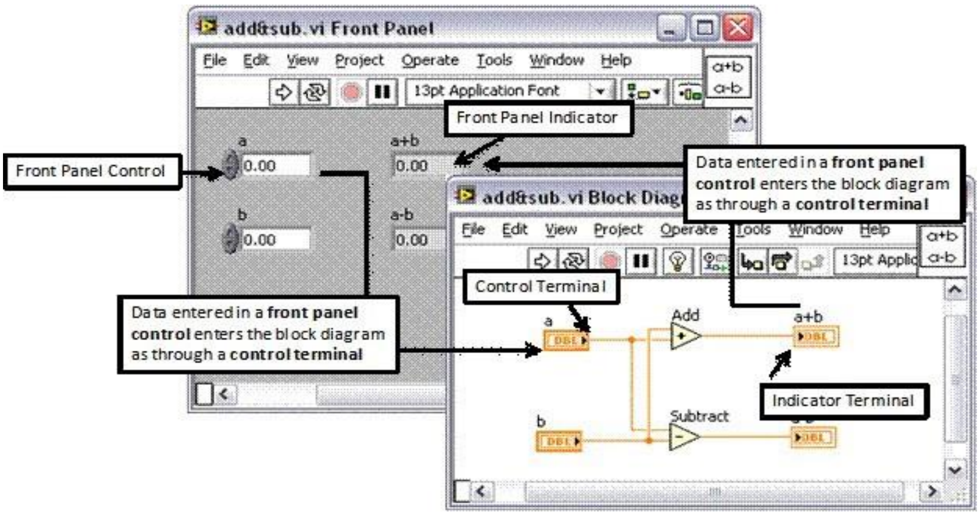


Figure 4- Lab view interface

- Data communication

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

- Signal processing:

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.

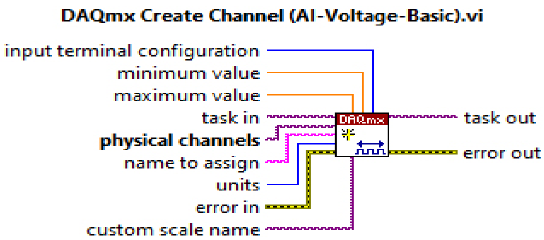


Figure 5- DAQ Create channel

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 Sample Clock
- the number of samples to acquire

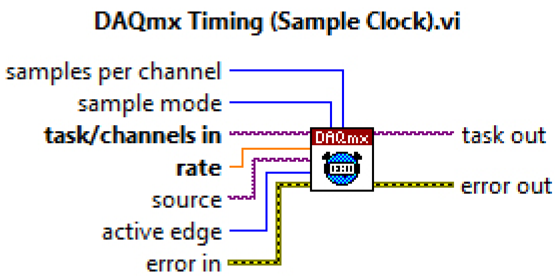


Figure 6- DAQmx timing

2.3.3 Property 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.

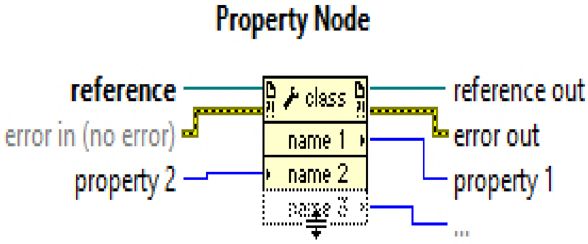


Figure 7- Property node

2.3.4 DAQmx 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.

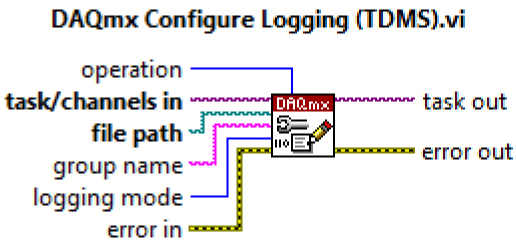


Figure 8- DAQmx configure logging

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.

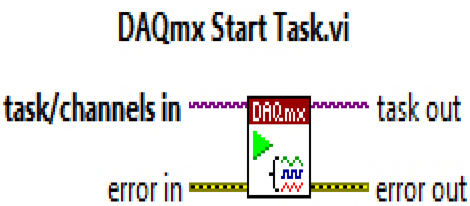


Figure 9- DAQ start task

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.

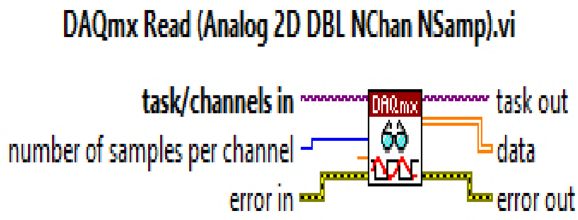


Figure 10- DAQmx Read

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.

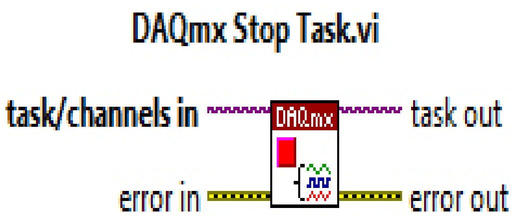


Figure 11- DAQmx stop task

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 12- 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.

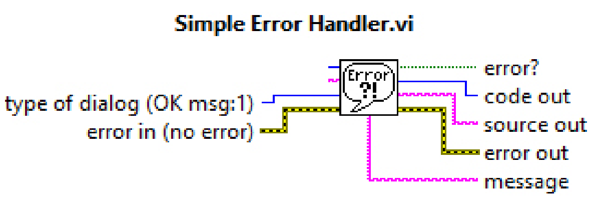


Figure 13- Simple error handler

2.3.10 Butterworth Filter

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

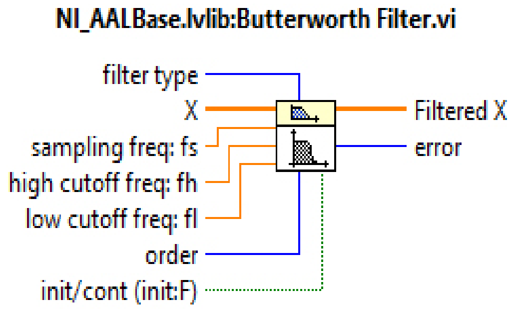


Figure 14- Butterworth filter

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.

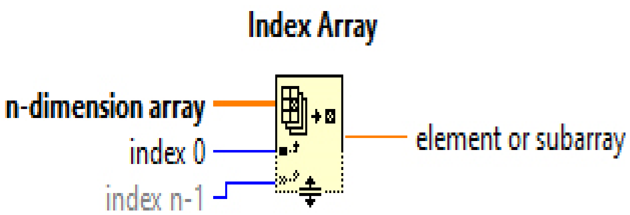


Figure 15- Index array

2.3.12 Build Array

This function is used to connect the multiple arrays or appends elements to an n dimensional array.

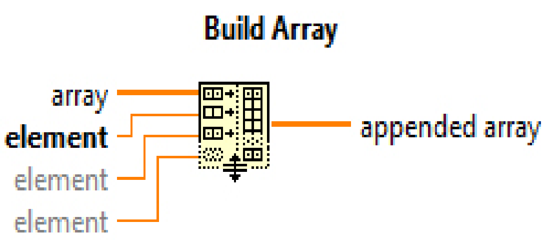


Figure 16- Build array

2.3.13 Array Max and Min

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

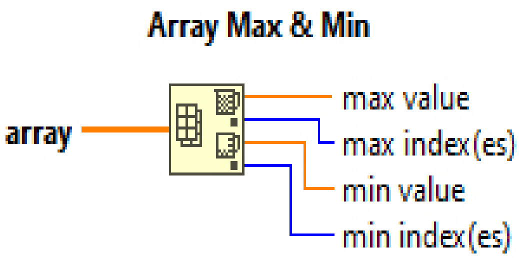


Figure 17- Array max and min

2.3.14 Compound 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.

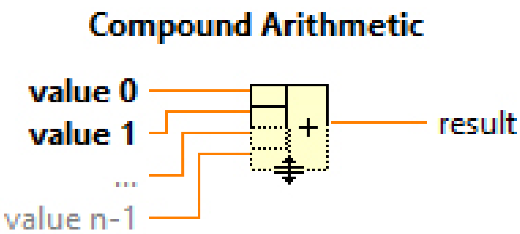


Figure 18- Compound Arithmetic

Chapter No.3

Methodology

In this chapter, new technique for phase angle that is developed and 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 Phase angle Technique

For measuring phase angle, an incremental encoder with LVDT sensor is used for measuring the phase angle and for phase angle Two new techniques were developed.

As the crankshaft is held between two centres and the stepper motor rotates it clockwise direction and getting an angular position of crankshaft through the encoder. Incremental encoder provides angular position of the crankshaft after every 0.03 degree as resolution of encoder is 12000 pulses per revolution. As the crankshaft rotates from the reference position and crankpin comes into contact with the slider carbide rod and starts lifting the slider, LVDT gives a reading. We fixed the distance when the crankpin rotates and start lifting the slider when slider moves up (say x = 2mm) at what angle this value comes for the first crankpin if it comes at 40.02 degrees from the reference axis then second crank pin is tested the same way and if the slider lifts which is ‘‘x’’ comes at say 40.01 degrees then it means crankpins are 0.01 degrees out of phase.

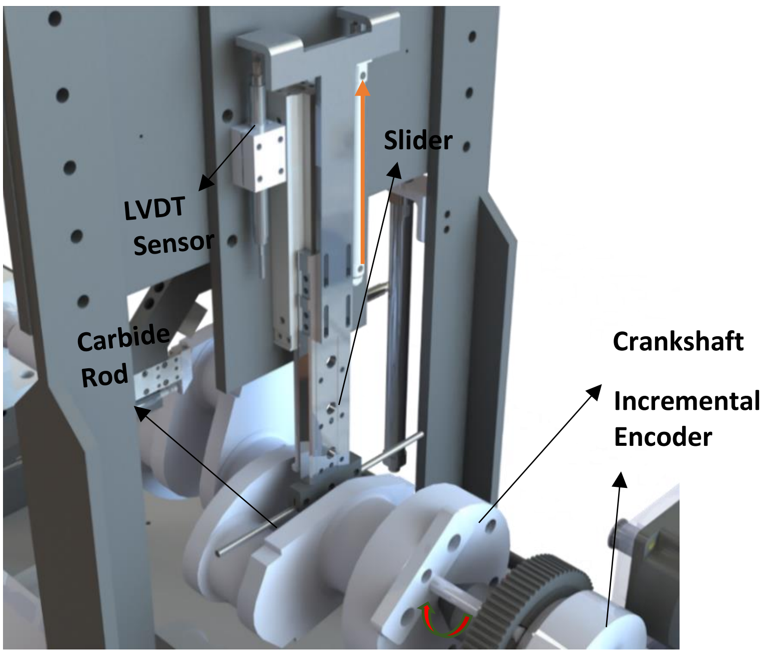


Figure 19- Phase angle measurement

The problem in this method is that if the crankshaft is not perfectly horizontally aligned then this slider distance which is fixed as it is ‘‘x’’ would be affected and it may come before or later the true angle value which is when perfectly align crankshaft due to inclination so a compensation factor will be required for this procedure which is difficult and time taking process.

In the second Technique that is developed for off centred symmetric objects, we add one step more in the previous object as the crankshaft rotates clockwise and starts lifting the slider and we get the 1st angular position for the specified slider distance as it was ‘‘x’’ in the previous technique, we continue to get data and LVDT value will go to a minimum when slider gets lifted from LVDT and then its value will start increasing again from minimum when slider starts moving down and came into contact with LVDT sensor and we get “x” again on certain angular position. Now we have two angular positions at which same x is noted, one value gets on upward slider movement and another downward slider movement. In post processing, the average of these two points is taken for getting the maximum lift of LVDT of every pin and to find out phase angle between pins of 3- and 4-cylinder crankshaft.

Advantage of this method is that no need to think about the crankshaft alignment whether it is perfectly horizontal or not, so this method eliminates this variable.

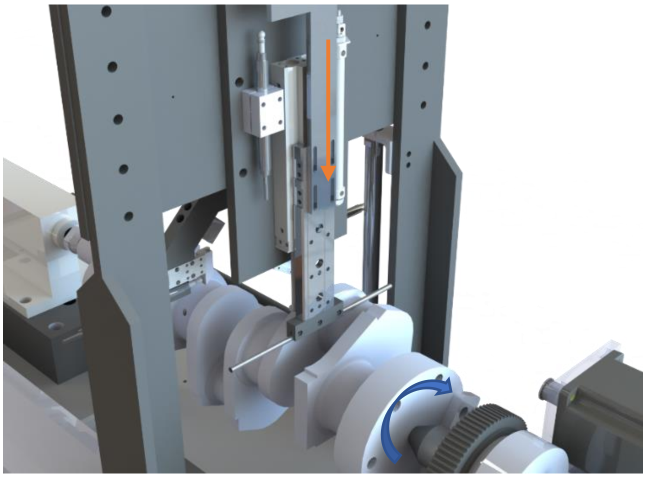


Figure 20- Second method phase angle

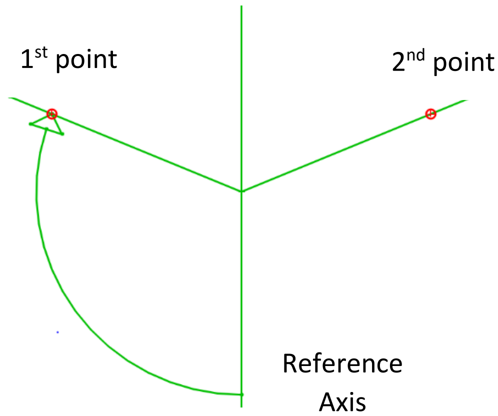


Figure 21- 2nd method for phase angle measurement

For Post processing LabVIEW program was built which takes data from LVDT Sensor and Incremental Encoder and gives phase angle between pins and their phase angle difference graph.

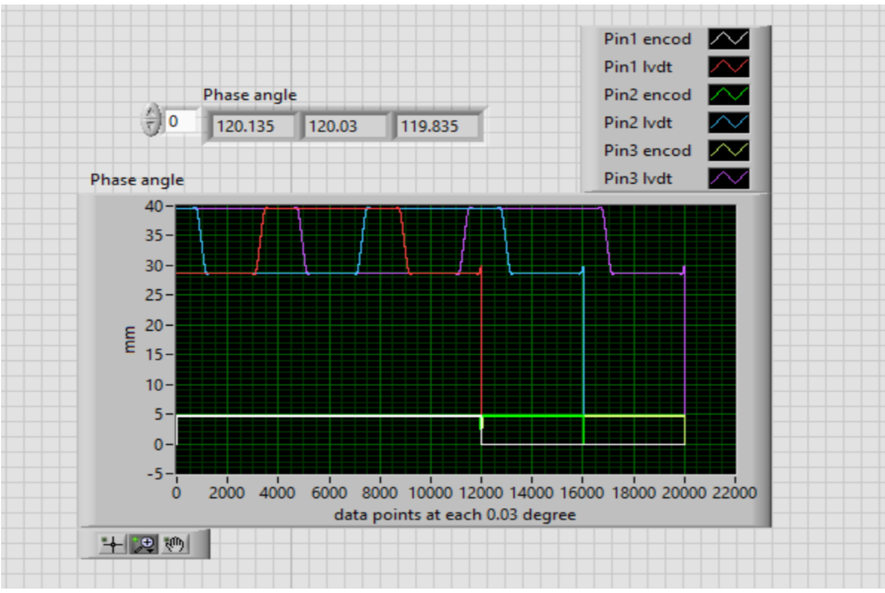


Figure 22- Front panel for phase angel

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 and high 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 incorporating two-point measurement method and V-block error separation technique. One pneumatic actuator is used to lift or lower the C-block assembly.

3.3 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.

3.3.1 Main 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., $57.130^{+0}_{-0.010}$mm. The total runout specification is 0.030mm (30micron). The length of journal is 39mm.

3.3.2 Pin 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., $69.83^{+0}_{-0.008}$ mm. The total runout specification is 0.010mm (10micron). However, the runout measurement is irrelevant to our project. The length of journal is 31mm.

3.3.3 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.

3.4 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.

3.4.1 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 for 3-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:Linear electric slider specs

1. Vertical Loading:	80kg
2. Horizontal Loading:	40kg

3. Ball screw Pitch:	5mm
4. Positional repeatability:	0.020mm
5. Ball Screw accuracy:	C7
6. Max moving speed:	250mm

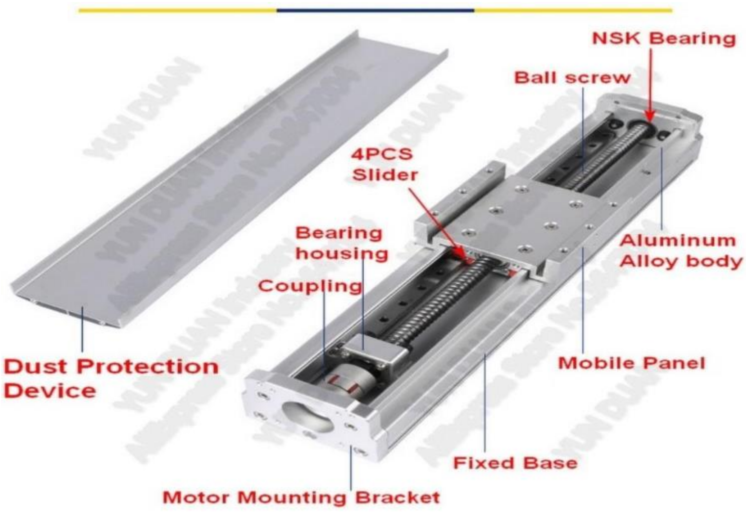


Figure 23- HS100 electric slider and its components

3.4.2 Linear Sliding Block and Rail

Hiwin is recognized for producing high precision guide rails and linear bearings with high loading 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.

3.4.2.1 HGW30

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.

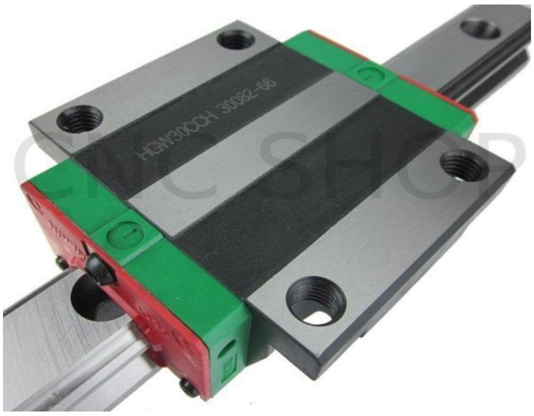


Figure 24- HGW30 Block and Rail

3.4.2.2 HGW20

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

Figure 25- HGW20 Block and Rail

3.4.3 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 Connectivity. 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:

1. Signal type: Analogue
2. Body Diameter: φ9.5mm
3. Body Length: 96mm

4. Measurement range: ±5mm
5. Accuracy: 0.25µm or 0.50% of reading (whichever is greater)
6. 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.

Figure 26- Solartron AT/5/P LVDT with Signal Conditioning Unit

3.4.4 DAQ Card(NI PCIe 6320 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 synchronization technology, comprising independent analogue and digital timing engines and retrigger able 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 consists of following aspects

Table 2- PCIe 6320 specs

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

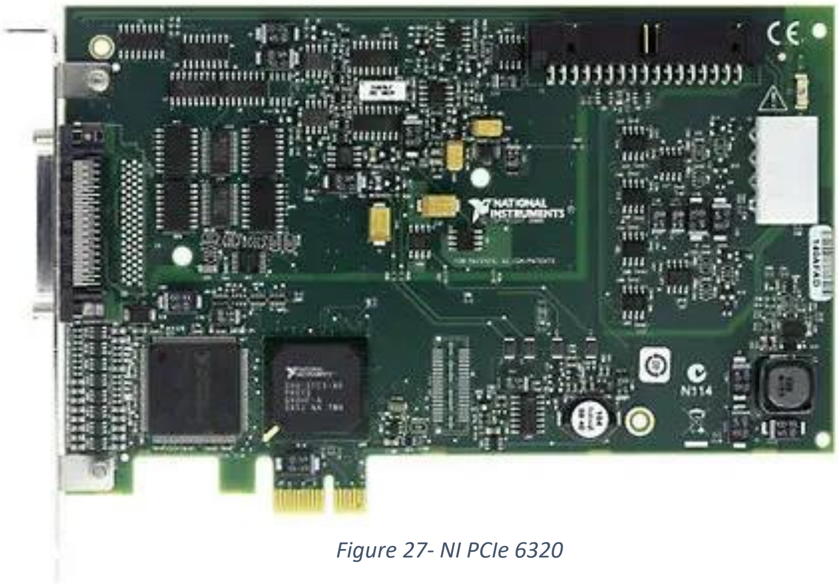


Figure 27- NI PCIe 6320

3.4.5 LabVIEW

LabVIEW program has been used for programming the data acquisition and can be furtherused to automate the machine for OEM product. It is used for easier to work with interfacecompared to conventional programming media and for visual data flow representation. A program written in LabVIEW is called a virtual instrument or VI.

The platform has two windows; Front panel for output display and running the VI andBlock diagram window for designing or writing the program.

3.4.6 Actuators

Pneumatic actuators have been used for lifting and lowering the measurement assembly. SMC is a well-known manufacturer of pneumatic actuators and available in both local and international markets. The required stroke length for lifting the C-block assembly such that it is safe from collisions while travelling along the crankshaft is 200mm.

There are various series of actuators available by the manufacturer depending upon the load, size and operating speed. CJ2 series is selected due to its compact size and load capacity.

a. Series and specifications: CJ2M16-200Z
b. Stroke Length: 200mm
c. Bore: 16mm
d. Operating Pressure: 1-7 Bar

Figure 28- SMC CJ2 M16-200Z Pneumatic Actuator

3.4.7 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. SMC sliding tables have been used.

Figure 29- SMC MXJ4-10N

3.4.8 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.

Following are the specifications of hollow shaft encoder:

Table 3- K100 Encoder Specs

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 30- K100 Hollow Shaft Rotary Encoder

3.4.9 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

3.5 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

3.5.1 Base Plate

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

Table 4- Hole Table for Baseplate

	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

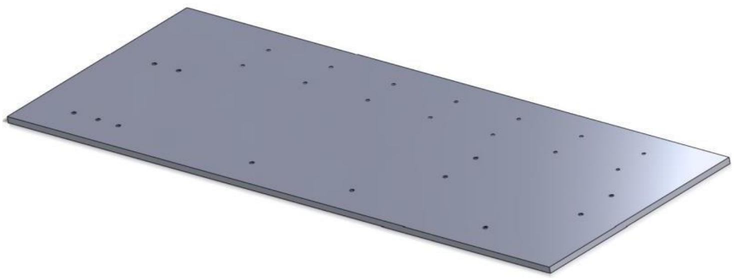


Figure 31- Base plate

3.5.2 Nema 23 Stepper 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 5- Nema 23 specs

Phase	2
Step angle	1.8 deg
Voltage	12-24v
Current	3A
Resistance	0.90Ω

Holding torque	1.2Nm
Shaft diameter	8mm

Figure 32- Nema 23

3.5.3 Nema 34 Stepper 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 customized to match the needs of your machine or are easily available in a wide range of winding and stack length configurations. It consists of following aspects.

Table 6- Nema 34 Specs

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

Figure 33- Nema 34

3.5.4 Crank shaft mounting assembly

one is fixed and other is pneumatic. after the crankshaft is put in between thesetailstocks, 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.

3.5.4.1 Crank Driving Assembly and Tailstock

The fixed tailstock is mounted on a base. It consists of a dead center shaft mounted on three shaft clamps. 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.

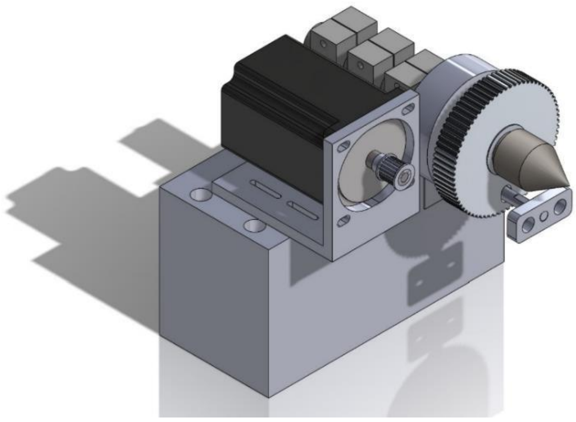


Figure 34- Driving Assembly

3.5.4.2 Crank driving assembly section view

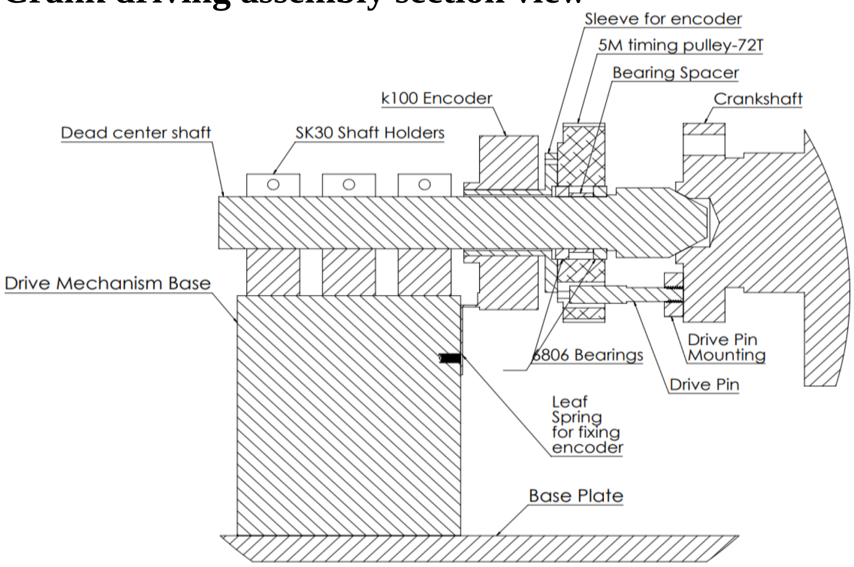


Figure 35- Crank Driving Mechanism Assembly section view

The height of the dead centre axis is 180mm. A NEMA-34 stepper motor is used to drivethe 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 centre is fixed, the pulley and encoder are rotating with the crankshaft during operation.

3.5.4.2 Pneumatic Tailstock

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.

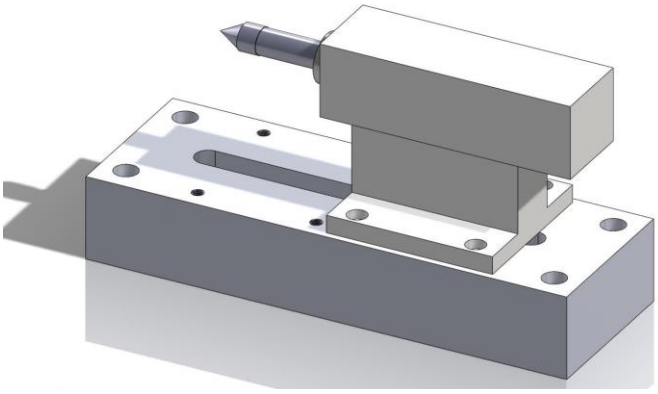


Figure 36- Pneumatic Tailstock Assembly

3.5.5 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 37- Left) HS100 Tower, Right) HG30 Tower

3.5.6 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.

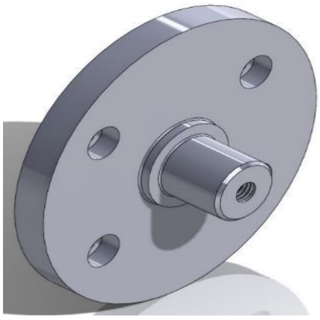


Figure 38- 5204-Bearing Pin

3.5.7 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 39- C-Block Mounting

3.5.8 C-Block Body

This is one of the most crucial parts of this machine. Its design has been iterated and revised several times before reaching an optimum design. 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 14 mm for measurement.

3.5.8.1 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.

3.5.8.2 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 extendedposition when main journal is being measured.

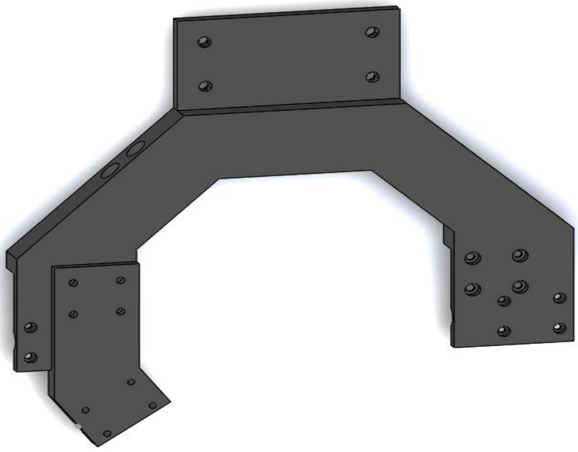


Figure 40- C block

3.5.9 Mounting for φ 8mm and 5mm Carbide Rods

The 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.

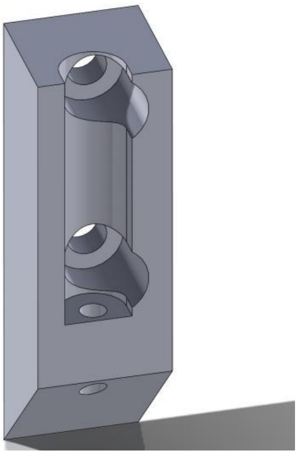


Figure 41- 5mm Carbide Rods Mounting

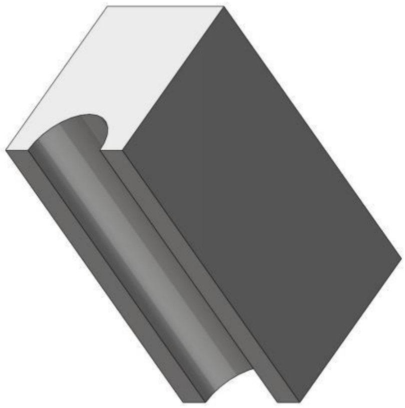


Figure 42- 8mm Carbide Rod Mounting

3.5.10 Clamps for SOLARTRON AT/5/P

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

Figure 43- Clamp for Solartron AT/5/P

3.5.11 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 44- Pneumatic Actuator Mounting

3.6 Design of machine

The design of sub-assemblies is presented in this section.

3.6.1 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

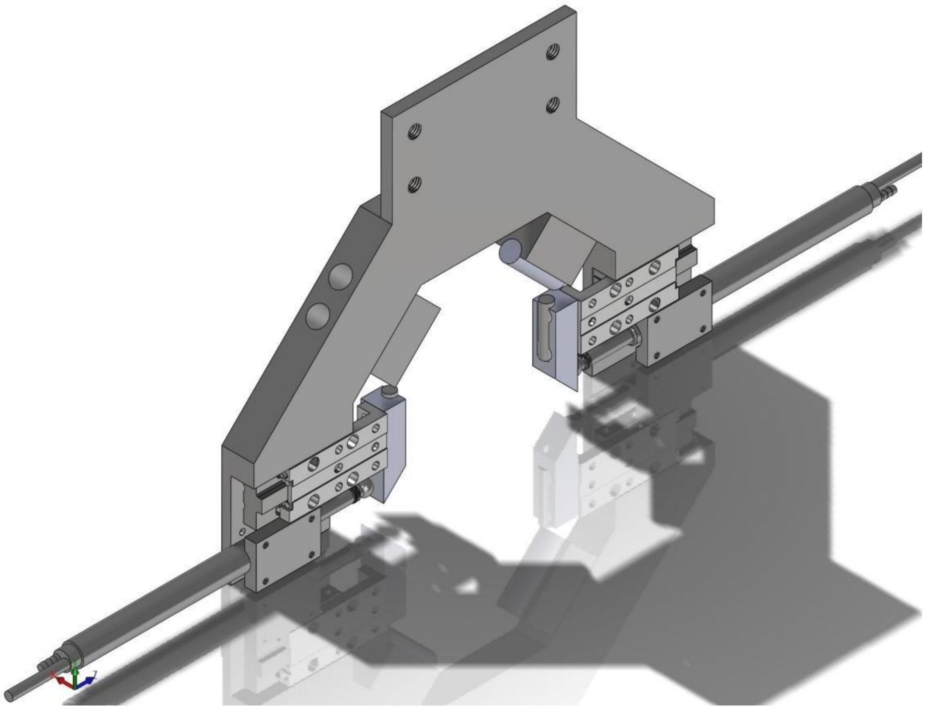


Figure 45- C-Block Assembly Designed

3.6.2 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

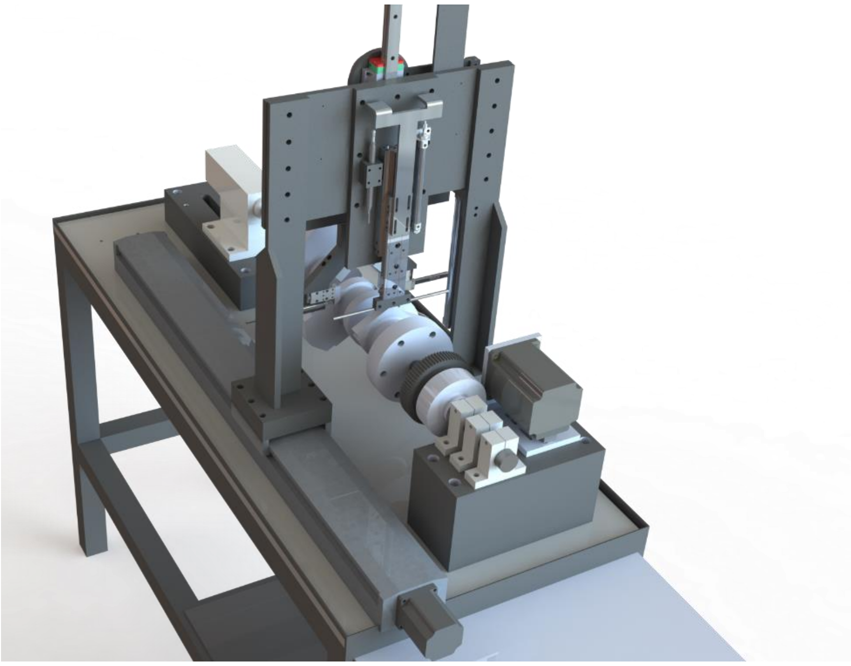


Figure 46- Assembled measurement mechanism

3.6.3 Fully Assembled Machine

Fully assembled machine has following subassemblies:

1. Measurement Mechanism
2. 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.

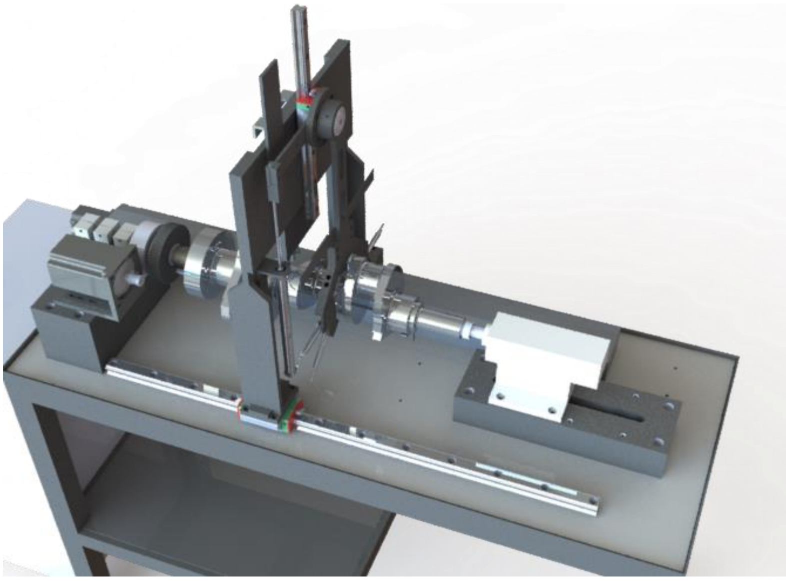


Figure 47- Assembled Machine Design

Chapter No.4

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.

4.1 Testing

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

4.1.1 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 phase angle and its variation in the range of 0.03 degrees. The current setup can take 12000 readings perrevolution. This means that the reading interval can be made as small as 0.03°.

4.1.2 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.

4.1.3 Test design

For the design of test for crankshaft inspection machine, the accuracy and repeatability areof most importance. The test should run repeatedly and the results should still remain same.For current test of the crankshaft, slider having carbide rod is lowered onto the pin journals and the crankshaft is rotated two revolutions. These two turns lift the slider and because of slider LVDT gives readings of rise and fall twice in two cycles. This makesit easier to compare the readings for the phase angle variation.

4.2 Phase Angle Post Processing program

As shown in the figure, LVDT readings (mm) and Encoder data(degrees) that are synchronized have used for post processing. As incremental encoder is used so before index raw data have been deleted and then specified value say(x=34) have been found from the LVDT data at certain angle that are coming from Encoder with the increment of 0.03 degrees. Lift of LVDT that is “x” is noted at two positions and took their average for phase angle measurement. Similarly, same test is taken for all pins of 3-cylinder and 4-cylinder crankshaft and measure phase angle between crank pins

The test setup is shown in the LabVIEW block diagrams as follows

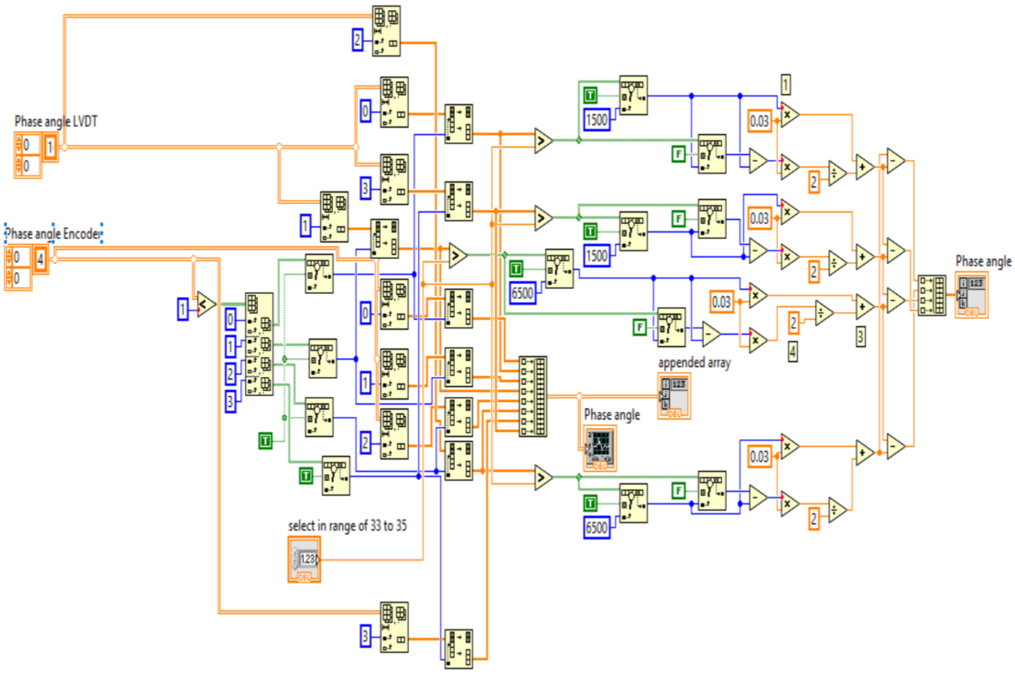


Figure 48- LabVIEW program Block Diagram

Here is the front panel display which shows the phase angle for current 4 cylinder crankshaft so it is showing angle between pin 2 to 1 , pin 3 to 2 , pin 4 to 3 and pin 4 to 1. So pin 1, pin 4 are same so angle between them is zero and pin 2 and 3 is same so angle between them would also be zero.

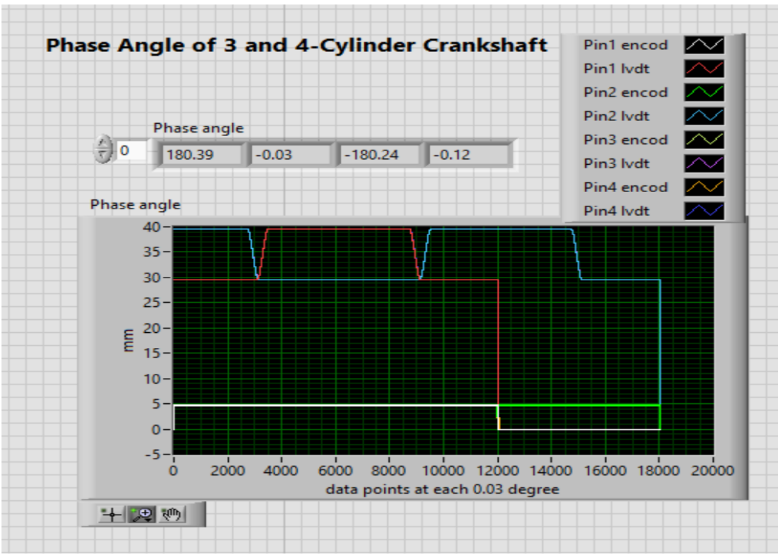


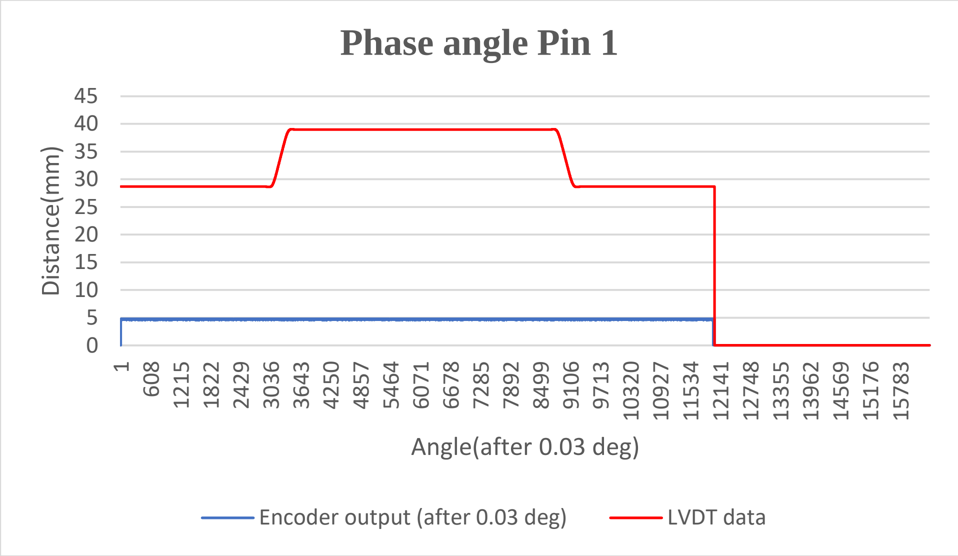
Figure 49- LabVIEW program Front Panel

4.3 Processed Data

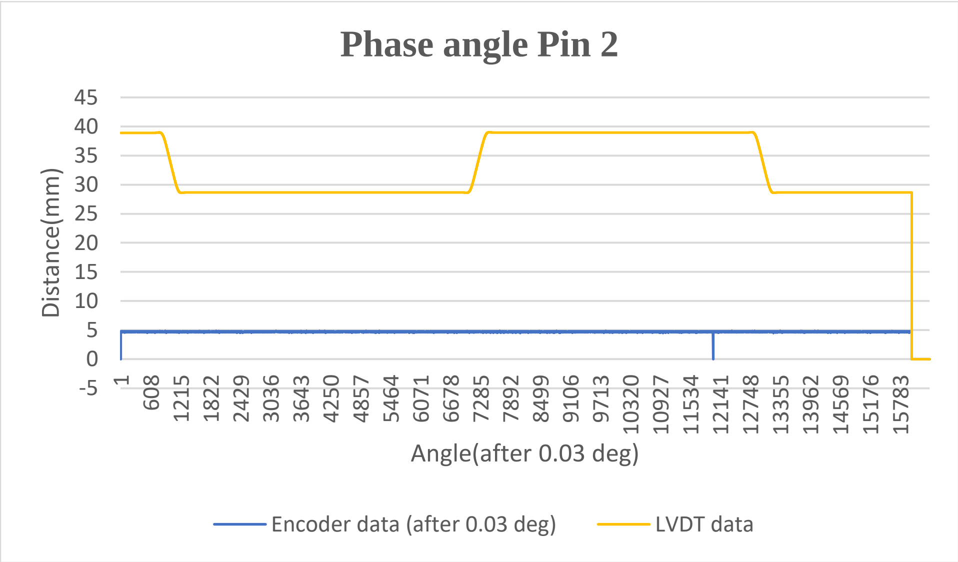
The signal of LVDT is the raw signal is in volts, an orderof 0.001 V. it can be scaled to convert it into microns. The raw data is scaled by applying gain and then the variation in probe to get plots of slider and encoder data to calculate phase angle diameter between crank pins. This is shown below.

4.4 Graphical results

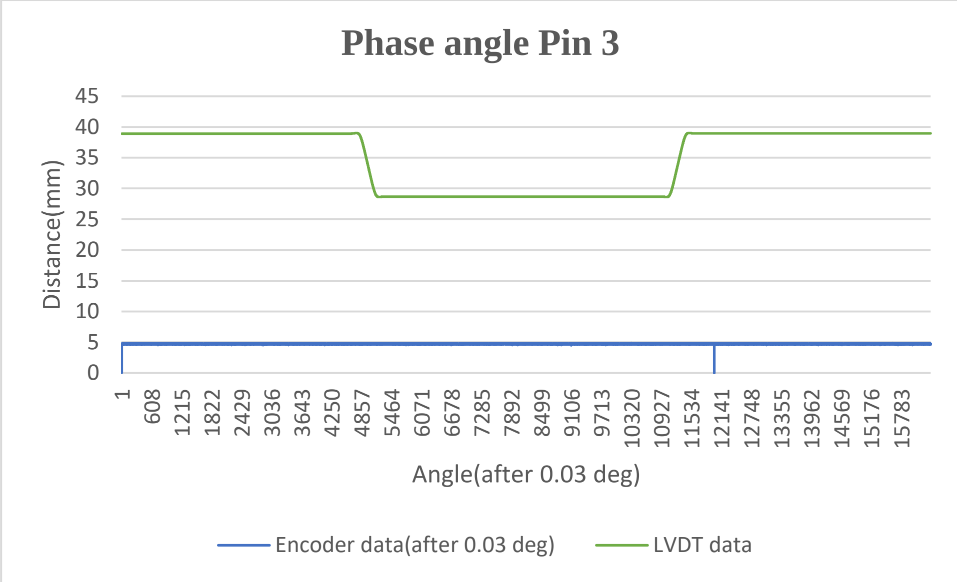
4.4.1 3-cylinder crankshaft



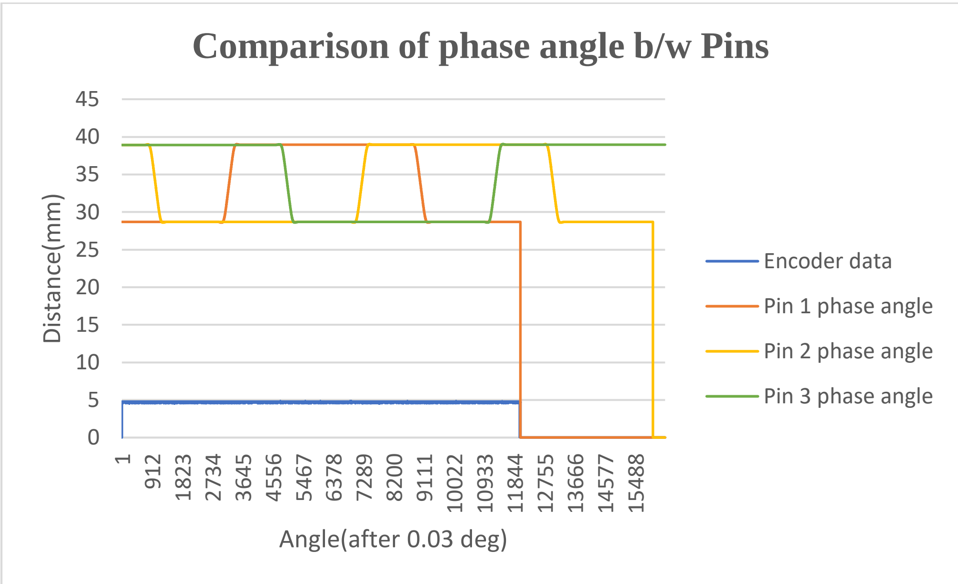
Graph 1-Pin 1 phase angle



Graph 2-Pin 2 phase angle

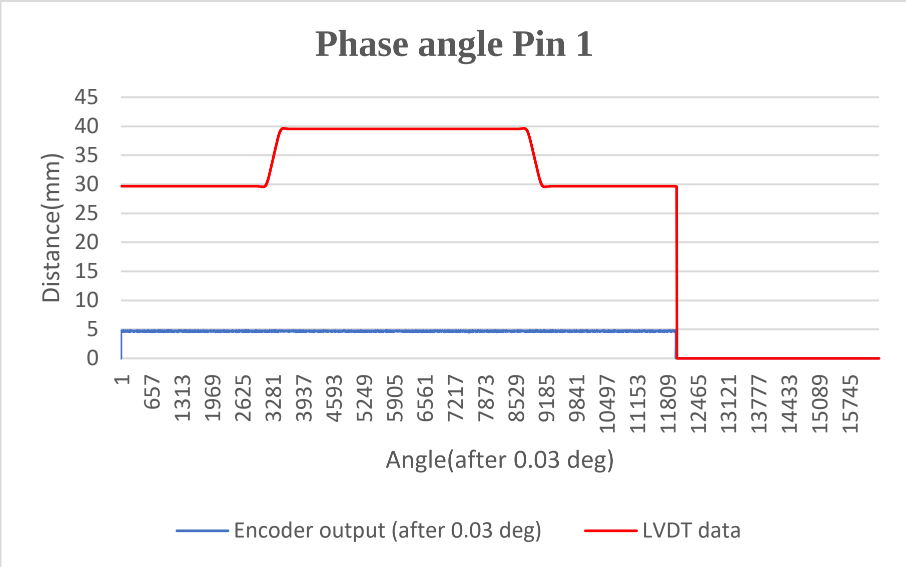


Graph 3-Pin 3 phase angle

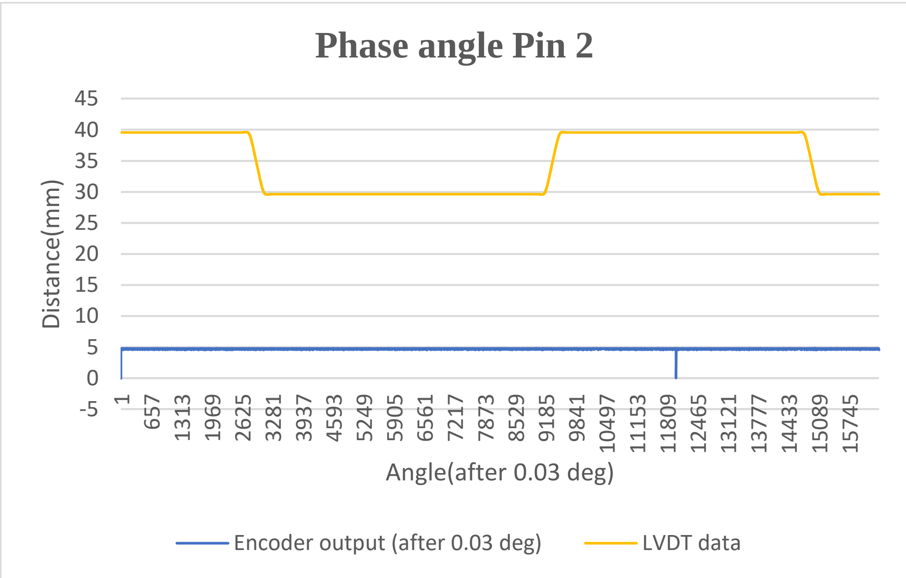


Graph 4-phase angle Comparison b/w pins

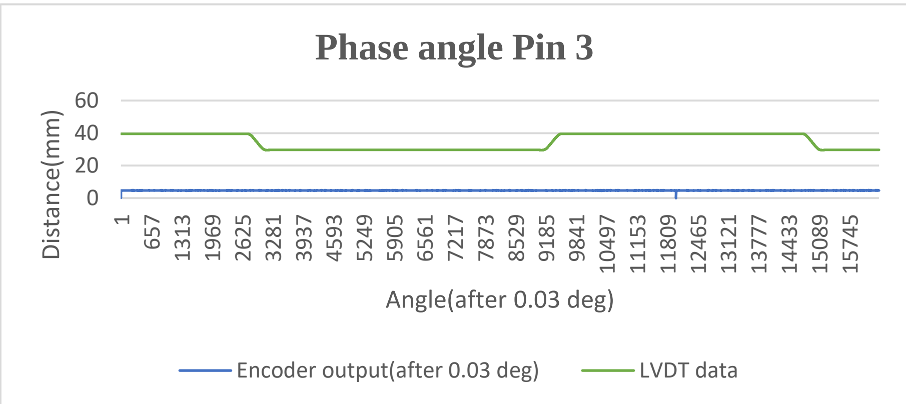
4.4.2 4-Cylinder crankshaft



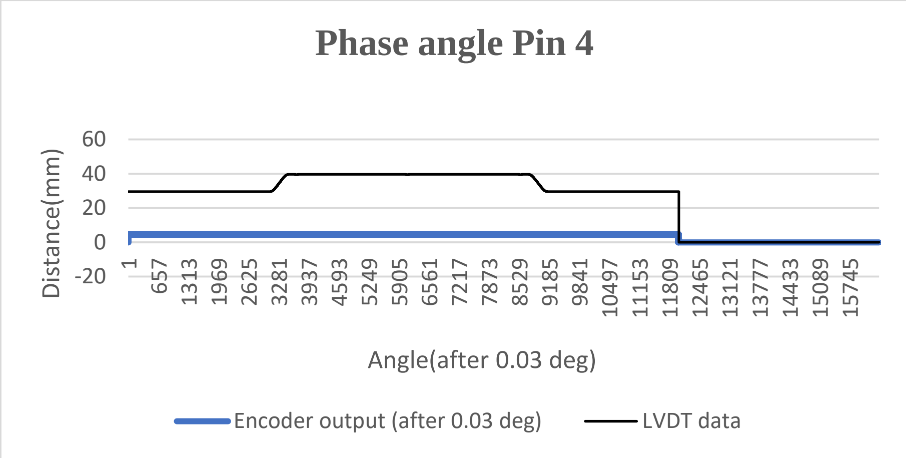
Graph 5- Pin 1 phase angle



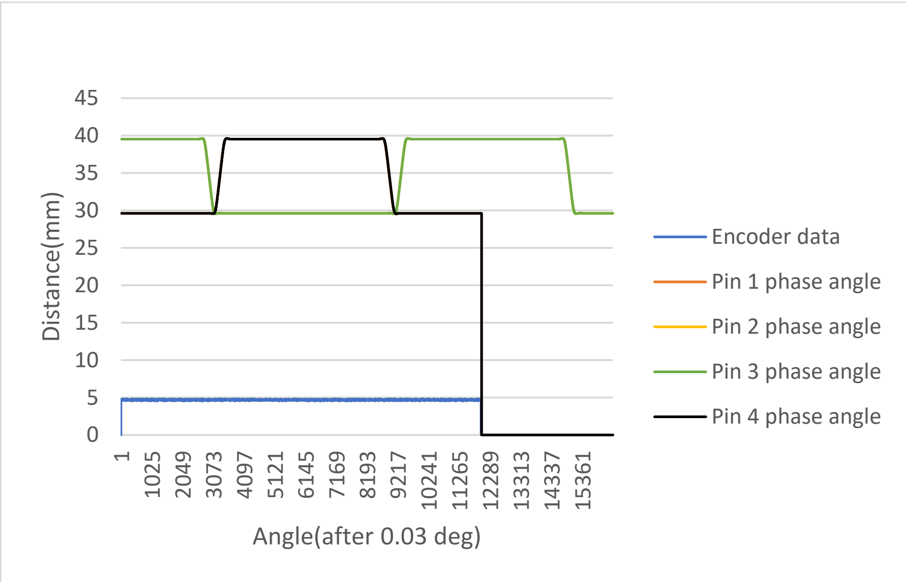
Graph 6-Pin 2 phase angle



Graph 7-Pin 3 phase angle



Graph 8-Pin 4 Phase angle



Graph 9- Phase angle comparison b/w pins

The machine satisfies both the designer and user intended functions. It performs inspectionfor both 3- and 4-cylinder, can effectively measure phase angle between pins.

Chapter No.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.

5.2 Recommendations

5.2.1 Functional Improvements

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

1. As 12000 pulses Incremental encoder is used for angular position so accuracy is limited to 0.03^o 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.

2. The machine can be automated for industrial use for inspection of large crankshafts with different lengths as it is now for just two type of crankshafts.

5.2.2 Design Improvements

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

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

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