Design and Manufacturing of In-Process Grinding Gauge

A Final Year Project Report

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Bachelor's of Mechanical Engineering

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ABSTRACT

The purpose of this project is to design and fabricate an in-process grinding gauge. This project is funded by Hybrid Engineering and will serve as proof of high-level capability of Hybrid Engineering. The gauge will be used to measure external diameter of the shaft which is being grinded by grinding wheel and once the shaft reaches the desired diameter then grinding process will be stopped. This gauge will help to make a grinding process an automated one. One LVDT probe is utilized to take the readings with an accuracy of 1 micron. The accuracy and precision requirements are specified by the Hybrid Engineering. The design of machine components is dictated by the dimensional constraints rather than stress and loading conditions since most components are stationary and have light in weight components to hold. The design is optimized to minimize the effect of friction on it. It is mainly due to innovative arrangement of carbon tips which will measure diameter of shaft and will make line contact with the shaft and thus will reduce the impact of friction. V-type shape is used so that it can get fit on the shaft and thus measure diameter of the shaft accurately.

ACKNOWLEDGMENTS

First of we are grateful to Allah almighty for blessing us with the motivation and persistence to complete this project provided the given situation of COVID-19. We are also thankful to our parents and family for their continued support throughout the project. And we are very thankful to the administration and staff of the School of Mechanical and Manufacturing Engineering for giving 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.

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ABBREVIATIONS

LVDT	Linear Variable Differential Transformer
Al	Aluminum
MS	Mild Steel

CHAPTER 1: INTRODUCTION

In process grinding gauge is a special type of measuring gauge which can measure the external diameter of a shaft while it is being grinded. This gauge has its applications in Industrial Cylindrical Grinding Machines, Crankshaft Grinding, automobile industry etc. This gauge can be a variable one or fixed one. Variable gauge means it has a range of some minimum diameter to some maximum diameter which it can measure. Fixed one can only measure one diameter. Fixed gauge can measure more accurately than variable one because it simply acts as a go/no-go gauge. Each has its use according to its requirements.

This report is focused on the fixed in process grinding gauge which has a very small tolerance because this will be used to measure different shafts which will be going to be used in automobiles so there is not any chance for error in it. This gauge is going to consist of a gauge head in which it has carbide tips in which it is going to hold rotating shaft. Then there is a LVDT inside the gauge head which is going to measure the diameter by converting the change in its length into voltage which by proper calibration will tell us its diameter. A Linear Variable Differential Transformer, or LVDT for short, is an electromechanical position transducer (sensor) which provides accurate and frictionless positional feedback information about the linear mechanical position of an external force or object. Linear variable differential transformer works on the same principle as the AC transformer but instead of supplying a load current or high voltage, it uses basic transformer principles of mutual inductance to measure linear movement.

We have tolerance of +/- 1 micron. Our gauge head is also fixed on an anchor like system in which the gauge head will automatically align itself to make the shaft eccentric. If we don't have a system like this, then it will be hard to measure the shaft's diameter because unless is eccentric with shaft it will give wrong diameter. Our whole gauge is placed on a pneumatic slider. A pneumatic linear slide combines an air cylinder power source with a guide mechanism that supports the workload over a precise linear path. They can perform tasks as simple as a pressing operation, or as demanding as multi-axis robotics. This will help us to move our gauge towards the shaft till it starts touching and then holding the shaft properly. Since the slider is pneumatic so it will not go back the instant it comes in contact with the rotating shaft.

This gauge is connected to the electrical circuit which will be converting signals from the LVDT into potential difference then it will be converted into useful information which by proper calibration will tell us the diameter of the shaft. This electrical circuit will also consist of a program

CHAPTER 2: LITERATURE REVIEW

In this chapter, we'll go over the sources we used to gather information for this project. This covers the specifics of the methods employed and the components that will be utilized. Selection is based on the following criteria:

LVDT

High-precision gauge instruments and other associated apparatus are currently the domain of SOLARTRON. Pencil probes and unique transducers are just two examples of the many sensors/probes available for linear measurements provided by this device. To establish the orientation of the tip of the probe, each probe includes an induction sensor. These sensors are accessible in two alternative combinations: a linear variable differential transformer or a half bridge. Angle and flatness measurement with excellent linearity, repeatability, and high resolution.

1. Automatic gauging with pneumatic probes and mechanical interfaces.
2. Outside diameter measurement using two probes which can easily withstand side load.
3. Inner diameter measurement (bore gauging) using mini probes.
4. TIR (Total Indicator Reading) measurement, which is obtained by the difference of maximum and minimum readings.

5. One of the important post-process gauging applications is the grading of bearing components. The customized gauge blocks and flexures can be sued for this purpose.
6. Process monitoring such as distance travelled by a component of a mechanical assembly.
7. The smaller diameter probes (6mm diameter) are suitable to reach intricate smaller areas for inspection.
8. Inspection of different geometric shapes since they have high repeatability.

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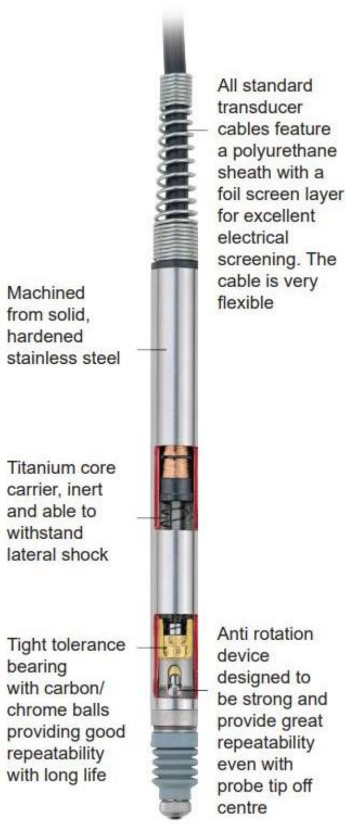

Figure 1 – Solartron LVDT

Header	Header
AX/S – spring push	Spring actuation Measuring ranges: ±0.25, ±0.5, ±1, ±1.5, ±2.5, ±5 & ±10 mm Accuracy:1 µm Repeatability: 0.05 µm Tip force: 0.7N IP65 sealing
AX/P - Pneumatic Push	Pneumatic Gaiter actuation Measuring ranges: ±1, ±2.5, ±5 & ±10 mm Accuracy:1 µm Repeatability: 0.05 µm Tip force: 0.7N IP65 sealing
AJ/P - Jet Pneumatic Push	Measuring ranges: ±1, ±2.5, ±5 & ±10 mm Accuracy:1 µm Repeatability: 0.05 µm Pneumatic actuation using built in piston IP50 sealing
AT - Feather Touch	Measuring ranges: ±1, ±1.5, ±2.5, ±5 & ±10 mm Accuracy:1 µm Repeatability: 0.05 µm Tip force: 0.18N IP50 Sealing
AW - Ultra low tip force	Spring and pneumatic actuation Measuring ranges: ±5 mm Accuracy: 1 µm Repeatability: 0.05 µm Tip force: 0.03 N IP50 Sealing

A6G - Small Diameter Probes (06 mm)	Measurement ranges: ±1mm Accuracy as low as 1 μm Repeatability: 0.05 μm Tip force: 0.7N IP65 Sealing Spring and pneumatic actuation

Table 1 – LVDT Types

Why not optical solution?

Engineers have developed and enhanced optical assessment methods throughout the years as the optical sector has advanced. Direct crankshaft examination equipment, on the other hand, have a far lower price point and are far more reliable. Electromagnetic pollution interferes with the optical sensors' operation, making them less effective in an industrial setting. We determined that optical sensors are a bad option for a multi-purpose crankshaft examination machine after studying this equipment. Optical sensors, on the other hand, have a benefit in a lab setting since they may be completely isolated from electromagnetic noise.

Sliders

The logistics, automation, and precision sectors all make extensive use of electric sliders. Ball screws and feedback servo motors make these preferable to pneumatic lifters for micron-level adjustment because they are exceedingly stable and precise.

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Stepper Motor

Due to its ability to coordinate or sync itself with the output pulse from the controller to driver, stepper motors are frequently utilized for precise placement and speed controls. Two of the most frequent methods of operating a stepper motor are constant current and constant voltage. Torque is difficult to accomplish at high speeds with a constant voltage drive. Constant current drives, on the other hand, can easily produce torque even at greater speeds, making them a convenient and extensively used approach.

Half-step, full-step, and micro-step are the most frequent methods of excitation for stepper motors. The excitation mode can be selected based on the required torque and positional accuracy for a particular application. The stepper motor converts electronic signals into mechanical movements once they have been pulsed. The shaft is progressively moved by each pulse. A stepper motor with a 1.8-degree resolution would require 200 pulses to complete a full revolution of the shaft.

The rotor and stator of a stepper motor are two of the most important components. Rotor 1, Rotor 2, and a permanent magnet complete the rotor assembly. Axial magnetization of rotors means that if one rotor is magnetized toward the south, the following rotor will be magnetic in the north direction. The stator mostly consists of small teethed magnetic poles, each with a winding. In order to have the current flowing in the identical direction through both poles, each windings are linked to the winding on the other side. As a result, a pair of poles known as a phase can be formed. A stepper motor can be a single phase, a two phase, or a five-phase motor, based on the model. The blades on the rotors are physically offset from each other, and the rotor perimeter contains tiny teeth.

Rotor 2's north polarized teeth are drawn to the south polarized poles of phase A, but the south polarized poles of phase A are drawn away from rotor 2. Rotor 2 is polarized south by an offset angle, which causes the teeth of phase B poles to be out of alignment with those of rotor 2, which in turn results in a misalignment between phase B and phase B poles. The teeth of rotor 2's south polarized teeth will be drawn to the north polarized phase B when phase shifts from A to B Because of this, stepping motors rotate perfectly through their resolution angle when excitation switches from one phase to the next.

Dynamic characteristics of a stepper motor include:

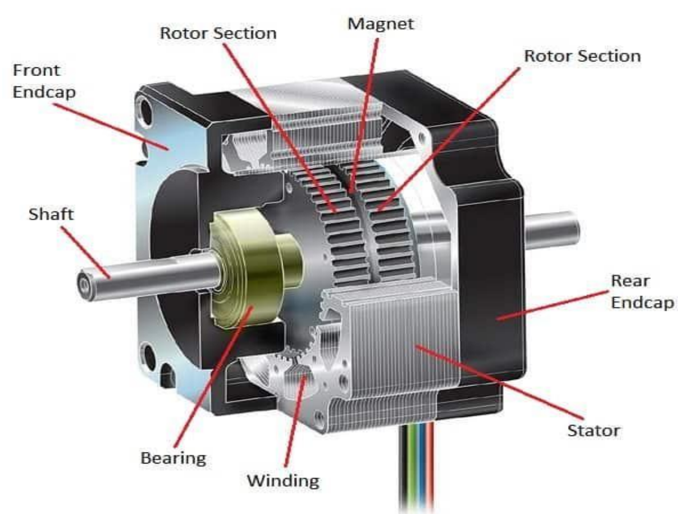

Figure 2 – Stepper Motor

Header	Header
Speed-torque	These characteristics are determined by the type of driver and Motor • When the motor is not running, the maximum holding torque is displayed. • Maximum torque at a particular speed is indicated by the pullout torque. • A motor's maximum starting frequency indicates the greatest pulse speed at which it may stop or start instantaneously, assuming zero friction and inertial loads.
Maximum response frequency	Acceleration or deceleration of the motor gradually shows the maximal pulse rate
Inertial load – starting frequency characteristics	Stepper motors (having inertia) have incorporated certain lags or advances during instant actuation or when the motor stops, and these characteristics show the changes in initial frequency subjected to inertial load.
Vibration characteristics	These characteristics indicate the rotation of motor when a pulse is applied and it accelerates, or when it is about to stop, it overshoots the angle.

Table 2 – Characteristics of a Stepper Motor

DAQ

A data acquisition system consists of the following units:

1. Sensors
2. Conditioning unit
3. DAQ card/module

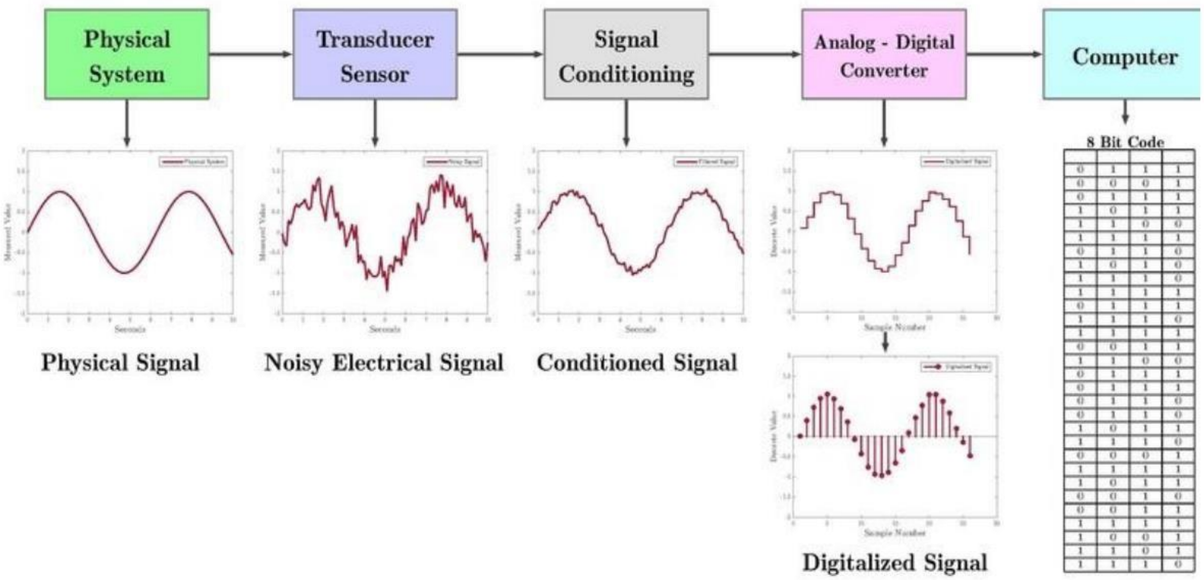

Figure 3 – Data Acquisition Software

Sensors

Physical quantities can be measured and converted into electrical signals using a transducer (also known as a sensing device). In our example, we used a linear variable differential transducer (LVDT) that transforms length changes into voltage changes. Length gauge (LVDT) is another name for this device. In our crankshaft inspection machine, the Solartron LVDT model AT/5/p was chosen as the principal sensor with a resolution of 0.25 microns and repeatability of 0.05 microns

Condition Unit

Clean, amplified, or attenuated noise signals coming from sensors deployed in a system are the primary goals of a data acquisition system's conditioning unit. Due to electrical, optical, or mechanical interference, the signal generated by the sensor is sometimes severely distorted. In other cases, as was the case here, the sensor signal is minuscule in comparison to the physical quantity. This is why the signal is amplified and cleaned by using a conditioning device. Our sensor's conditioning unit is a boxed in-line conditioning module (BICM), which runs on a bipolar DC supply of about 15 volts. An LVDT sensor is used to calibrate the BICM.

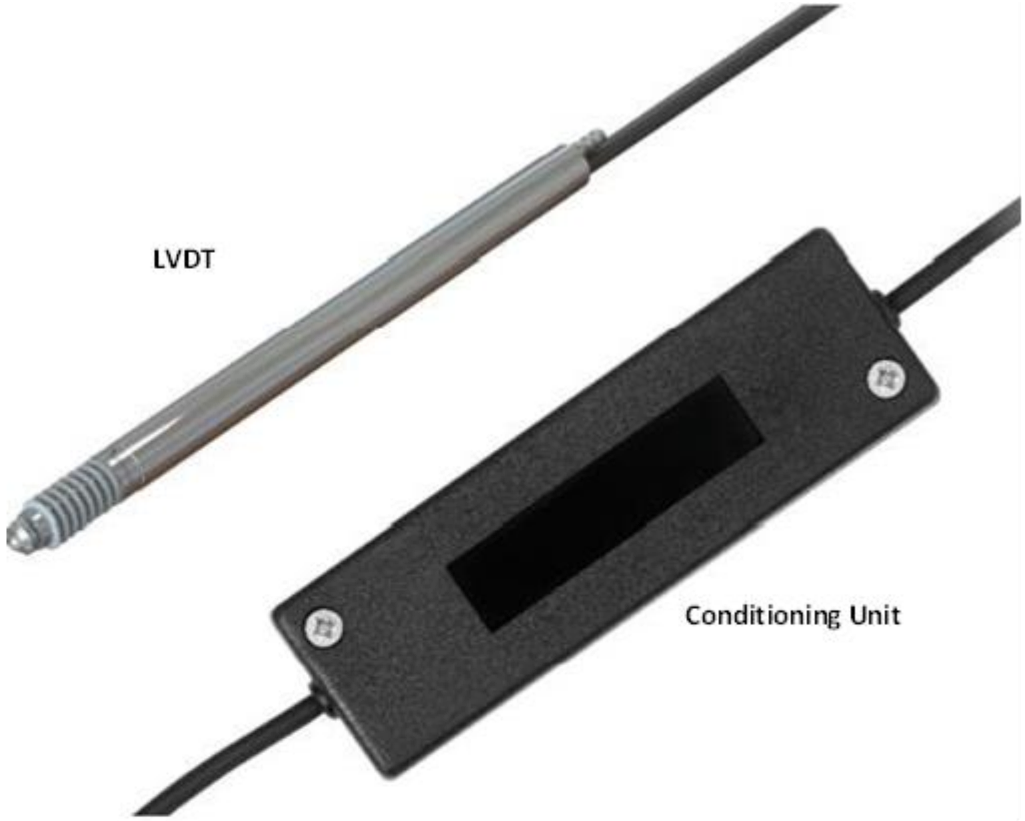

Figure 4 – LVDT with Conditioning Unit

DAQ Module

A data acquisition card or module converts the electrical signal generated by the sensor or conditioning unit to a digital signal that the computer can read. A DAQ card or module has a built-in analog to digital converter, which converts analog signals such as voltage or current to a corresponding digital signal. The DAQ module used in the machine we developed is a National Instruments USB X Series card. It is a multifunction input and output device which provides 16 analog inputs AI and 1MHz sampling frequency. It also provides two analog output channels, and 24 digital I/O channels are also available on this device.

Lab VIEW

Laboratory Engineers use virtual instruments in their designs National Instruments created the graphical programming language known as Workbench, or LabVIEW for short. Data collection, instrument control, and automation are all possible uses for this technology. Given its ease of use and visual data flow depiction, it has been selected for usage in the crankshaft inspection machine. In addition to the front panel, the platform contains a block diagram window. The front panel shows the controls and graphs of the readings while the block diagram window is used for the majority of the programming.

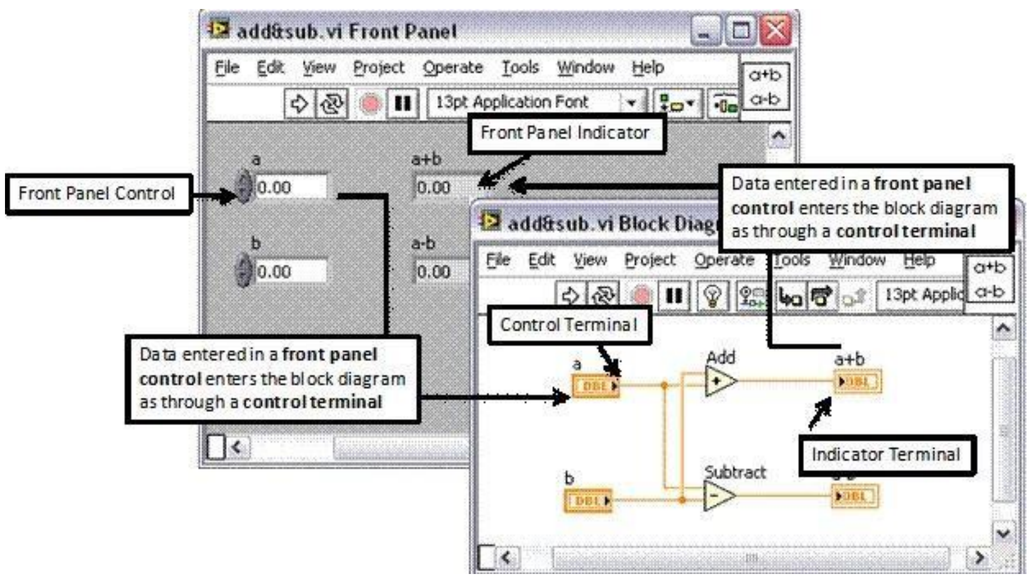

Figure 5 – LabVIEW with front panel and block diagram

Selection of materials

Selection of materials is the most crucial part of the entire system. The whole assembly was required to be made as light as possible. Aluminum is a good material for such lightweight yet not so strong assemblies.

In this project, a combination of Mild Steel (MS) and Aluminum is used depending upon their use in the component being manufactured. As there are a number of different components, each is being manufactured with a different material.

Aluminum

Aluminum is the member of group 13 of the periodic table. That is extremely lightweight and is non-corrosive. Aluminum is relatively soft as compared to the other metals, due to which it is easily machined but it is its main disadvantage too. Due it its low hardness, it cannot be threaded, because the threads would not be able to withstand the force.

Some of the components that are in the project manufactured from Aluminum are:

Density	$2.5 - 2.9 \times 10^3 kgm^{-3}$
Yield Strength	$5 \times 10^8 Pa$
Hardness (Vickers)	$1.18 \times 10^8 Pa - 1.49 \times 10^9 Pa$
Young’s Modulus	$6.8 \times 10^{10} Pa - 8.2 \times 10^{10} Pa$

Table 3 – Properties of Aluminum

The arm

The purpose of arm is to hold the LVDT and as an attachment between the gauge head and the main shaft. The profile of the arm is rather complex and hard to manufacture, also it should be light weighted to decrease the lateral load on the shaft. It should be hard enough to hold the gauge. So, we chose aluminum.

The holding block:

The holding blocks are used to hold the shaft in place and to join the whole assembly with the base plate. They are available in different sizes in market. They are usually made of aluminum, so we also went with the aluminum ones.

Mild Steel

Apart from Al, the second main component used in the project is Mild Steel. (MS). Due to its wide availability in the market and easy machineability it was considered. Some other reasons for its considerations are:

- High tensile strength
- High impact strength
- Easy availability
- Low cost

The components manufactured from Mild Steel are:

The Gauge Head

It is the most important and critical part of our assembly is the gauge head because that is the component that will be in contact with the grinding shaft and will face most vibrations and stresses. So, the head should be firm, sturdy and have high strength. So mild steel was chosen for this part as it is commonly available and can be machined rather easily than other hard forms of steel.

The main shaft

The main shaft is the one that will hold our aluminum arm and will provide pivot for the movement of the arm. The whole weight of the arm and the gauge will act on this shaft so it should be hard, sturdy and have high strength. So, we chose mild steel for the shaft too.

Base Plate

The base plate is the one on which the whole assembly rests. So, it should not deform when subjected to high vibrations or stresses due to the grinding shaft. So mild steel was chosen for the base plate too.

CHAPTER 3: METHODOLOGY

Details about each component's design needs as well as the criteria used to pick them have been outlined in this chapter. Finally, the final design for manufactured components has been shown at the end of this chapter.

One Point Method

This method was First, there was talk of using this approach. Using this procedure, the diameter of the shaft is only tested at one time throughout the grinding process. However, there were certain drawbacks to this plan. This design does not distinguish between the spindle mistakes and the actual measurement errors... You can think of the runout approach as being similar to a Coordinate Measuring Device (CMM).

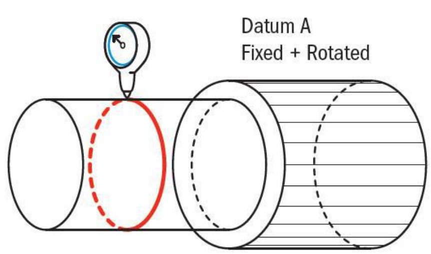

Figure 6 – One Point Method

V-Gauge Method

Finally, we were able to include this concept into our final model because it eliminated most of the problems connected with the One Point Method. A V-Shaped block or Gauge Head is utilized in this procedure. Using a V-shaped gauge avoids the need for an LVDT to accurately center the shaft. The spindle inaccuracies connected with the measurements will be eliminated because the shaft rests on the gauge itself.

A mathematical model governs this procedure. Using this design for flexible measurements is not viable because the Relative angle of the Gauge has to be modified based on the shaft diameter. Carbide blocks were put in the gauge to prevent it from being ground down by the shaft being forced against it repeatedly.

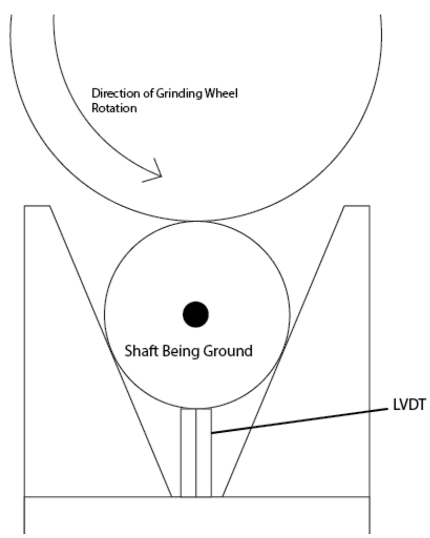

Figure 7 – V-Gauge Method

SELECTED COMPONENTS

Components that are used in this project, either locally acquired or internationally shipped, are discussed below:

Slider

Sliders are used widely in the industries to move components. They are extremely precise and have minimum tolerances. In our project we used SMC MXQ8-75. The MXQ precision slide is ideal for applications requiring closely held parallelism and perpendicular specifications. The table and bearing guide are integrated into one precisely machined part made of hardened stainless steel. This minimizes tolerance stack-up associated with multiple part assemblies and affords height tolerances of +/-0.05mm. The bearing is a recirculating linear guide in a stainless-steel housing.

Series and Specifications	SMCQ-75
Stroke Length	75mm

Table 4 – Specifications of the slider

DAQ Card

In order to feed LVDT's analogue signal into the computer, it must be transformed into a digital signal first. Since digital signals are generated from analog signals, an acquisition card is needed. An analogue-to-digital converter (ADC) is included. It has the following features:

Analogue Inputs	16
Digital I/O	24
Analogue Outputs	2
DIO max clock rate	1MHz

Table 5 – CAQ Card Specifications

Figure 8 – DAQ Card

LVDT

LVDTs are extremely precise instruments that can only be used in a limited number of circumstances. However, there are not many possibilities for high-precision, highly repeatable, and accurate LVDTs in the LVDT market. SOLARTRON metrology is the most suitable alternative in this situation. Sub-micron precision and repeatability are the hallmarks of their LVDTs. Omron and TEConnectivity are other key competitors. These images aren't up to SOLARTRON's standards in terms of quality and accuracy. In addition, the needed measurement range is not available with the same resolution and accuracy. [8]

SOLARTRON metrology's AT/5/P LVDT probe was chosen. It's a spring- or pneumatic-powered feather touch probe. Spherical Tungsten Carbide is used for the tip. In addition, there are more dimensions:

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).

For our particular application, a much longer tangent line (at least 13mm long) is required to measure the main and pin journal dimensions, even though blade style tips are provided. Spherical carbide-tipped drill bits were selected for this reason.

Figure 9 - LVDT

Carbide Tips

Carbide tips that are rectangular in shape are placed at the points where the shaft will touch the gauge head. The main purpose of using them is to prevent the grinding the of the gauge due to the continuous contact with the shaft. As carbide is extremely hard when compared to mild steel, it will not grind and will maintain the original angle. They have following dimensions:

Height	8mm
Width	15mm
Thickness	3mm

Table 6 – Dimensions of LVDT

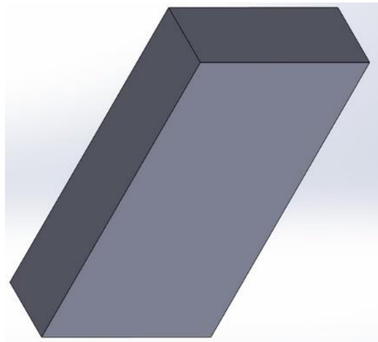

Figure 10 – Carbide Tip

Arm

The whole gauge head will be mounted on the arm, which is manufactured from aluminum. The arm will be simply supported on ball bearings which will allow the free rotation. A scree will be attached on the lower side of the arm to stop the rotation of the arm. A hole is made at the rear end of the arm to generate a counter moment, so that it doesn't bend too much due to the weight of the gauge head.

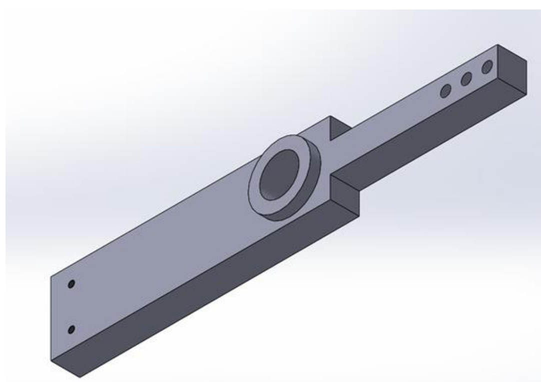

Figure 11 - Arm

Bearings

The arm will be supported on the deep groove ball bearings, they are 10mm in diameter and are two in numbers, one on each side. The dimensions of the bearing are:

Model	SKF-6203-RS
Inside Diameter	10mm
Outer Diameter	30mm
Thickness	9mm

Table 7 – Bearing Specification

Figure 12 – SKF-6203-RS

Support Brackets

These vertical brackets are used to hold the main shaft from both sides. These have screws to loosen or tighten the shafts on both sides. And the screws on the bottom to place the support block firmly on the base plate. The dimensions of this block are:

Height	33mm
Width	41mm
Thickness	14mm
Locking Bolt Size	M3
Clamping Bolt Size	M4

Figure 13 – Support Bracket

Sleeve

The arm is to be tighten from both ends, it will exert a force on the bearings and will restrict their rotation. A sleeve will be inserted on the main shaft, which will fit between the inner and outer race of the bearing (thickness). It will keep the bearings on their place and can allow for a more rigid assembly.

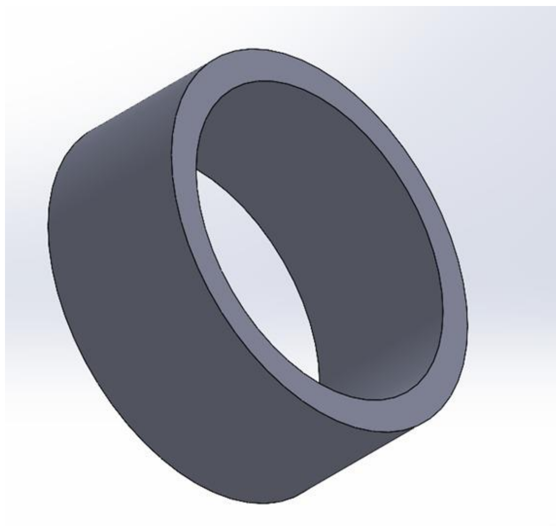

Figure 14 - Sleeve

Cutting Oil

However, outside the scope of our project, normal cutting oil was used, because there was no special requirement for it, other than that it must keep the contact point of LVDT tip and Shaft cool, so that the readings are not dis

CHAPTER 4: RESULTS AND DISCUSSIONS

This discussion includes all the working procedures and software that were used in it. All the steps along with all the empirical and mathematical data.

Working of V-Gauge Method

The gauge is held between by a tailstock and a stepper motor. Stepper motor rotates the shaft at desired speed. The tailstock and the motor are fixed onto the table. A grinding wheel is being pressed onto the shaft, which will grind the shaft to our required diameter. The Gauge head will also be pressed onto the shaft (see figure 2). As the wheel will grind the shaft, its diameter will decrease and when it happens the shaft will move further into the gauge. When it happens the shaft will press the linear variable differential transformer (LVDT) which will give the linear travel distance by the shaft. So, a relation can be established between the diameter of the shaft and linear distance travelled. A control system will be established which will disengage the grinding wheel as soon as the required diameter is achieved.

Tilting and Grinding Effects

In V-Gauge method there is a problem of tilting of gauge. The gauge must not be tilted in order to measure the exact linear travel of the shaft. So, to keep the LVDT and the Gauge aligned, V-shape was used. The gauge is fixed on the arm that helps to keep the LVDT aligned. To overcome the grinding effects, the carbide tips are used. As carbide is extremely hard and whereas the gauge material is soft (Mild Steel). As the shaft must maintain a constant contact with the gauge, the shaft can possibly grind the gauge. So, carbide tips are only placed in the slots made in the gauge at the points where shaft will touch it.

Figure 15 – Gauge Head (isometric View)

SolidWorks Simulation Study

A Solidworks simulation study was conducted for the optimum angle of the gauge head. We required a linear distance which should be large enough to be measured easily and not large enough to exceed the reading measurement of LVDT. The Solartron LVDT which is used in our case can easily detect linear changes up to 1µm. The optimum angle came out to be 8o, but due to manufacturing limitations 10^{o} was chosen. At an angle of 10o the linear change in distance when the shaft is ground by 1µm came out to be 2.88µm. The graph from the simulation study is attached below:

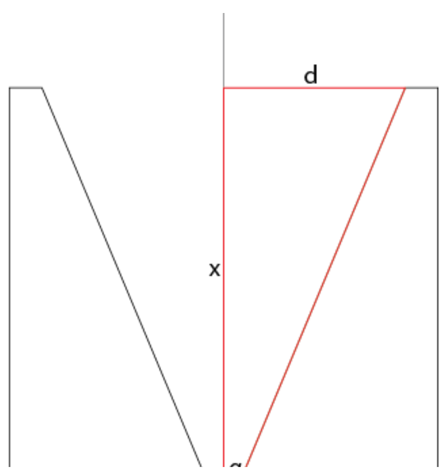

Figure 16 – Side View of the Gauge

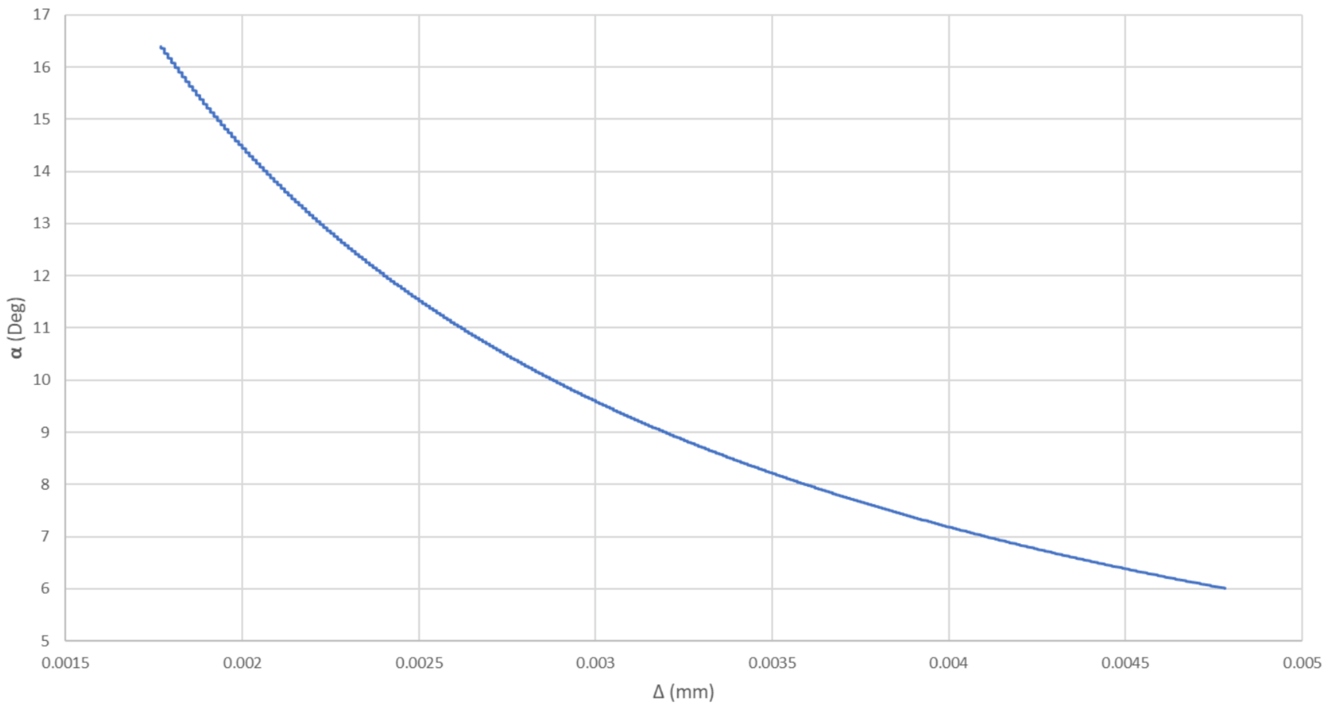

Figure 17 – Angle Vs Distance

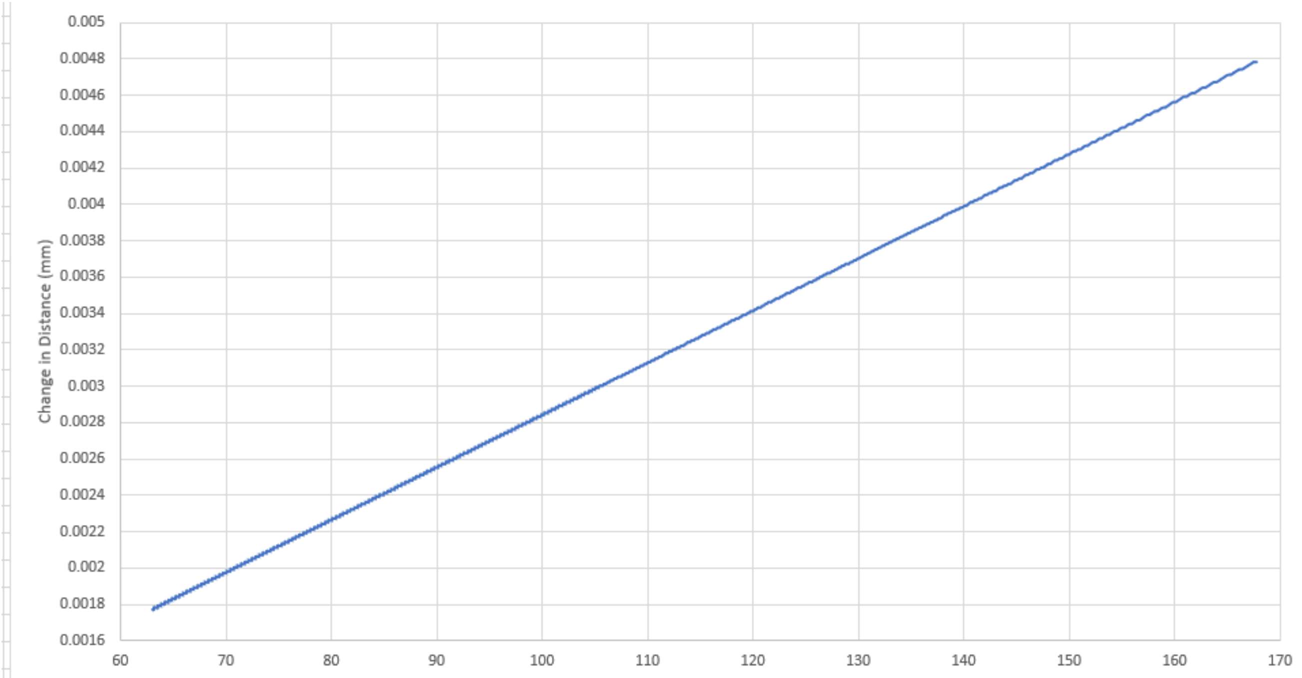

Table 8 – Linear Distance of LVDT vs Change in Diameter of the Shaft

The above graph shows the experimental data that links that change in the diameter of a shaft (50mm). As the shaft is being ground, the LVDT is pushed towards the shaft. So, the LVDT is in contact with the wheel all the times. The signal is passed through the QAD card which changes it into the digital signal and the result is shown above.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Aluminum and Mild steel were used in the project depending upon the use of the part being manufactured. The machining of the parts was carried by a number of machines, all being utilized from the Manufacturing and Resource Center (MRC). In this way the aim of manufacturing an In-House In-Process Grinding Gauge was achieved.

The issues encountered during the fixing and simulating were resolved by repeated testing and experimentation. The shaft is mounted on a self-center chuck and is held onto the place by a tailstock on the other end. The camshaft is rotated by a Stepper motor which is discussed in the above sections of the report.

LVDT is mounted on a SMC-MXQ75 linear slider, which is spring loaded, so as to maintain a contact with the shaft at all the times.

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APPENDIX I: TECHNICAL DRAWINGS OF MANUFACTURED COMPONENTS

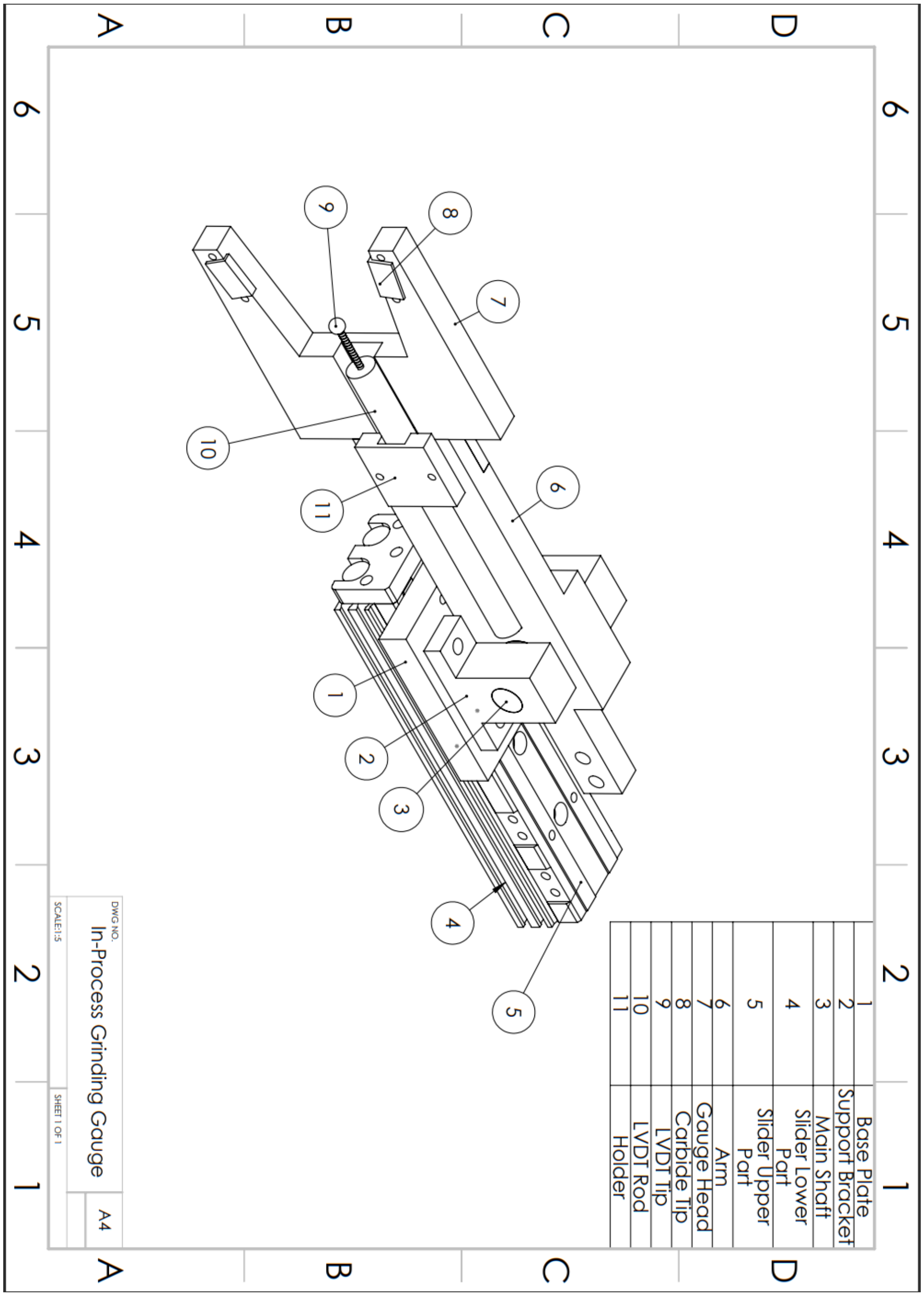

Figure 18 – List of Components

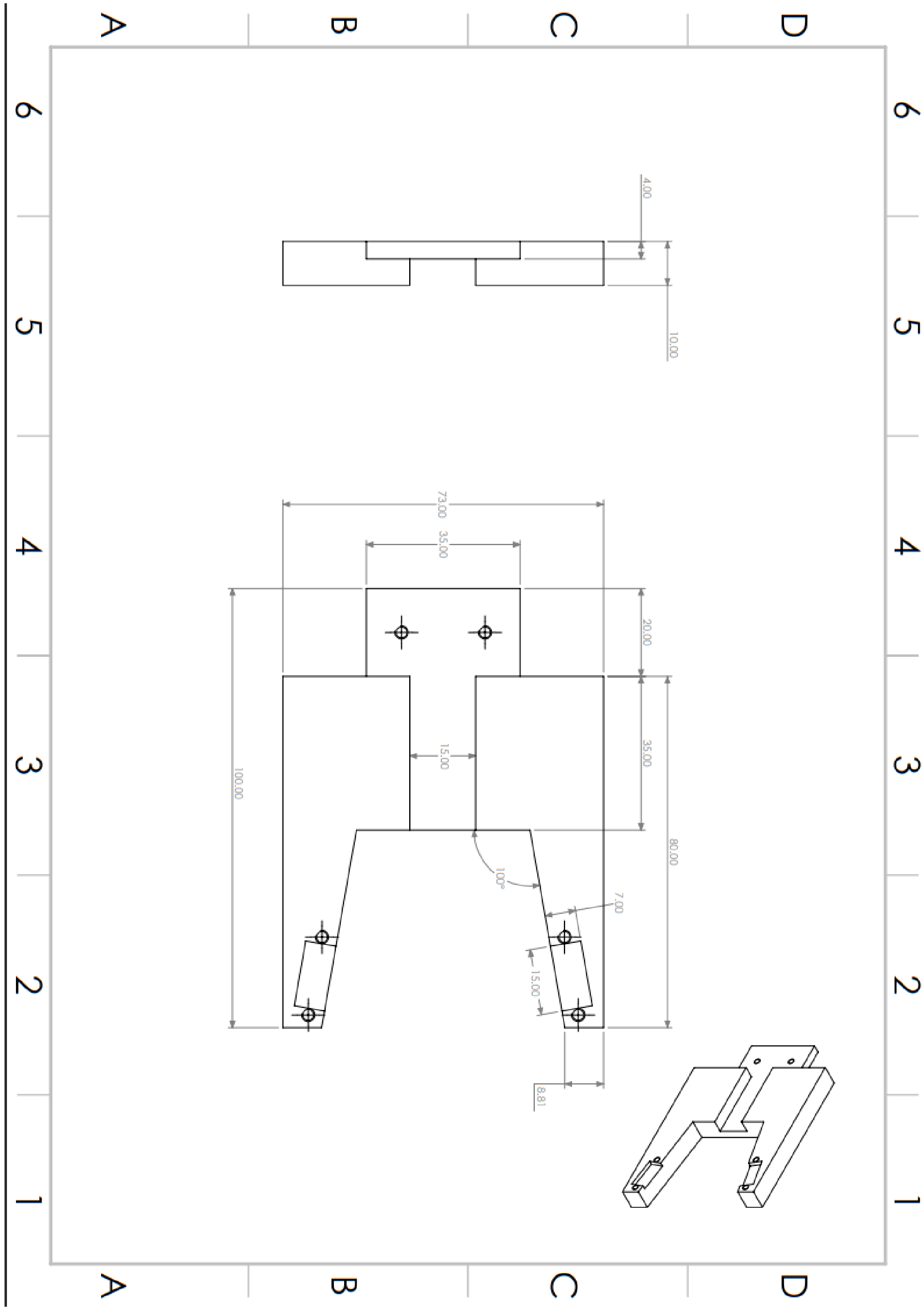

Figure 19 – Gauge Head

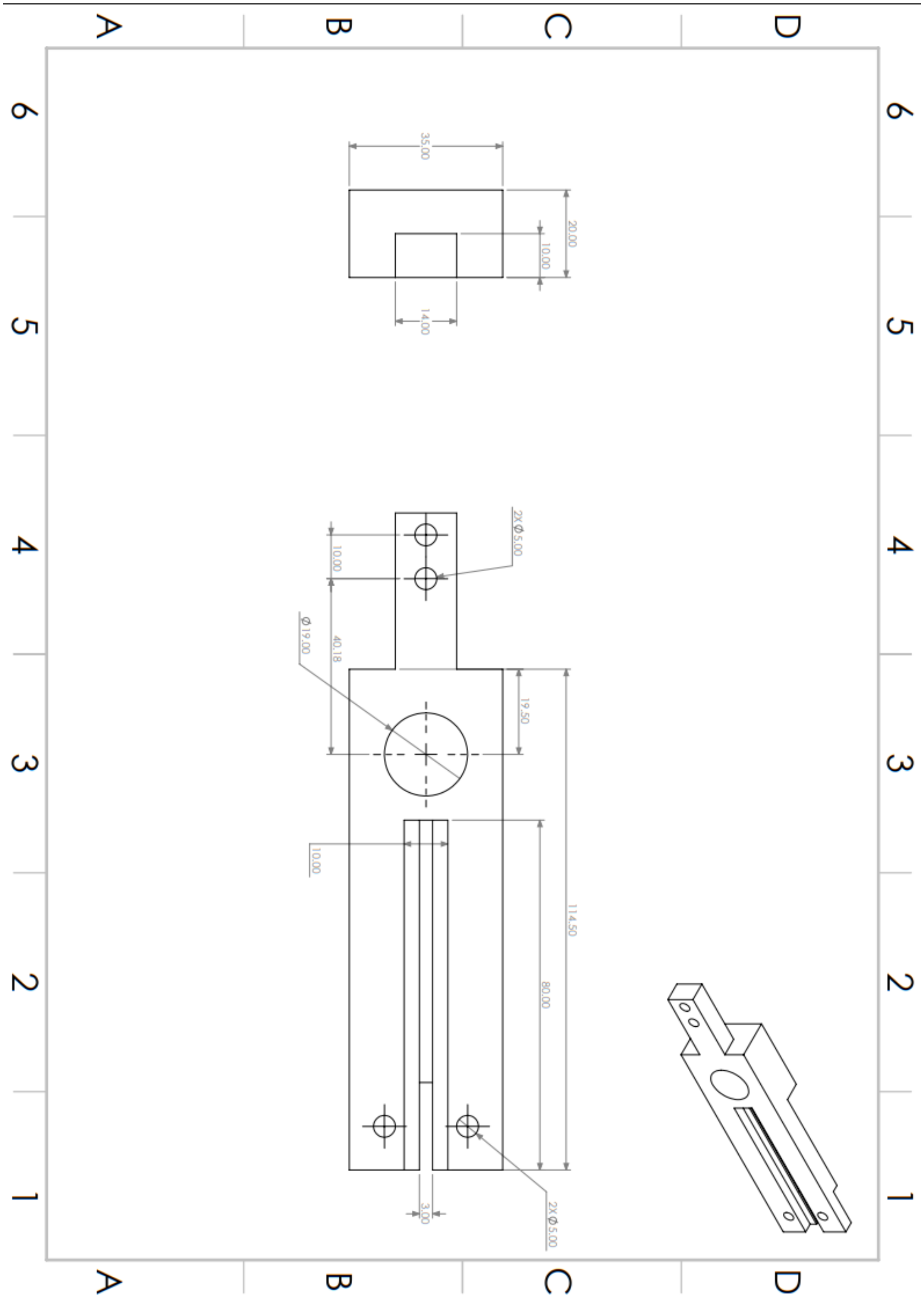

Figure 20 - Arm

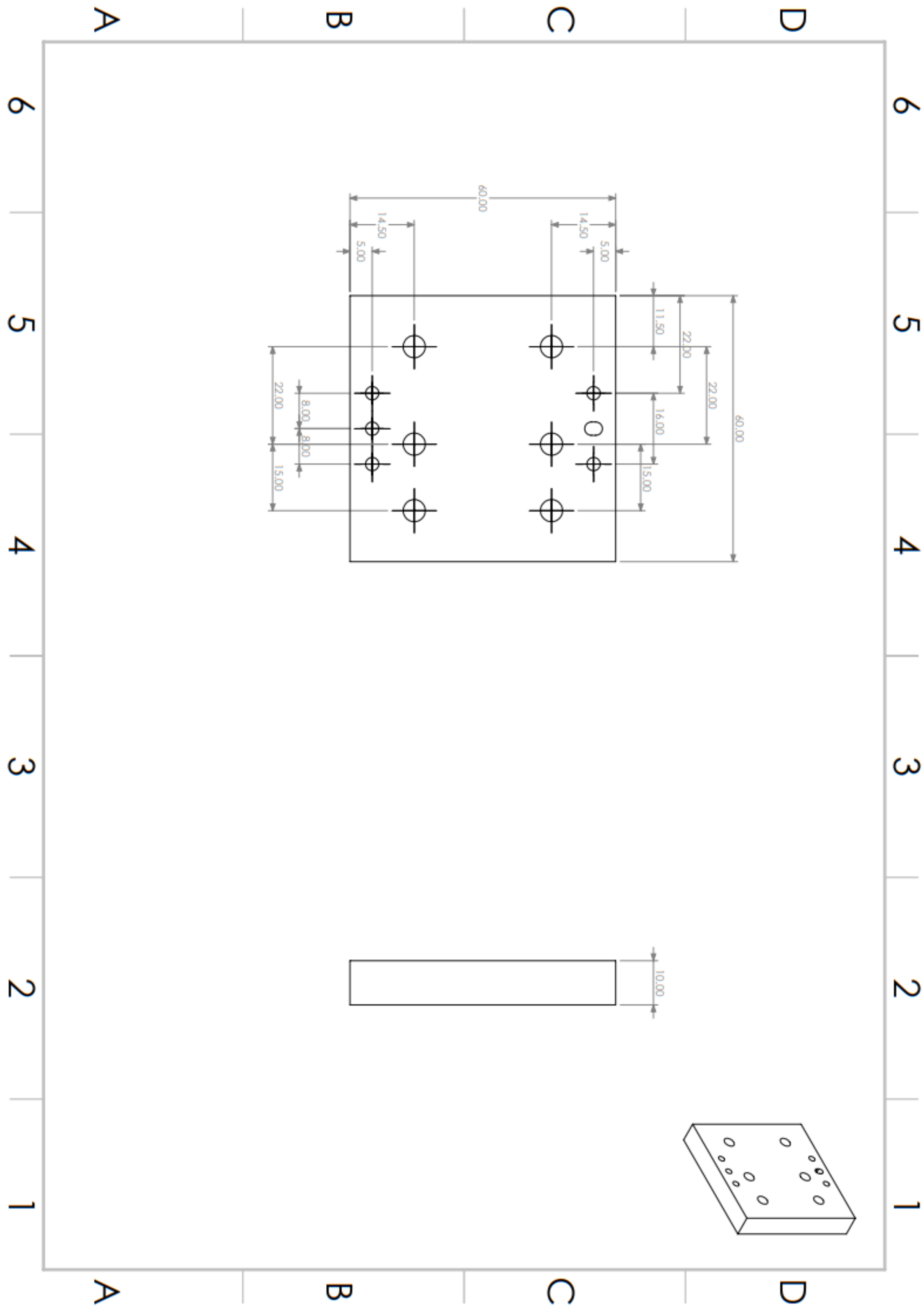

Figure 21 – Base Plate

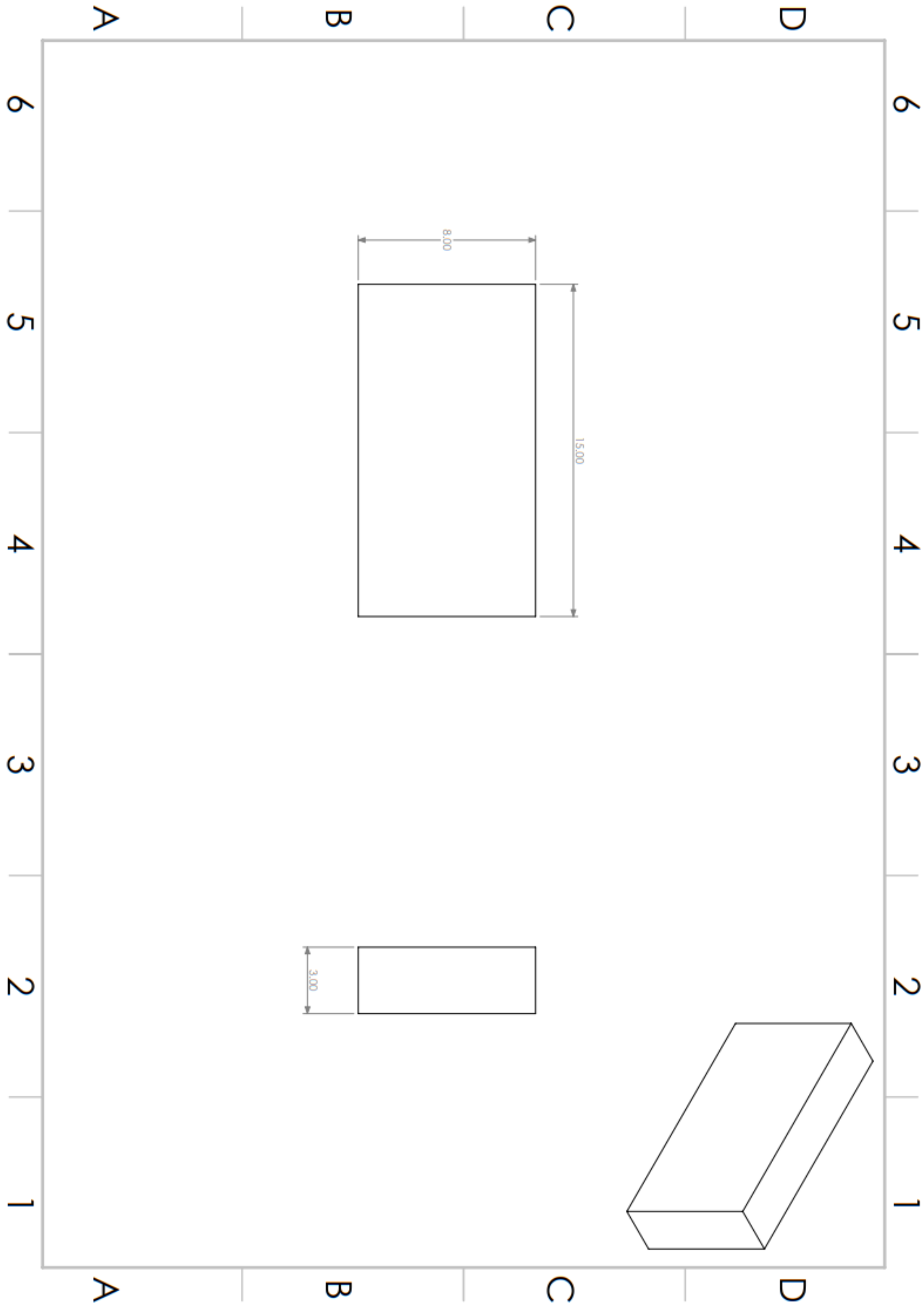

Figure 22 - Carbide