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HÜDRODYNAAMILIST LAAGRIKAELA KANDVA SEADME MODERNISEERIMINE JA DISAIN

MAGISTRITÖÖ

MEHHATROONIKA ÕPPEKAVA

Üliõpilane: Modith Hadya Leelananda
Üliõpilaskood: A146458
Juhendaja: Dmitry Shvarts

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AUTORIDEKLARATSIOON

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TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING

Department of Electrical Power Engineering and Mechatronics

MODERNIZATION AND DESIGN OF HYDRODYNAMIC JOURNAL BEARING APPARATUS

HÜDRODYNAAMILIST LAAGRIKAELA KANDVA SEADME MODERNISEERIMINE JA DISAIN

MASTER THESIS

Student:	Modith Hadya Leelananda
Student code:	A146458
Supervisor:	Dmitry Shvarts

Tallinn, 2017

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently. No
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LÕPUTÖÖ ÜLESANNE

Üliõpilane: Modith Hadya Leelananda

Õppekava, peaeriala: MSc Mehhatroonika, MAHM 02-2013

Juhendaja: Dmitry Shvarts, teadur, Elektroenergeetika, ja mehhatroonika instituut, Tallinna Tehnikaülikool

Konsultandid: Dotsent, Mehaanika ja tööstustehnika instituut, Tallinna Tehnikaülikool

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School of Engineering

THESIS TASK

Student	Modith Hadya Leelananda
Study programme, main specialty:	MSc in Mechatronics, MAHM 02-2013
Supervisor:	Dmitry Shvarts, Research Scientist, Department of Electrical Power Engineering and Mechatronics, Tallinn University of Technology
Consultants:	Priit Põdra, Associate Professor, Department of Mechanical and Industrial Engineering, Tallinn University of Technology.

Assignments to be completed and schedule for their completion:

1. Study of the previous works related and comparing the existing apparatuses with Feb-17 our apparatus
2. The design of the existing apparatus.   Feb-17
3. Designing of the new mechanical and control system   Mar-17
4. Compiling and writing the report   Apr-17
5. Thesis report compilation and changes recommended by the supervisor.   May-17

Engineering and economic problems to be solved: Modernization of the existing old apparatus by new components and design. Making the apparatus to be worked in a safer and easier environment, the comfortable way by using numerous solutions.

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Supervisor: Dmitry Shvarts   /Signature/………..   Date………

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FOREWARD

This thesis was written as a part of my Master degree program in Mechatronics at the Tallinn University of Technology. This work is related to the laboratory apparatus which is present in the Tallinn University of Technology in a dismantled state. The purpose of the work involves the modernizing and redesigning of this apparatus which incorporates suggesting the missing parts available from the market. It additionally incorporates the system is being monitored and controlled by using a Human Machine Interface. This work consists of mechanical, electronic, and software field's integration.

I express my deep sense of gratitude to my Supervisor, Dmitry Shvarts for his guidance in each step and providing abundant knowledge and experience throughout the study. I would like to thank my secondary supervisor professor Priit Põdra for his guidance on the subject, without which this thesis would not have been possible. I would also like to thank Robert Hudjakov for the supervision and guidance in writing the paper. I would like to thank the people who are directly or indirectly connected to the following work. I would like to thank the department of Mechatronics, my primary and secondary supervisors for their suggestions, encouragements, and guidance in writing the thesis and approaching the different challenges during the thesis. Finally, I would like to thank my parents for their constant support and encouragement to me during the all the times.

EESSÕNA

Käesolev lõputöö on kirjutatud seoses minu Tallinna Tehnikaülikooli magistriõppe programmiga mehhatroonika instituudis. Lõputöö on seotud ülikoolis asuva demonteeritud laboriaparaadiga. Töö üks eesmärke on kõnealuse seadme moderniseerimine ja ümber disainimine soovitades vastavalt turul pakutavale puudu olevaid osi. Süsteemi jälgib ja kontrollib HMI (Human Machine Interface). Käesolevas töös on ühendatud mehaanika, elektroonika ja tarkvara valdkonnad.

Tänan südamest oma juhendajat Dmitry Shvartsi mind igal sammul juhendamise ja oma rikkalikku kogemuste- ja teadmistepagasit minuga jagamise eest läbi kogu magistriõppe. Tahaksin tänada ka oma teist juhendajat Priit Põdrat, kelle nõuanneteta poleks magistritöö kirjutamine võimalik olnud. Tänan mõlemat juhendajat mind suunamast, julgustamast ja minuga kogu töö kirjutamise vältel erinevaid väljakutseid ületamast. Lisaks sooviksin tänada Robert Hudjakovit tema nõuannete eest ning inimesi, peamiselt mehhatroonika instituudist, kes on otseselt või kaudselt seotud käesoleva magistritööga. Lõpetuseks tahaksin tänada oma vanemaid nende alalise toetuse ja julgustamise eest.

1 INTRODUCTION

Modernization is an inevitable process. Modernization and the updating of the system are done in every part of the consistent life, where one need to upgrade to the rapidly developing environment. This paper deals with the redesign and upgrading of the old journal bearing apparatus present in the laboratory of the Tallinn University of Technology. It is a laboratory equipment for examining the pressure distribution in the journal bearing.

1.1 Problem statement

Laboratory of machine elements of the university has a disassembled journal bearing device with some parts absent. The work involves the designing of this missing parts along with the development of the other necessary parts to deliver a complete equipment with which could be used to examine the pressure distribution in the bearing and testing different material for the shaft as well as the bearing. The redesigning of the device includes the loading system, bearing, and shaft. The main task of the work is explained in Figure 1.2.

Figure 1.1 demonstrates schematic diagram of the journal bearing apparatus which must be developed. The system to be designed includes the mechanical system and the control system. In the loading system, the load gauge must be replaced as per designing requirements. The loading system is old and consumes an unnecessary space. This has been explained in detail in chapter 2. In the control system, need to suggest and design the drive system for the shaft which must be able to rotate at different speeds. The task also involves the controlling of this drive system using a human-machine interface through a personal computer.
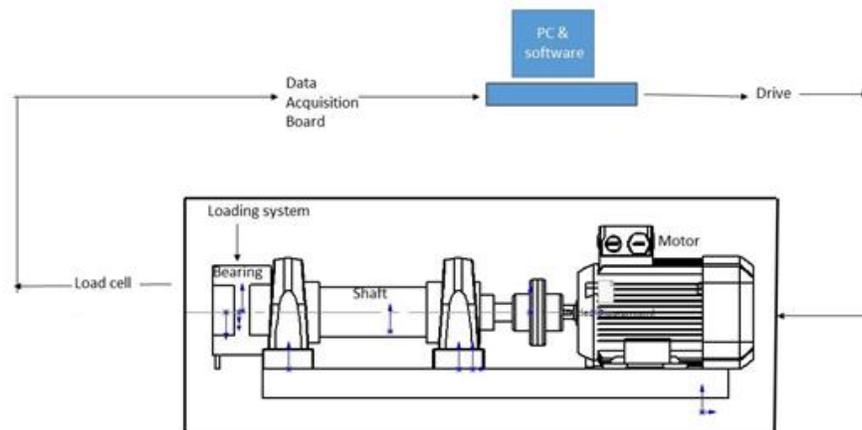
Figure 1.1 Schematic of journal bearing apparatus

1.2 Significance of the work

The outcome of this work will be a mechatronic solution for an old apparatus. The approach of this work gives the idea how the mechanical design has been redesigned without losing its traditional way of mechanism, with a lesser part to be taken care of. As the apparatus, itself is a laboratory machine for the student to learn the pressure distribution of oil in a journal bearing at various points and at various speeds, the work has higher significance to students at the industrial level applications and engineering.

1.3 Objectives and Goals

The Objectives and goals included in the work are explained in Figure 1.2 where the system is subdivided into parts and the task includes in the subdivisions has been explained. The apparatus is divided into load, drive, motor, sensor, control system including the human-machine interface. However, the main task of the work is as follows,

- The design of missing parts in the apparatus,

- The redesign of loading system,

- The design of the measurement system,

- The design of a drive control system,

- The design of a data acquisition system,

- The design of the human-machine interface.
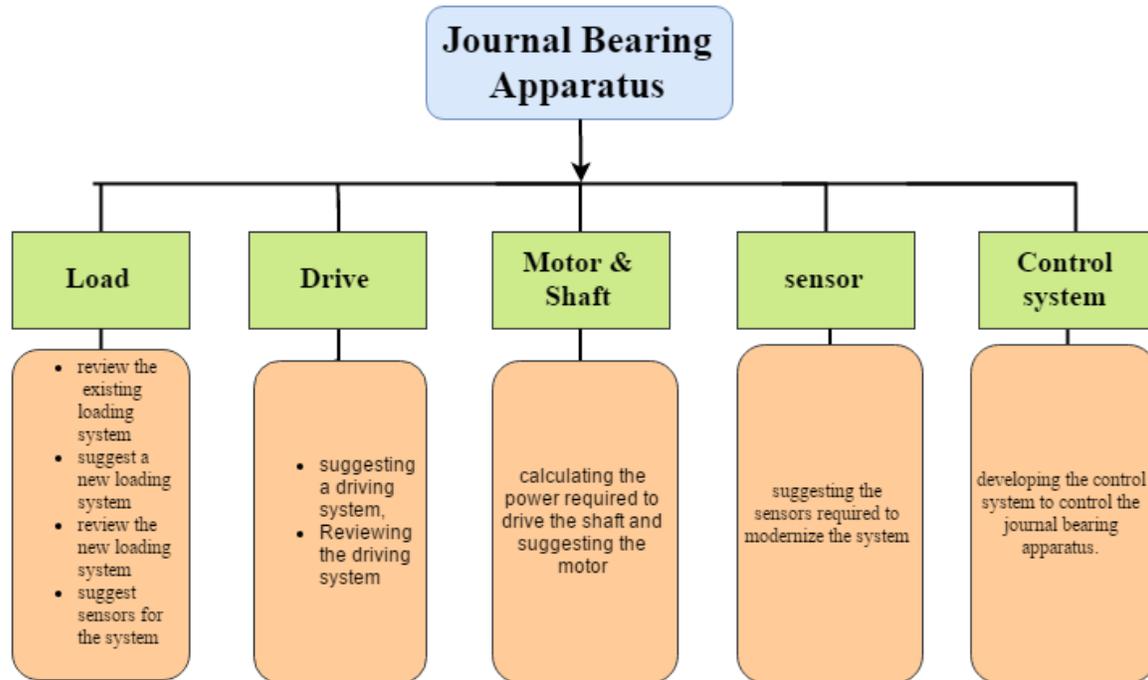
Figure 1.2 Flowchart of the objectives

1.4 Background of the Bearing and the apparatus

The study on journal bearing comes under Engineering Tribology, where the journal bearing is the most recognized types of plain bearing which comprise a sleeve with a shaft rotating inside and a thin film of lubricant, limiting the contact between them. A test rig may be an equipment or apparatus utilized for measuring the performance of any mechanical equipment. Test rig can be placed in the laboratory for studying the pressure distribution of the journal bearing [1].

The principal of journal bearing plays a vital role in the automobile industry where it is widely used in the automotive applications like crankshaft bearings, piston pin joints, and crankshafts. The bearing guiding the shaft should have good thermal properties, strength, and load bearing capacity. In order to get a better power transmission from the engine, the friction between the bearing and the shaft should be lower. The direct contact between the shaft and the sleeve should be avoided since it will damage both the sleeve and shaft. The lubricant will form a thin film between the moving surfaces. A convergent wedge is always developed which is formed due to the relative surface speeds and the lubricant viscosity to carry the applied load [2] as shown in figure 1.3. The pressure build-up varies according to the load on the bearing. The maximum pressure for every bearing should be determined so that it does not exceed the limits under any working condition [1].

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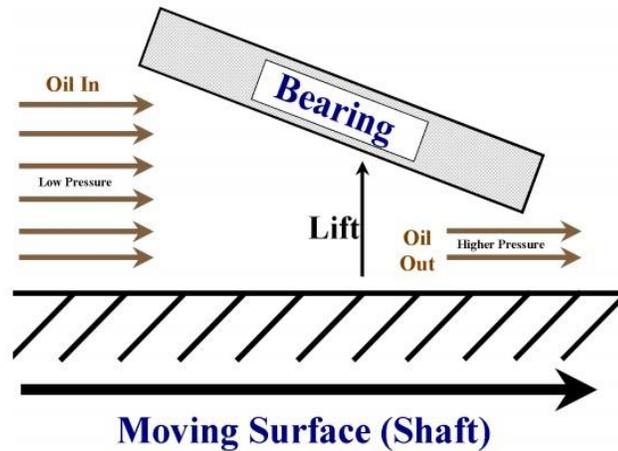
Figure 1.3 basic development of an oil wedge [2]

One of the most unique or the distinct features of the apparatus in this work is the operating of the loading system. Depending on the working conditions and types of applications used, load to the journal bearing can do by two kinds, load directly applied on the shaft like metal to metal contact of loading, which may cause the damage to the shaft while loading and another kind of loading are done is on the bearing. Since the load is applied on the sleeve, the gap between the top layer of the shaft and the sleeve will be reduced forming a converging surface at the top, which on rotation of the shaft develops pressure inside the bearing. [1]. The load is applied to the bearing in this work. Most of the apparatus or the papers on the journal bearings, the load applied on the bearing is done by weight hangers where the force is towards the bottom. Hence the apparatus in this project deals with, is unique where the load applied is towards upwards with the help of a metal belt.

1.5 Scope

The work is focused on the suggesting the suitable solutions for the absent and redesigning the required parts of the apparatus. The work is also focused on suggesting the control system for the device .The pressure distributions calculations when it subjected to the various conditions when the load is applied and the design of the bearing related to the same conditions are not in the scope of the work. However, the previous works and the researchers were done related to the pressure distribution calculations when it is subjected to the various conditions as well the various parameters are discussed in this work.

1.6 Deliverables & methodology

Being a laboratory learning material the device should be able to deliver the knowledge, where the operator must be able to learn and examine the process that is occurring in the journal bearing apparatus. Hence this work must be able to deliver

- 3D Model of the previous apparatus along with the modified design
- Should be able to control the device using a control system
- Technical details of the parts

1.7 Thesis Structure

Chapter 2 provides the descriptions and the fundamentals of the existing journal bearings. Chapter 3 is the literature review of the similar researches which have been carried by different authors. Chapter 4 deals with the existing test rigs in the market and the laboratories. Chapter 5 gives the overview of the system and the subsystem, its mechanical design, drive system and the monitoring system will be discussed. Chapter 6, provides the parts which are missing in the current apparatus and also the parts which are available in the market are suggested. The mechanical design analysis is given in chapter 7. Chapter 8 provides a control system to be designed for the device. Chapter 9 gives shows the calculations and flow simulations of the journal bearing. Monitoring and controlling system are discussed in chapter 10. Chapter 11 presents the conclusions from the work.

2   EXISTING JOURNAL BEARING APPARATUS

The development of the modified conceptual model needs an overview of the previous or the existing model which would help to know what needs to bring into the new concept and what needs to be replaced with the existing one. This section deals with the description of the conceptual design of the existing system that has been developed using the SOLIDWORKS software. SOLIDWORKS is a computer-aided design and computer-aided engineering software developed by Dassault Systèmes. The 3D model is created by taking the exact measurements from the parts that are procured from the laboratory. These available parts are assembled in the CAD software to make a sensible device. The model is then checked for the working procedure. The description and the operating principle of the conceptual existing apparatus are as follows: The complete model rests on a metal base plate. It consists of a motor, shaft, coupling, pillow blocks, oil storage tank, bearing, oil hoses, loading system, a frame or a housing and manometers. In these parts, the available ones are the shaft attached to two single row deep groove ball bearing, frame, loading system, and the bearing. The rest of the parts are created to match the profile of the available parts.

The shaft or the journal has two ends, one end is attached to the motor and the other end to the bearing. The motor end is fixed to the motor by using a coupling and the motor is fixed to the base plate by using the metal bolts. The shaft is supported by two pillow blocks. These pillow blocks are taken AST bearings from the exact measurements which suit the dimensions of the ball bearings attached to the shaft available. The bearing end of the shaft is attached to the bearing where the shaft rotates freely supported by the lubrication oil. The lubrication to the bearing is supplied through a hose connected to the oil storage tank which is fixed above at a certain level to give free oil flow to the bearing. The bearing is fixed to a frame, which also supports the loading system.

The loading system is explained in the next section. This loading system is fixed to the frame, where the load is applied to the bearing by means of a threaded screw. When the screw is turned, the force is applied from the bottom of the bearing through a metal belt attached to a disc supported by a ball bearing. The bearing has inlet and outlet holes for the inflow and the outflow of the lubrication oil. When the motor is rotated at a certain speed the oil is let inside the bearing and shaft is rotated along with the motor. The oil which flows to the bearing through a single inlet hole enters into the bearing, creates a layer and lubricates the surface of the shaft and the bearing. The oil which is under pressure flows out of the bearing through an outlet holes to the manometers via hoses or pipes. The manometers are supported by a stand. The waste oil which goes out of the bearing is collected in an oil tray which can use again to the lubrication. To change or Redesign the current conceptual design, the system ought to be broken into Subsystems where the way of the System can be analyzed. This study will help in comprehension and to review the way of the working of the device. Various studies and examinations have been conducted on the journal bearing setup which will be discussed in the next chapter.
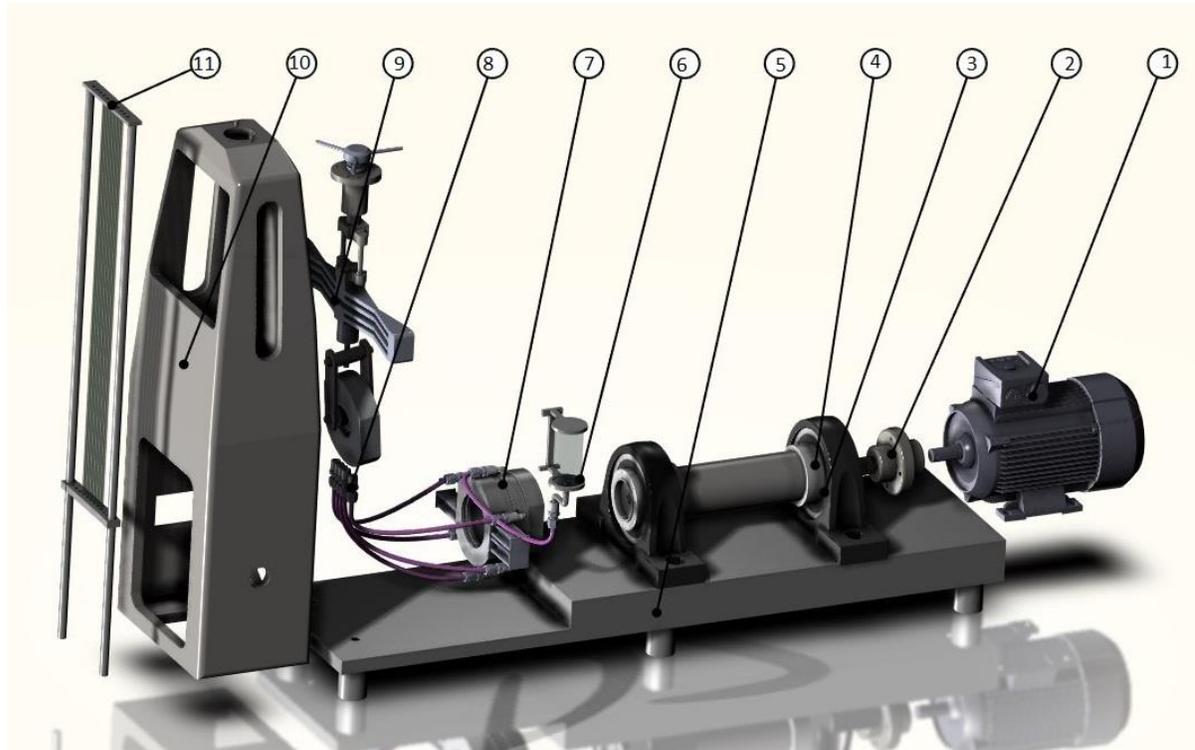
Figure 2.1 The existing journal bearing apparatus, 1) Motor, 2) coupling 3) Pillow block, 4) Shaft, 5) Base Plate, 6) Oil storage tank, 7) Bearing, 8) Oil hoses 9) Loading system 10) Frame 11) Manometers

Table 2.1 original dimensions of the parts procured from the laboratory

No		
1	Journal diameter (D)	60mm
2	Length to diameter ratio (L/D)	0.95
3	Operating speed (N)	3000rpm
4	Total length of the shaft including the coupling and bearing part	405mm
5	Length of the coupling shaft	51mm

2.1 Existing loading system

Fundamentally, the loading method of the existing system is based on the principle of the screw jack arrangement, where the loading of the journal bearing is done by lifting by means of a metal belt which can be seen in Figure 2.2. The number of screw threads determines the amount of the height be lifted. The metal belt which causes the loading on the bearing housing consequently loads the shaft. The Force required turning the screw to lift the bearing is calculated by an equation along with the torque required to overcome the friction between the nut and thread are explained below. The journal bearing

housing is reinforced by means of a frame where it is fixed through the nut and bolt arrangement. The loading method of the present system is fundamental. The previous arrangement had a dial indicator to read the force applied, which gives the reading of the load applied to the bearing and the journal. The analog load gauge is old and space consuming that need to be redesigned, supplanted with the digital load gauge where it consumes a less space.
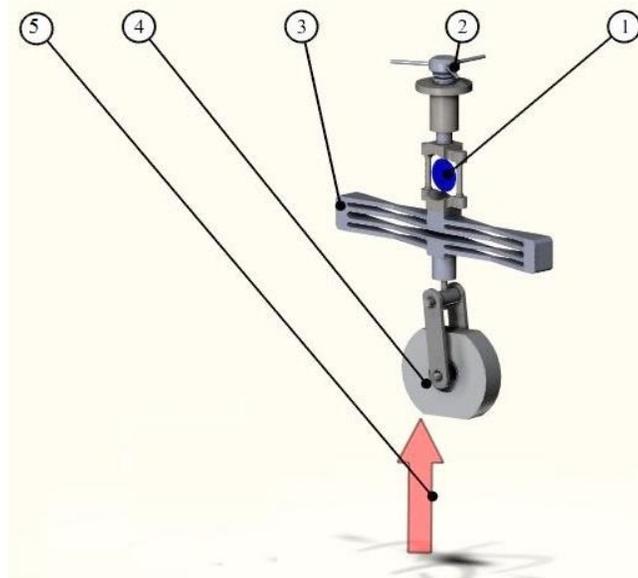
Figure 2.2 Existing loading system, 1) Dial indicator, 2) Screw 3) Load gauge, 4) Disc 5) Metal belt.

1)

2)
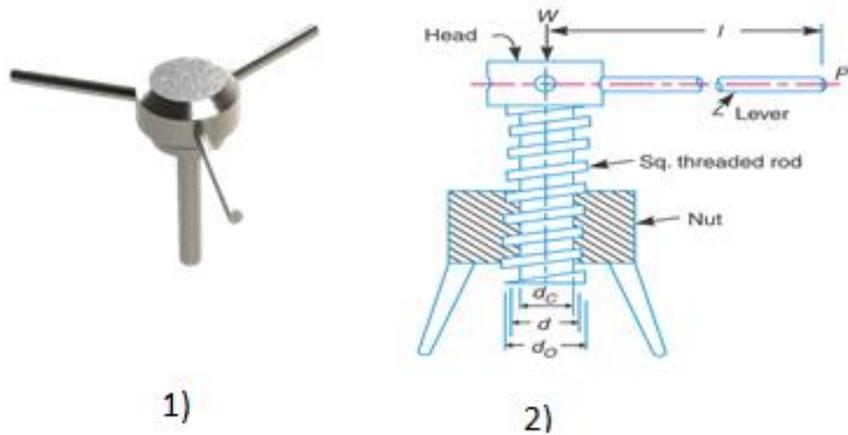
Figure 2.3, 1) Triple bar screw, 2) Screw Jack[3]

The Figure 2.3 (1) demonstrates the triple lever screw bar used to load the bearing in the existing system. The mechanism to load the journal is similar to the screw jack mechanism. The screw jack is a device, for lifting heavy loads, by applying a nearly littler exertion at its handle. Demonstrating for the screw in the second picture in Figure 2.3 in which is a typical type of screw jack which comprises of a square threaded rod similar to the design of the thesis work which is inserted into the internal thread of

the nut. The load to be raised (Journal bearing in case of this work) is put on the head of the square threaded bar which is rotated by the force exerting toward the end of the lever for lifting the load can be determined[3]. From the Equation **Error! Reference source not found.**) [3] we can determine the torque required to overcome friction

$$\tan\alpha = \frac{p}{\pi d}$$

(2.1)

Where α – Helix Angle, rad,

   p - the pitch of the screw, m,

   d –mean diameter of the screw, m.

$$P = W\left[\frac{\tan\alpha + tan\emptyset}{1 - \tan\alpha.\,tan\emptyset}\right]$$

(2.2)

Where P – effort applied at the circumference of the screw to lift the load, N,

   W - load to be lifted, N and

   $\emptyset$ -The friction angle, rad.

From the [3] Equation (2.2) we can determine the force applied to the circumference of the screw to lift the load. It is able to measure the physical properties of the shaft and the bearing using the computer aided software, SOLIDWORKS shaft being approximately 10 kg (98.07N) and bearing approximately 5 kg (49.04N). Being one of the requirements of the work is to utilize the existing system, the existing screw with 50 mm (millimeter) thread length, d=8 mm mean diameter and assuming the pitch p-1,25mm is used by increasing the length of the screw. The load carried by the belt is simulated in the coming chapter.

2.2 The existing parts and the parts to introduced

Figure 2.4, 1) Bearing housing, 2) Inner Bearing, 3) The existing outer bearing, 4) The existing bearing shaft, 5) motor [16], 6) The existing load gauge

Picture1 in figure 2.4 shows the Bearing housing or the frame as referred in this work is the frame which houses the many parts which include the loading system journal bearing, load gauge. One of the requirements of the work is to consider the frame while redesigning of the other parts. As figure 2.2 demonstrates the existing loading system lies inside this frame, it consumes most of the space inside the frame. The frame has a large hole in the back of the frame where the journal can be inserted into the bearing, which resides inside the frame.

Picture 2 in figure 2.4 demonstrates the inner bearing design. Fabricating this part design is troublesome, the gap for the outlet of the oil are small and to manufacture the part with that extensively small hole is quite a tough job. The holes of the outlet run through the center of the bearing to the edge of the bearing. Since the task of manufacturing such is a part is challenging, one, and it is necessary to change the design of the inner bearing while without changing the size of the bearing.

Picture 3 in figure 2.4 beside shows the design of the existing bearing, where the model can be seen with the inlet hole towards the front side of the model and the drain holes towards the end of the edges of the design. The inner bearing is fitted inside this bearing where the inlet holes are matched for the. As mentioned earlier in the inner bearings, the design is quite complicated to manufacture, hence need to be redesigned.

Shaft: The shaft which exists need to redesigned as per the new requirements. Which will explain in the further chapters

Motor: The existing system does not have motor, hence the to drive the shaft at a variable speed a motor is required

coupling: To connect the shaft and the motor, a slight miss alignment should be composited by the coupling

Plumber Blocks: plumber blocks have to introduce into the system to hold the shaft at the two ends.

Picture 6 in figure 2.4 beside shows the existing load gauge. The load gauge data should be sending data to the Human Machine Interface (PC). The previous load gauge has an analog dial indicator connected to the load gauge to measure the date.

Pipes: For the flow of the lubricant from the lubrication tank to the bearing and also from bearing to the manometers hoses need to be introduced into the system.

2.3 Summary

In this chapter, the existing journal bearing system with its fundamental working principle has been discussed. In the existing loading system section, the principle of the working of the applying force on the bearing has been given. In the next section the parts which are available, parts which are needed to be replaced and parts need to be introduced has been discussed. This chapter helps to analyze the

existing system. The next chapter gives the literature review done on the similar subject.

3   LITERATURE REVIEW

Since the paper deals with work containing both mechanical and control system, various papers have been published regarding the subject. The design of Journal Bearing Test Rig by Raajeshkrishna R. Govindaraj Vikrant Mehamala Satishkumar [1], this paper deals with the design of the journal bearing test rig where Figure 3.1. demonstrates the design. It discusses the developing of the mechanical design of the test rig, which helps to measure the load bearing capacity and the pressure distribution of a journal bearing. The authors further discuss that the design can also to be used check on the different materials behavior and properties. The design was developed as a laboratory equipment to determine the maximum pressure in the journal bearing, under certain conditions. The authors further discuss that the set-up has some design constraints flexibility. The force applied to the bearing in this design is by adding weights by using the weight holder to create the necessary pressure in the bearing. The bearing is rotated by a motor with 1500 RPM, 0,5-1,5Hp. However, the paper does not discuss regarding the control system and the methods to control the system by using a personal computer. The design is suitable for the manual adding of the weights where the load is applied downwards. [1]
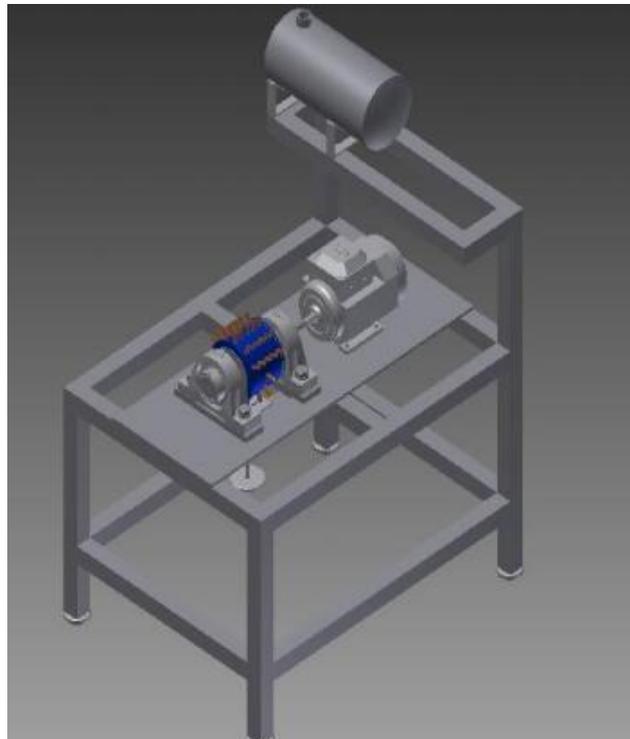
Figure 3.1 design of journal bearing test rig by Raajeshkrishna R. Govindaraj Vikrant Mehamala Satishkumar [1]

When it comes to the lubrication in the journal bearing three kinds of regimes apply: hydrodynamic or full- film, mixed film and boundary [4] say in one of the journals by Noria Corporation, lubrication consulting services, and training. Further explaining, in his article "Boundary Lubrication, an Appraisal of World Literature," W.E. Campbell defines boundary lubrication as "lubrication by a liquid under conditions where the solid surfaces are so close together that appreciable contact between opposing asperities is possible." [4]
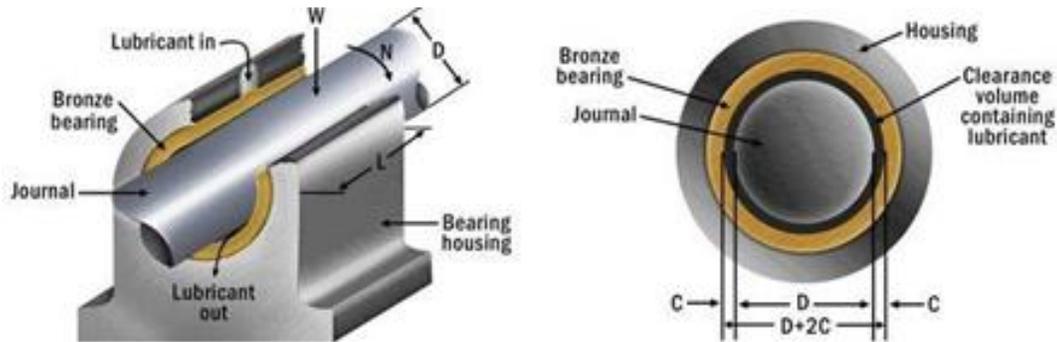
Figure 3.2 Typical Journal Bearing [4]

The author [4] further explains there is no possible mechanical wear will occur once the normal operating speed of the shaft is reached and the full film lubrication is achieved. When this regime is achieved, there won't be any asperities contact, hence the bearings can operate with minimum wear. The journal further shows how the pressure-viscosity provides the load carrying capacity of a journal bearing. This is when the fluid pressure is created in the lubricating film. The higher pressure on the lubricant creates the higher viscosity at the pressure point. In the case of rolling-element bearings, this pressure is high enough to raise the lubricant's viscosity to the point where it will deform the bearing's rolling elements [4].

Raajeshkrishna R. Govindaraj Vikrant Mehamala Satishkumar in 'The design of Journal Bearing Test Rig' [1] have calculated the pressure the distribution for various angles by determining the pressure distribution by using Reynold's Equation. The paper says that the eccentricity plays a vital role in varying the pressure in the bearing, where Eccentricity is the distance between the center part of the sleeve and center part of the shaft. Hence the change in pressure is directly proportional to change in the eccentricity. So, the ratio of eccentricity to the clearance gives the eccentricity ratio. Eccentricity ratio can vary from 0 to 1. If the ratio is zero, then the shaft is exactly in the center of the bearing sleeve [1] and there is no pressure in the bearing.

Table 3.1 Pressure distribution for with minimum and maximum tolerances varying roll-up angles [1]

Angle, Degrees	Pressure, $*10^3 \text{N/m}^2$	Pressure, $*10^4 \text{ N/m}^2$
	Maximum tolerance	Minimum tolerance
0	0	0
20	$0.5980*10^3$	$0.6414*10^4$
40	$1.124*10^3$	$1.2058*10^4$
60	$1.5145*10^3$	$1.6247*10^4$
80	$1.7224*10^3$	$1.8478*10^4$
100	$1.7227*10^3$	$1.8480*10^4$
120	$1.5151*10^3$	$1.6253*10^4$
140	$1.1246*10^3$	$1.2065*10^4$
160	$0.5984*10^3$	$0.6420*10^4$

Experimental measurement of the friction torque on hydrodynamic plain journal bearings during start-up by J. Bouyer n, M. Fillon: the paper deals with the results focused on the measurement of bearing torque during start-up with varying specific pressure the where the friction coefficient is obtained by varying feeding conditions, radial clearance, and length for four different bearings. Also, the paper discusses the study dealing with bearing characteristics influencing the friction coefficient.[5]
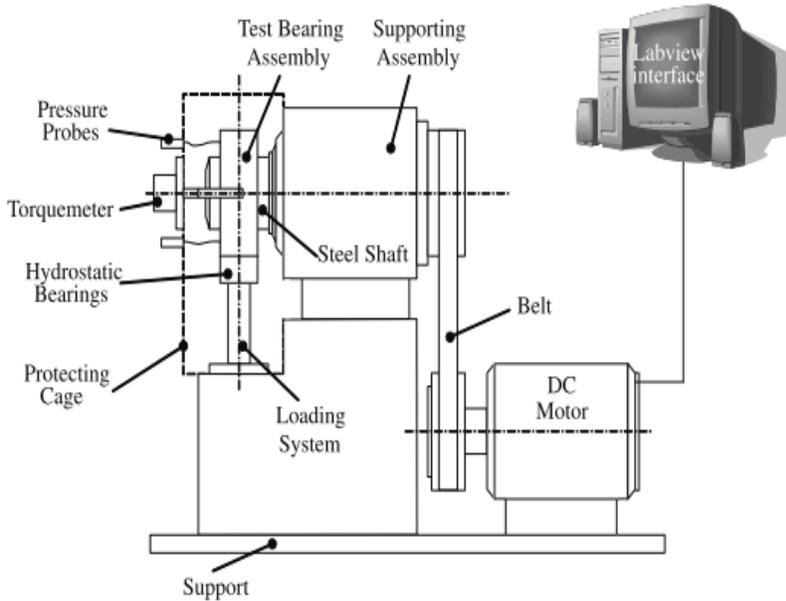
Figure 3.3 Journal bearing test rig [5]

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Figure 3.3 shows a schematic view of the test rig. The assembly consists of a shaft rotated by a variable speed DC motor on rolling element ball bearings, the latter being controlled by means of a LabVIEW program and National Instruments data acquisition boards. The program allows both controls of the test rig and data

acquisition of temperature, pressure, flow rate, displacement, and torque. [5]

Numerous Journal papers have been published regarding the control system, in the case of this task, it is to control the speed of the motor and to measure the load cell data. SPEED CONTROL AND MONITORING SYSTEM FOR SINGLE PHASE INDUCTION MOTOR USING LABVIEW WITH MOTOR PROTECTION by Saritha M, Sofiya A, Arun S Dev, Atheena Francis, Aswathi R: This paper deals with speed control of the single-phase induction motor and monitoring by using LabView software. [6]

PLC APPLICATION FOR SPEED CONTROL OF INDUCTION MOTORS THROUGH VFD Tiwari, Anshul Singh, Abhay Pratap Dixit, Aditi Sen, Debojyoti: The paper deals with controlling the speed of a three-phase induction motor using variable frequency drive (Power Flex 4m) using Allen Bradley programmable logic controller (Compact Logix programmed using RSLogix 5000). The programming is done through by RS Logix 5000 Ladder logic software to control the speed of the motor. [7]

Upgrade of the motor test unit (Masterproef Faculteit Industriële ingenieurswetenschappen master in de industriële wetenschappen: energie) by Geutjens Kevin: The paper deals with the upgrading of the local didactical motor test unit. The communication to the PC, the old I/O panels will be replaced by a new Beckhoff PLC, fitted with an Ethernet connection, PROFINET connection and the necessary I/O terminals. In order to send the necessary data to the PC program, the connection between the PC and the PLC will be established with an Ethernet cable by using the TwinCAT ADS Ethernet protocol.[8]

3.1 Summary

At the end of the chapter, it can be concluded that there are numerous researches and papers have been done on the similar subject, however, the papers with the device design pertaining to the conditions and objectives that this paper deals are very little. As discussed earlier the loading of this device is different with the other apparatus available in the market which makes this design peculiar in this case. Hence the similar devices which are in the markets are discussed in the next chapter.

4 MARKET OVERVIEW

4.1 TM 280 by Gunt Hamburg [9]

TM 280 by Gunt Hamburg, the similar design to the thesis work is used to measure the Pressure at different points of the journal bearing. In hydrodynamic journal bearings, the shaft and the bearing shell are separated from each other during operation by a lubricating film. By the pressure distribution in the bearing gap, the supporting function of the full film oil in the journal bearing can be explained. With the help of TM 280 unit, it is able to visualize the axial and radial pressure profile in the journal bearing with hydrodynamic lubrication. Depending on the design, the measuring points are allowed, where the pressure is measured. Where in the case of TM 280, there are 12 measuring points around the circumference of the bearing shell and 4 measuring points in the longitudinal direction. [9] By using the manometers with reference to the height of the liquid column, the obtained pressures can be measured. The assembly consists of a motor-powered shaft that rotates in a freely movable bearing housing. Oil is used as the lubricant. The displacement of the shaft journal depending on the speed and direction of rotation as well as the characteristic behavior during start-up can be observed through the transparent bearing housing. The Speed of the shaft and direction of can be varied. The force applied to the bearing can be varied by the weights supplied with the unit. The temperature in the bearing gap is measured in order to determine the viscosity of the lubricant.TM280, the loading system is different compared to the apparatus in this task as the load for the bearing is done by the weights towards the downward direction. And as well as the product lacks the PC monitoring system.

Figure 4.1 Journal bearing apparatus, Gunt Hamburg [9]

4.2 PG-2 1Ł - test rig for journal bearings [10]

The test rig shown in Figure 4.2 is a test rig from KMiP Department, Faculty of Mechanical Engineering, Gdansk University of Technology. Test rig PG II 1Ł is used for measuring of static characteristics of journal sliding bearings. The system is controlled by an internal feedback loop by using a computer for input parameters adjustment. The assembly has a computerized data acquisition system for high repeatability of test conditions and immunity to interference. Force applied and shaft speed can be varied by the help of a pre - programmed function. The Journal Bearings can be tested with either water or oil as lubrication. The system is equipped with a friction force sensor. The tested bearing is fixed in a rigid housing, which is supported by the hydrostatic bearing. The motor rotating speed is controlled by a vector type frequency inverter, which allows testing fully loaded bearings in start - up and stops conditions. [10]

Figure 4.2 PG-2 1Ł - test rig for journal bearings [10]

Table 4.1 Specifications of PG-2 1Ł [10]

No	Specifications	Measured quantities
1	· Radial load: up to 25 kN	· Friction force
2	· Tilting torque: 0 - 5000 Nm	· Radial force
3	· Rotational speed: 0 - 4000 rpm	· Temperature of sliding elements
4	· Journal diameter of tested bearings:	· Rotational speed
5	30 - 110 mm	· Tilting torque

The model shown below is KMD-07 journal bearing apparatus and its specifications are

Table 4.2 Specifications of KMD-07 [11]
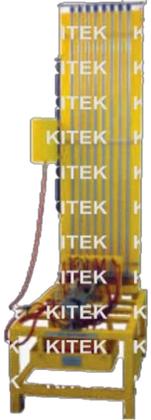
	No		
Figure 4.3 KMD-07 [11]	1	Model Number	KMD-07
	2	Brand Name	Kitek
	3	Specifications	70mm dia (nominal dia) 75mm dia 4 adjustable weights
	4	Recommended oil	SAE 10
	5	Motor	DC shunt wound speed 1500 RPM in dual directions
	6	Pressure measurement	16 tubes mounted manometer panel.
	7	Manufacturers	KITEK technologies private limited US $1,500-2,500 / Unit

4.3 Chapter Summary

From this chapter, it can be summarized that the journal bearing apparatus are available from the market to buy. As explained in this section before the TM280 is produced by the Gunt, Hamburg with 12 measuring points around the circumference of the bearing, where the pressure is measured. TM280 although it is similar to the design in this work, the force applied to the bearing is by weights. KMD 07 is another example of the Journal bearing apparatus available in the market where the apparatus itself costs from 1500-2500 US $. since the main objective of the chapter is to analyze the cost for the device available in the market to the cost of the apparatus the paper deals with. The materials required for apparatus are all discussed in the coming chapters the cost related to the particular material is calculated and it is compared with the device available in the market to the device in this paper.

5   PROJECT DESIGN CONFIGURATION

In this chapter, Project Design configuration, the device is subdivided into separate entities to distinguish and to study the device with the particular functions. The System ought to be broken into Subsystems before designing the whole apparatus and then assembled into a complete device. The process will help to understand the device and to enhance it to improve a comprehension to review the way of the working of the device.
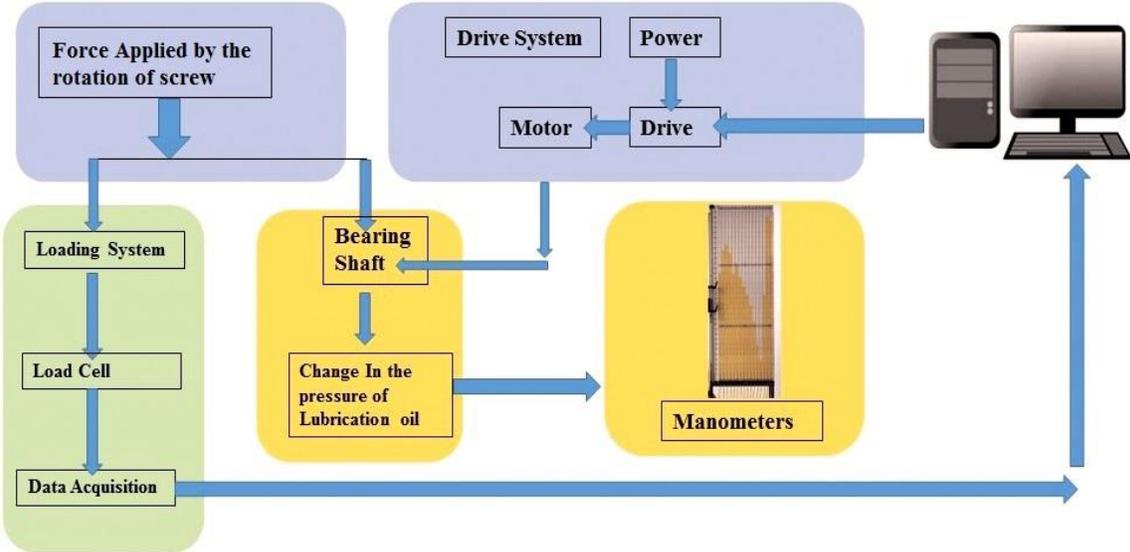
Figure 5.1 subsystem configuration

From the block diagram demonstrated the system can be breakdown into:

- Drive system
- Mechanical system
- Monitoring system

The mechanical system mainly consists of the shaft, bearing, Pillow blocks, loading system, coupling, base plate and the mounting unit.

The drive system consists of the variable frequency drive, Motor.

Monitoring system consists of a Personal computer, Human machine interface.

5.1 Drive system

A single AC drive system consists typically of an input transformer or an electric supply, frequency converter, an AC motor, and load. Inside the single frequency converter, there is a rectifier, DC-link, and inverter

unit[12].
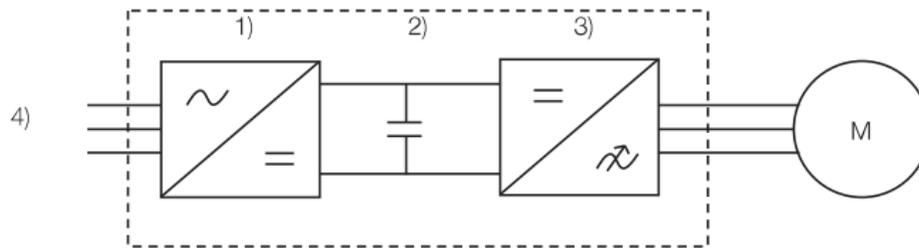
A single frequency converter consists of 1) rectifier, 2) DC-link,
3) inverter unit and 4) electric supply.

Figure 5.2 AC Drive system [12]

As per the requirements of the task to operate the journal bearing at different speeds, it is a somehow difficult task to control the speed of a three-phase induction motor as it is basically a constant speed motor. The speed control of induction motor causes has its drawbacks such as the as the decrease in efficiency and low electrical power factor[13]. In this task, the different methods of speed control of a three-phase induction motor by means of the drive are discussed. However, there are other ways to control the speed of a motor. The Speed of Induction Motor is changed from Both Stator and Rotor Side. The speed control of three phase induction motors from stator side is further classified as:[13]

- V / f control or frequency control.
- Changing the number of stator poles.
- Controlling supply voltage.
- Adding rheostat in the stator circuit.

The speed controls of three phase induction motor from rotor side are further classified as[13]:

- Adding external resistance on the rotor side.
- Cascade control method.
- Injecting slip frequency emf into rotor side.

5.2 Selection the motor and the frequency converter[12].

Motor: the main shaft or the journal is rotated by using the motor. Importance should be given to the torque requirement, the speed of the motor.

Variable Frequency Drive or Frequency converter: As per the requirements of the task, the motor should be able to operate at varying speed hence a variable frequency drive is used to control the motor speed that rotates the motor connected to it by changing the frequency and voltage supplied to it.

1) Check the initial conditions: In order to select the correct frequency converter and motor, check the mains supply voltage level (380 V to 690 V) and frequency (50 Hz to 60 Hz). The mains supply networks frequency

27

doesn't limit the speed range of the application. [12]

2) Check the process requirements[12]:

- Need for starting torque

- Speed range used

- Type of load will be present.

3) Select the motor[12]: The motor selection is done on the vital importance of its torque requirement. The motor must be able to come across the process overloads and be able to produce the torque required for the specified work. The motor's thermal overloadability should not be exceeded. It is also necessary to leave a margin of around 30% for the motor's maximum torque when considering the maximum available torque in the dimensioning phase.

4) Select the frequency converter. The frequency converter is selected according to the initial conditions and the selected motor. The frequency converter's capability of producing the required current and power should be checked. Advantage should be taken of the frequency converter's potential overloadability in the case of a short-term cyclical load. [12]

5.3 The torque and the power calculation of the journal

However, the calculated results show the power required is 0,0573kW. With suggestions, the motor with 0,75kW power is selected. For the selection of the motors, it is necessary to know the power and torque required to drive the shaft.

5.3.1 The torque and the power calculation of the journal

Rotating mass – 9,60042 kg.

The diameter of rotating mass – 70 mm.

The frequency of rotation, max – 3000 rpm.

Moment of mass inertia [14]

$$I = \frac{m \cdot R^2}{2},$$
(5.1)

where m – rotating mass, kg;

R – Radius of rotating mass, m.

Then

$$I = \frac{m \cdot R^2}{2} = \frac{9{,}60042 \cdot 0{,}035^2}{2} \approx 0{,}00588025$$ kgm2.

The torque

$$T = I \cdot \varepsilon,$$

Where ε – angular acceleration, rad/s^2

Let us consider achieving of maximal speed in 10 seconds. Then the angular acceleration can be found as follow[14]

$$\varepsilon = \frac{\omega}{t} = \frac{\pi \cdot n}{30 \cdot t} \qquad (5.2)$$

where ω – angular velocity, rad/s;

t – Time, s;

n – Frequency of rotation, min-1.

Then

$$\varepsilon = \frac{\pi \cdot n}{30 \cdot t} = \frac{3{,}14 \cdot 3000}{30 \cdot 10} \approx 31$$ rad/s^2 or 1776,169116 deg/sec2

The torque [14] will be equal to

$$T = I \cdot \varepsilon = 0{,}00588025 \cdot 31 \approx 0{,}1822775$$ Nm.

The power of motor [14]

$$P = T \cdot \omega = T \cdot \frac{\pi \cdot n}{30} = 0{,}1822775 \cdot \frac{3{,}14 \cdot 3000}{30} \approx 57{,}2673$$ W. Or 0.05726kw

5.4 Motor

AC motors are mostly preferred in industrial applications because of their low costs and Durability. AC motors are driven by alternating current (AC). The AC motor has a stationary Stator and inside the rotor. Stationary stator has coils to produce a rotating magnetic field with alternating current, and the output shaft connected to inside rotor for producing a second Rotating magnetic field [15]

ELECTRIC MOTOR APPLICATIONS, Certain factors must be considered when selecting an electric motor, for a specific application. Among these considerations are [16]

(1) The source voltage and power capability available,

(2) The effect of the power factor and efficiency of the motor on the overall system,

(3) The effect of the starting current of the motor on the system,

(4) The effect of the power system on the operation of the motor,

(5) The type of mechanical load, and

(6) The expected maintenance it will require

The properties that make an AC (alternating current) motor the choice for most constant-speed industrial drives are not necessarily those needed for control system applications. The majority of the latter applications require a motor that can operate over a vast variety of speeds with high starting torque. The main advantage the AC motor has over the DC motor is that it's compatible with the AC signals from AC drive and control devices. This eliminates the need to convert signals from AC to DC and back.[15]

5.4.1 Considerations for Mechanical (Motor) Loads

There are three basic types of mechanical (motor) loads connected to electrical power systems. These are DC, single-phase AC, and three- phase AC systems. DC motors are ordinarily used for special applications since they are more expensive than other types and require a DC power source. Typically, they are used for small, portable applications and powered by batteries, or for industrial/commercial applications with AC converted to DC by rectification systems. A major advantage of DC motors is their ease of speed control. The shunt-wound DC motor can be used for accurate speed control and good speed regulation. A disadvantage is the increased maintenance caused by the brushes and commutator of the machines. DC shunt-wound motors are used for variable speed drives on printing presses, rolling mills, elevators, hoists, and automated industrial machine tools[17]. Series-wound DC motors have a very high starting torque. Their speed regulation is not as good as that of shunt-wound DC motors. The series-wound motor also requires periodic maintenance because of the brush/commutator assembly. Typical applications of series-wound DC motors are automobile starters, traction motors for trains and electric buses, and mobile equipment operated by batteries. Compound- wound DC motors have very few applications today[17]. Single-phase AC motors are relatively inexpensive. Most types have good starting torque and are easily provided 120-volt and 240-volt electrical power. Disadvantages include maintenance problems due to centrifugal switches, pulsating torque, and rather a noisy operation. They are used in fractional horsepower sizes (less than one horsepower) for residential, commercial, and industrial applications. Some integral horsepower sizes are available in capacitor-start types. Uses include machine cooling system blowers, and clothes dryer motors [17]. Specialized applications for single-phase motors include: [17] Shaded-pole motors used for portable fans, record players, dishwasher pumps, and electric typewriters. They are low-cost and small, but inefficient. single-phase synchronous motors used for clocks, appliance timers, and recording instruments (compact disk players). They operate at a constant speed. Universal motors (AC/DC) motors used for many types of portable tools and appliances, such as electric drills, saws, office machines, mixers, blenders, sewing machines, and vacuum cleaners. They operate at speeds up to 20,000 r/min and have easy speed control. Remember that AC induction motors do not have speed control capability without the addition of expensive auxiliary equipment. [17]

Three-phase AC motors: Three-phase AC motors are often called the "workhorses of industry." Most motors used in industry, and several types used in commercial buildings, are operated from three-phase power sources. There are three basic types of three-phase motors: (1) induction motors, (2) synchronous motors, and (3) wound-rotor induction motors (wrim). [17]

Synchronous motors: Three-phase synchronous motors usually are employed in very large horsepower ratings. One method of starting a large synchronous motor is to use a smaller auxiliary DC machine connected to the shaft of the synchronous motor, [16]

Motor selection: while deciding the required motor for the task, every motor has their own pros and cons. Depending on the level of application level and performance motors are selected. Induction motors are selected. Induction motors are simple, low cost, and straightforward [18]. Whereas servo motors have its own set of advantages like higher performance, smaller sizes, and faster speeds, Permanent magnet synchronous motors offer advantages on high-energy- consuming and high-dynamic applications, compared to induction motors. Synchronous servo motors can also use with the variable frequency drives producing higher efficiencies than an asynchronous motor, using perhaps 30% less energy in positioning applications. [18]

The slip is often defined at the motor's nominal point (frequency (f_n), speed (n_n), torque (T_n), voltage (U_n), current (I_n) and power (P_n)). At the nominal point the slip is nominal: where [12]

$$S_n = \frac{(ns - nn)}{ns} * 100\% \qquad (5.3)$$

$$N_s = \frac{2 * fn * 60}{pole\ number} \qquad (5.4)$$

5.5 Motors in the market

1)   2)   3)

Figure 5.3 Motors available in the market, 1) Siemens 1LE1 Reversible Induction AC Motor[19], 2) Schneider Electric 0.75 kW Servo Motor, 220 V, 2.39nm, 3000 rpm [20], 3) CM111, CM211 Severe Duty [21]

Siemens 1LE1 Reversible Induction AC Motor[19]

- Three phase motor ideal for a wide variety of applications.
- High-efficiency motors to meet IE2 regulations.
- Energy efficient low noise design
- Motors have keyways and fitted keys
- Corrosion resistant, low copper aluminum alloy Suitable for DOL starting or inverter drive use.
- Price: £293

Table 5.1 Properties of Schneider Electric 0.75 kW Servo Motor, 220 V, 2.39nm, 3000 rpm [20]

No		
1	Supply Voltage	220 V
2	Output Speed	3000 rpm
3	Power Rating	0.75 kW
4	Stall Torque	2.39Nm
5	Shaft Diameter	19mm
6	Length	165.7mm
7	Width	80mm
8	Depth	80mm
9	Dimensions	165.7 x 80 x 80 mm
10	Maximum Output Torque	7.16 Nm

Rockwell automation CM111, CM211 Severe [21]

- 3/4 - 400 Hp
- TENV, TEFC
- 900, 1200, 1800, 3600 rpm
- 208/230/460/575V AC • Class F Materials
- Rolled Steel or Cast Iron
- CT 2:1, CT 4:1, CT 10:1, CT 20:1, CT 1000:1, VT 20:1, Sine Wave Energy Efficient.

5.6 Selecting the drive

- Identifying the power supply voltage
- Choosing the motor's power and current rating
- Selecting the drive's ordering code from the rating table based the motor's nominal power rating. [22]
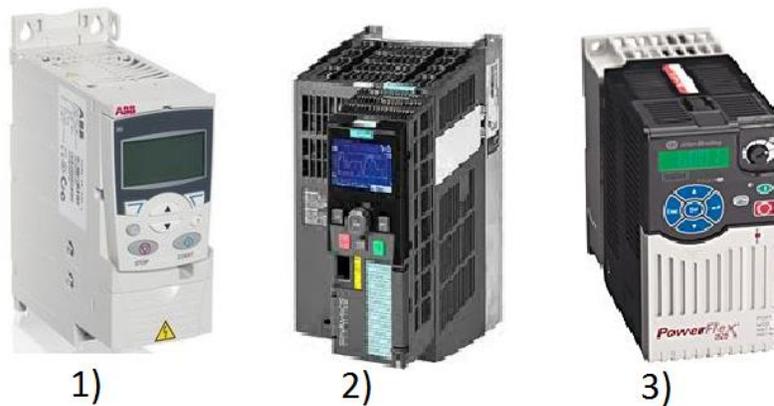
Figure 5.4 Drives available in the market, 1) ABB, ACS355 [22], 2) Sinamics g120 [23] 3) PowerFlex 525 [24]

ABB, ACS355 [22]

- Flexible performance- Reduce the need for external PLC components with built-in sequence programming
- Quick and easy commissioning
- Compact and uniform design
- Supported motor types
- Application-specific product variants
- Communication with major automation networks

Sinamics g120 [23]

- power ratings from 0.05kW (1 /6 hp) to 85 MW built-in math and logic eliminate the need for a separate PLC
- fully integrated into the drive and include Safe Torque Off, Safe Stop 1, Safety Limited Speed and Safe Brake Control
- High degree of flexibility and combinability
- Higher-level, standard Safety Integrated concept
- Standard and unified functionality
- Remote monitoring

Rockwell automation, PowerFlex 525 [24]

- Power ratings of 0.4…22 kW / 0.5…30 Hp in global voltages from 100...600V
- EtherNet/IP networks with built-in EtherNet/IP™
- Able operate at higher temperature up to 70 °C (158 °F)
- Help in reducing cost and improve energy efficiency

5.7 PLC

A Programmable Logic Controller (PLC) is a programmable controlling device used for automation of (industrial) processes, such as factory assembly lines, chemical processes or even amusement rides. The advantage of using a PLC instead of a normal computer is that a PLC can handle many in- and outputs, and controls the system in real-time. Also, both the hardware and software of a PLC are optimized to operate in various conditions[8]. In this task to control the various operations of the variable frequency drive, it is necessary to use the PLC. In the table are mentioned below are some of the PLC manufacturers, where can be considered for the automation.

Figure 5.5 Controllers 1) CX9020 Embedded PC [25], Beckoff, 2) MicroLogix 1100 Controller

CX9020 [25]:

The CX9020 is a compact, DIN rail-mountable Ethernet control system with 1 GHz ARM Cortex™ A8 CPU. The connection for the Beckhoff I/O systems is directly integrated into the CPU module. The unit offers automatic bus system identification (K-bus or E-bus) and independently switches in the corresponding mode. The CX9020 comprises the CPU with two microSD card slots, the internal RAM, and 128 kB NOVRAM as a nonvolatile memory. The CX9020 Embedded PC was developed for optimum interaction with EtherCAT. [25]

MicroLogix 1100 Controller [26]:

- Includes built-in 10/100 MBps EtherNet/IP™ port for peer-to-peer messaging
- Provides 8 KB memory (4 KB user program with 4 KB user data)
- Let's access, monitor and program from any Ethernet connection
- Supports on-line editing
- Provides embedded web server so that user can configure controller data to be displayed as a web page
- Contains isolated RS-232/RS-485 combination port for serial and networked communication
- Lets the user monitor and modify controller data through an embedded LCD screen

5.8 Load cell

Load: load can be defined as the force exerted on a surface or a body, whereas a load cell is a force measurement transducer to measure the force exerted on the body. There are several types of load cell types designs like bending beam, shear beam, and column designs. Based on the design configuration the design types of load cell are used. The type of the load cell used is the explained in the control system chapter depending on the type of configuration of the control system is used. It is always advised to use a kind load of load cell where the company of the control system chosen.

Force measurement system: Design considerations[27]

- Safety: when designing force measurement system, one should follow the necessary safety requirements.
- Environment: various Parameters must be considered depending on the environment conditions including the temperature, vibration, humidity, corrosive nature of the atmosphere.
- Installation space: The design must allow the feedback system to operate in a safe manner.
- Force transducer mounting

The electrical circuit consists of strain gauges or piezo resistors, typically connected in a four-arm (Wheatstone Bridge) configuration [28]. When there is a change in the resistance of the strain gauges the force helps to create a signal voltage. By the manipulation of electrical signal when the force is applied on the structure the strain gauges have organized in an electrical circuit which applied to the structure. A change in the resistance shows the degree of deflection.[28]
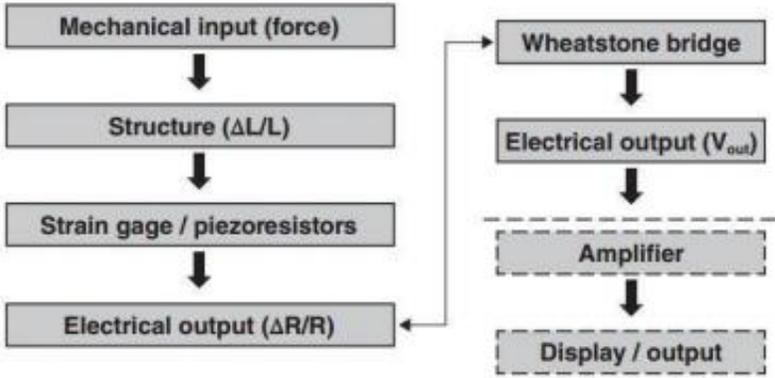
Figure 5.6 structure of typical load cell[28]

Based on the kind of the applications and the design configuration, the type of load cell is chosen. Analyzing the existing system of loading system. Loading was used done by rotating the screw which was connected to the load cell then connected to the belt which made the pull of the bearing. This is a tension (pull) kind of force applied to the load cell.

Low Range Precision Miniature Load Cell Model 31: Honeywell model 31 are the low range precision miniature load cells measure both tension and compression load forces of 50 grams to 500 g. These models

are for the highest accuracy, rugged miniature load cells[29].

PERFORMANCE SPECIFICATIONS

Characteristic	Measure
Load ranges[5]	50 g, 150 g, 250 g, 500 g
Linearity	±0.15 % full scale
Hysteresis	±0.15 % full scale
Non-repeatability	±0.1 % full scale
Tolerance on output 50 g to 150 g	0,1 mV/V max.
Tolerance on output 250 g to 500 g	20 mV/V
Operation	Tension/compression [3]
Resolution	Infinite

Figure 5.7 Performance specifications of Honeywell model 31[29]

Depending on the Installation methods which may be unexpected may affect the degradation of the equipment which may lead to lead to the uncertainty. Hence the after the installation, initial and subsequent calibrations are required to make sure load cell readings meets the needs of the task and achieves the required degree of uncertainty. [27]

A few sorts of uncertainty can be measured as far as statistical techniques, for example, a standard deviation which is known as Type A components. There are Type B uncertainties that are determined by another method. By combining of these two is combined uncertainty.[27] Thus:

Combined uncertainty $\qquad\qquad [(u1)2+(u1)2+……(un)2\ ]^{0,2}$ $\qquad\qquad$ (5.5)

where (u1) ...(un) are the individual uncertainty components. In the use of a force measurement system, uncertainties exist at all times, often the only time they are specifically referred to is during the process of calibration [28].

5.9 Chapter summary

In this chapter, the whole apparatus is divided into subdivisions and the available parts to the device in the market are discussed. In the drive system, the motor calculation gives the motor to select to be selected to the device. In the motor and drive selection table three available motors in the market are discussed, in which one can select according to the control system which should be selected to control the apparatus. The available control system is discussed in the further chapters. In the next chapter, the mechanical design of the apparatus is discussed.

6 MECHANICAL DESIGN OF THE APPARATUS

6.1 The bearing design
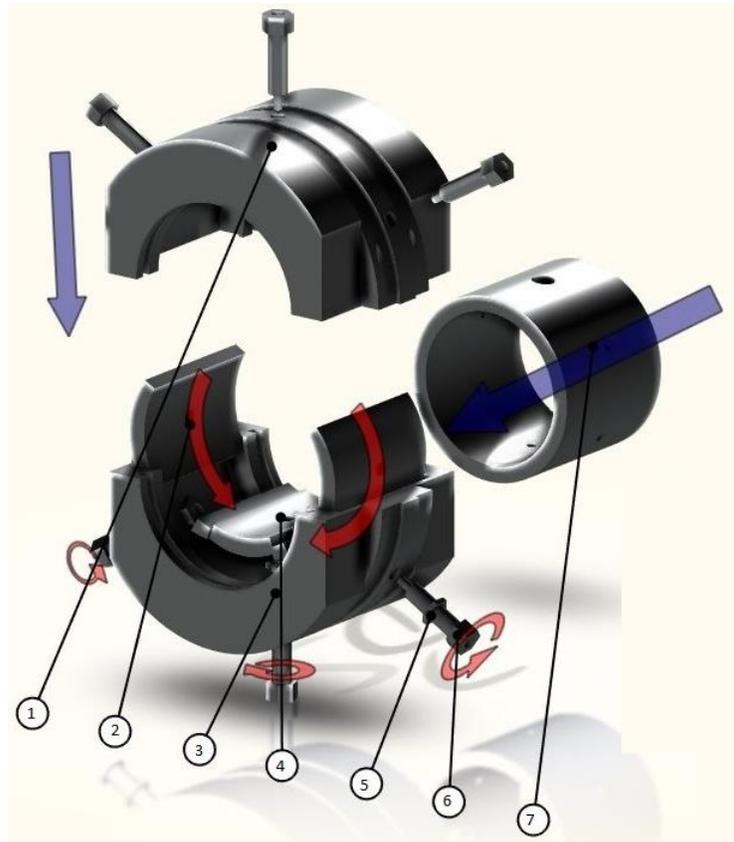
Figure 6.1 the design of the bearing, Exploded view, 1) Outer bearing upper part, 2) Metal pad, 3) Outer bearing lower part, 4) Middle metal pad, 5) Washer, 6) Bolt with the oil inlet and outlet, 7) Inner bearing.

The bearing should be strong enough to bear the load. Mainly the Bearing is made of mild steel, whereas the inner surface is well polished and made with high tolerance to avoid wear between the shaft and bearing during the application of load on the bearing and this will avoid the uneven distribution of pressure inside the bearing.

6.1.1 Problem statement:

The requirement for the design of the bearing is to modify the previous design. The design measurement shouldn't vary from the existing design. The existing bearing had the oil inlet in the front end of the bearing, where the oil used to flow from the front end of the bearing to the center of the bearing. The previous design is shown in the appendices. Hence to manufacture the bearing with the requirement of such openings need precision and manufacturing is difficult Hence the new design should be able to manufacture with fewer

difficulties. The Inner bearing has the same drawbacks. The outflow of the lubrication from the bearing is from the inner bearing. Where the oil flows from the center of the bearing and would flow from the center to the front end of the bearing It is then connected to the hoses than in turn to the manometers. The diameter of the holes in the inner bearing Is approximately around 1,5 mm. Hence to manufacture the bearing with a small hole is a difficult task, as the bearing is tested with different materials. It is necessary to be able to manufacture with fewer difficulties.

The modified design: Figure 6.1 is the new design where it is designed considering the above requirements. This design tries to eliminate the possible drawbacks. The upper and lower bearings are mounted together with the threaded bolts. The inlet and outlet of the lubrication oil are given through the outer bearing hence eliminating the inner bearing to be manufactured with such small openings. The inlet and outlet holes are given made in the center of the bearing, hence eliminating the hole to be made which would run all the half way through the bearing. The design shown in the figures are for the demonstration purpose and the number of inlet and outlet openings are demonstrated with limitations. The design is not subjected to the load simulations.
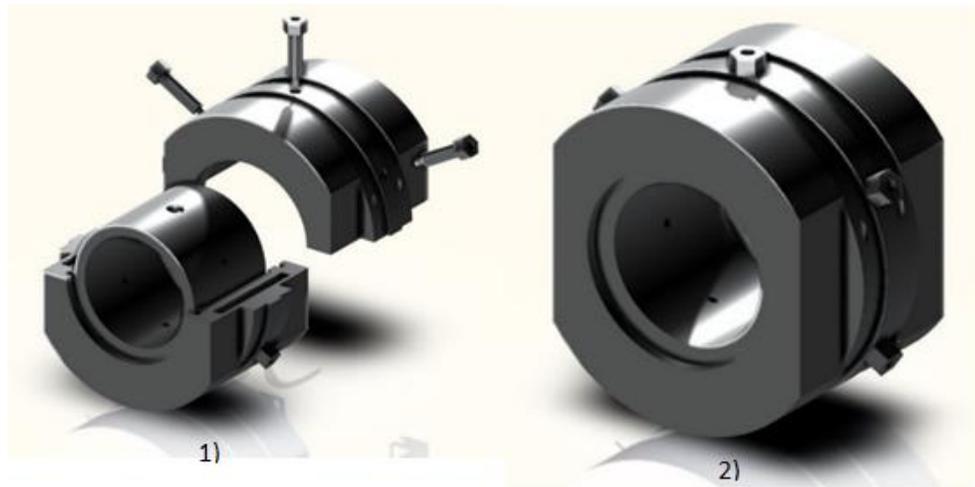
Figure 6.2 Installation of the part

The installation of the new journal bearing is explained as demonstrated in the above pictures in figure 6.2. Figure 6.1 shows the bearing completely in the dismantled state where the main or the inner bearing is parted from the outer bearing. The inner and the outer bearing are fixed to each other by means of threaded bolts. These bolts are produced with the inlet and outlet holes in the center for the flow of the lubrication oil to and from the bearing. The outer bearing is designed to house the metal pads which are inserted inside as shown in the figure. These metal pads act as tilt pads. In between these metal pads, rubber pads are inserted. The rubber pads are installed to absorb the shock while the bearing is loaded. The inner bearing is inserted in the inside as shown in figure 6.2. After the inner bearing is inserted inside the outer bearing the upper part of the bearing housing is attached to the lower part by means of a threaded bolt. The bolts and the oil hose are threaded to the inner and the outer bearings through metal pads supported by washers. Figure 6.2

picture 2 shows the assembled bearing.

6.2 The redesign of the shaft

Figure 2.4 picture 4 shows the existing journal with the ball bearing fixed with it. The shaft with one end that is fixed to the motor and the other end is the bearing end with which rotates inside it. Since the journal or the shaft is in a single piece, the shaft need to redesigned to represent the adaptability of it to supplant while it is worn out, easy to manufacture and to test the different materials

Figure 6.3 demonstrates the redesigned part of the shaft where the bearing end of the part is designed in such a way, to the point that it can be detached. The detachable part can be manufactured with different materials and their compositions, to study the properties how they deal with the continuous rotation of the bearing. The new dimesion of the bearing has the radius of 35mm and the length of 67.15mm which by preserving the length to diameter ratio of 0.95.
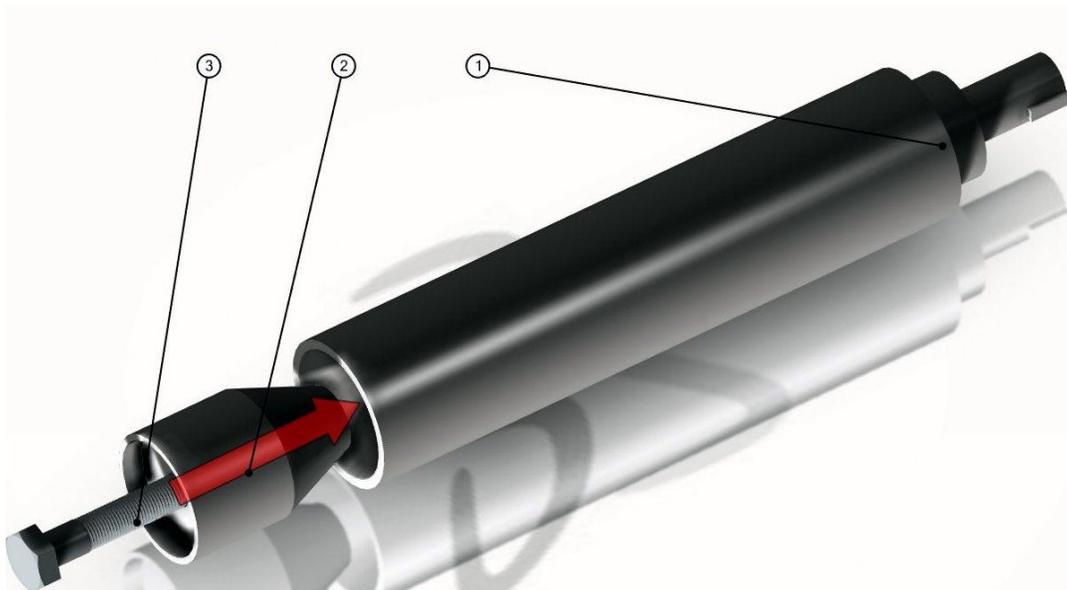
Figure 6.3 The redesigned shaft 1) Rotating shaft, 2) Detachable part, 3) Metal bolt.

6.3 Pillow block Mounted bearing

The mounted bearing is the supportive elements that hold the shaft at the two ends. The shaft is inserted in the bearing of the pillow blocks. These pillow blocks are mounted on the base plates. There are several bearing unit manufacturers. The one which is shown in the figure below is AST UCP214 pillow block mounted unit which is used in the design. The number of pillow blocks used in the units is two. One on the motor side of the shaft and the other at the bearing end. The technical information regarding the bearing units is mentioned in the Appendices of the paper. The unit is mounted on the base plate by using the two bolts on

the either ends. Since the existing system consists only two single row deep groove ball bearing on the either ends and missing the mounting unit to the system. It is necessary to suggest the required block unit the design.
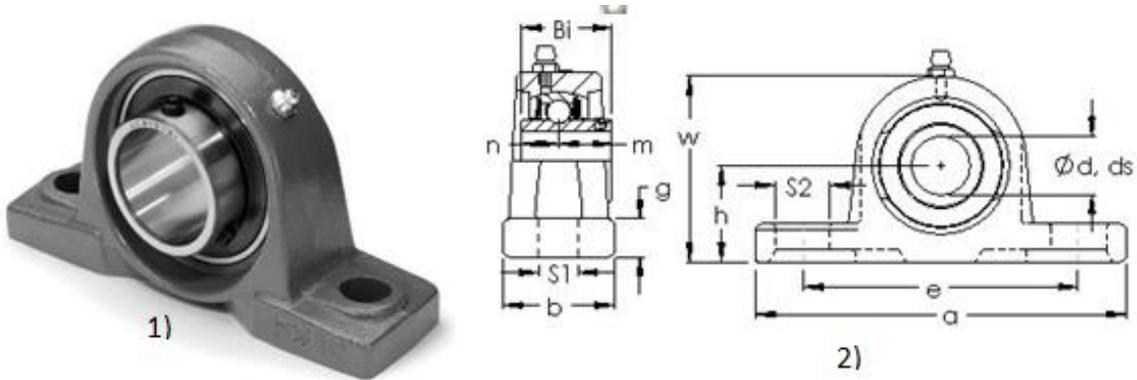
Figure 6.4 1) AST UCP214 [30], 2) Pillow block 2D diagram[30]

Table 6.1 UCP 214 specifications [30]

No	Specifications	
1	Bearing Type	Extended inner race with set screws
2	Dynamic Load Rating (Cr)	62,159 N
3	Static Load Rating (Cor)	44,022 N
4	Shaft Dia. (Fw)	70.000 mm
5	Shaft Height (h)	79.400 mm
6	Housing Width (b)	72.000 mm
7	Mounting Hole Center-to-Center (e)	210.000 mm
8	Housing Length (a)	266.000 mm
9	Mounting Slot Length (S2)	30.000 mm
10	Mounting Slot Width (S1)	25.000 mm
11	Housing Base Thickness (g)	28.000 mm
12	Housing Height (w)	156.000 mm
13	Bearing Inner Race Width (Bi)	74.600 mm

Various materials are used for the manufacture of the various bearing components some of the materials used are chrome steel-SAE52100, stainless steel, carbon alloy steel[31]. Eventually, a failure will occur when a ball bearing units are fitted and used on a piece of machinery, this period of operation until the unit cannot be used due to failure is called the bearing life. Failure may be caused due to fatigue and the lubrication degradation. Proper maintenance of the bearing and proper lubrication will ensure the long life of the bearing[32].

6.4 Coupling

Shaft couplings are the mechanical part which is used to connect the rotating shafts and absorb the misalignments between them. Depending on the shaft measurements and the torque requirements the coupling properties are chosen. It may be rigid or flexible. Coupling in this task is used to transmit rotating power from motor to the journal[33].

Figure 6.5 Beam type coupling[33]

There are various coupling styles: Beam, bellows, chain, Jaw, Diaphragm, Disc, Gear, grid, Oldham, Schmidt.

Considerations: The couplings are selected according to the type of application, whether is it used for motion control applications or for the power transmissions. Type of coupling used for the task is power couplings where it is designed for mild torques. The design shows there is very less parallel and angular misalignment, as this is one of the considerations for the selection of the coupling. Maximum RPM is another consideration. [33]

6.5 Base Plate

The base plate is the metal base which supports the whole apparatus to be fixed on. The plate should be rigid enough to withstand the weight of the device and wouldn't deflect when the applying load on the bearing. Since the frame which has a hole where the shaft is inserted inside the bearing is at quite a different height, another base plate is placed on the main base plate, where the motor and the pillow block units are mounted. Pillow blocks and the motors are mounted on the plate by using the Allen bolts. This plate is mounted on the main base plate where the frame and manometer stand are fixed on it. The whole device is placed on the table. The figure below shows the apparatus with the base plate dimensions.
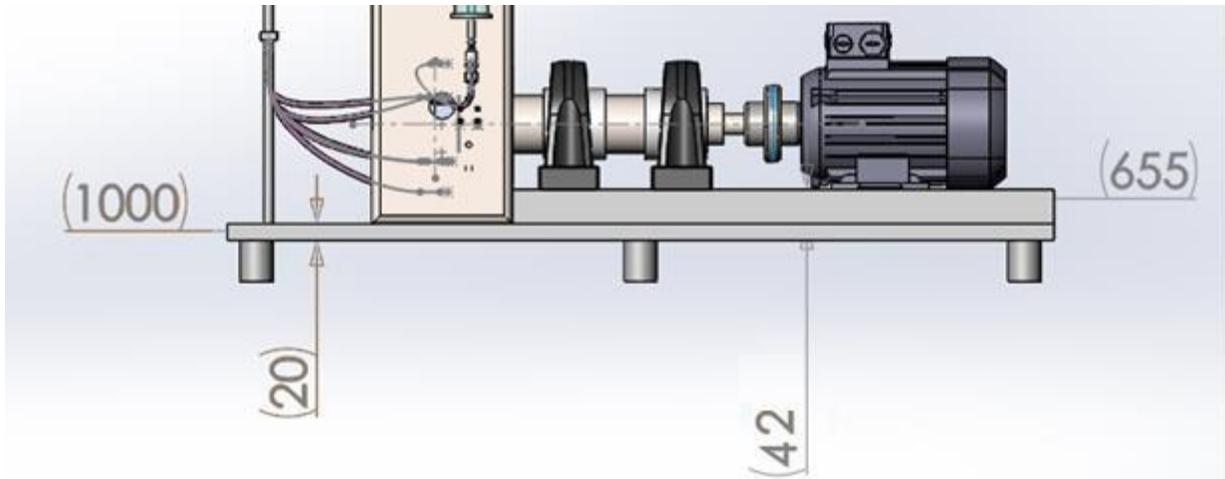
Figure 6.6 Base Plate for the apparatus

6.6 The sliding bar mechanism loading system

This mechanism involves the usage of the previous parts still eliminating the most of the space inside the frame. The mechanism involves the bearing is loaded by means of a metal belt which is attached to a metal bar. The metal bar is driven by a means of the screw mechanism. The screw bar is taken from the existing system but by modifying the length of the bar to 80mm screw bar. The upper metal bar is fixed to the frame by means of Allen screw bolts. The load cell is position in between the metal bars, by the compression, we can establish the force applied to the bearing by the screw mechanism. Figure 6.7 demonstrates the combination of the national instruments data acquisition system with Honeywell load cell with national instruments data acquisition board, chassis, and RJ50 connector.
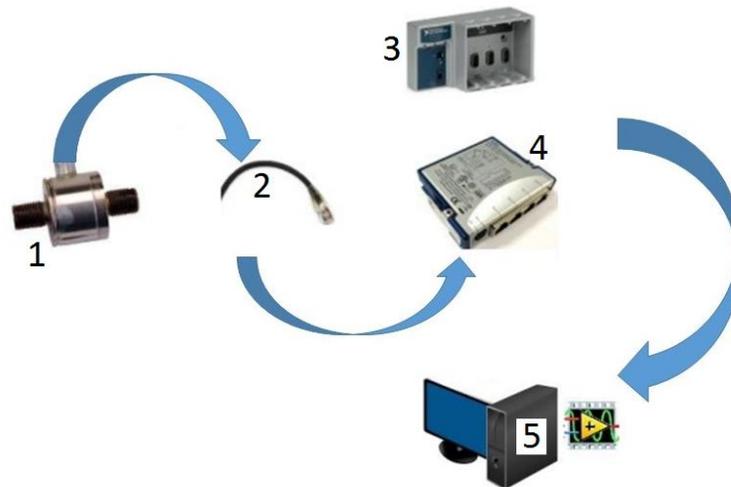
Figure 6.7 Load cell data Acquisition system, 1) Load cell, 2) RJ connector, 3) USB Chassis, 4) Data Acquisition board, 5) PC and Software

The figure below demonstrates the load cell position in the new loading system where the data acquisition board acquires data from the load cell and send it to the PC using LabVIEW software from National Instruments. The data acquisition board is connected to the USB sleeve which in turn is connected to the PC using USB cable.
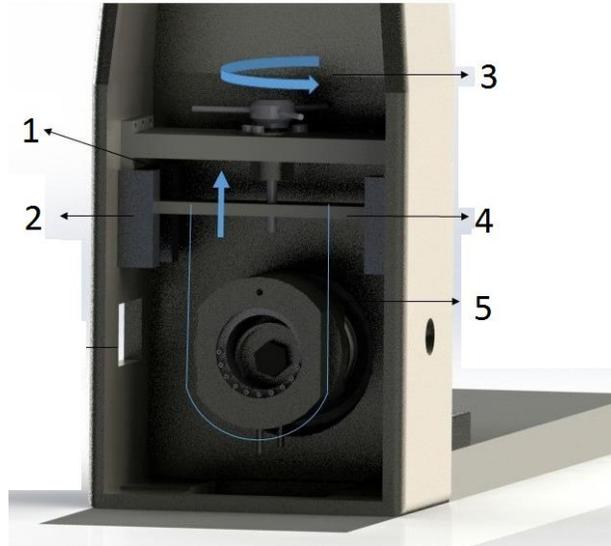
Figure 6.8 loading system through sliding bar mechanism 1) Load cell position, 2) Guide rails for the metal bar to move, 3) Screw head, 4) Metal bar which moves up and down by the screw mechanism, 5) Belt which pulls the bearing towards up

6.6.1 NI 9237 Data Acquisition Board

Figure 6.9 NI 9237 DAQ Board [34]

[34]The NI 9237 data acquisition module contains all the signal conditioning required to power and measures up to four bridge-based sensors simultaneously. For direct connectivity to the load cells from the NI9237 RJ50 jack is utilized which provide and offer custom cable solution.NI 9237 offer a high-quality, high-speed strain or load measurement system with zero interchannel phase delay with the high sampling rate and bandwidth of the. With 60 VDC isolation and 1,000 Vrms transient isolation, the NI 9237 offers high-common-mode noise rejection[34].

Figure 6.10 cDAQ-9174 (4 slot USB chassis)[35]

The cDAQ-9174 is a 4-slot CompactDAQ USB chassis Intended for small, portable, mixed-measurement test systems. Modules are available for a various kind of sensor measurements including load cells as per this task. CompactDAQ systems combine sensor measurements with voltage, current, and digital signals to create custom, mixed-measurement systems with a single, simple USB cable back to the PC, laptop, or netbook[35].

6.7 Concept generation

In the process of arriving at the final design, many conceptual designs are created. Each design has their own pros and cons. prior to the arriving to the conclusion of the final design considering the requirements of the task, a set of solutions are created. These solutions are checked for fulfilling the necessary requirements. These set of solutions are compared with their particular pros and cons. Then the best solution is selected for the final design.

As per the main requirement is the loading system and suggesting the suitable parts for the apparatus, the following loading systems are discussed for to be one of the solutions.

The figure below shows the simple loading system where the bearing is loaded by means of a screw jack actuated by an actuator. This design is very simple, consumes less space, loading is not manual. In this design, the loading is very easy where an actuator is used to lift the screw jack instead of the hand wheel. This does not eliminate the conventional method of loading the bearing by lifting, however, the design needs an actuator which must control by an actuator and hence the actuator should be monitored through a user interface. This design removes the frame from the original device. The design also eliminates the conventional method of loading by a steel belt. This may cost compared to the other devices to be compared. Hence much detailed research has not been done on the installing the screw jack and operations by this method
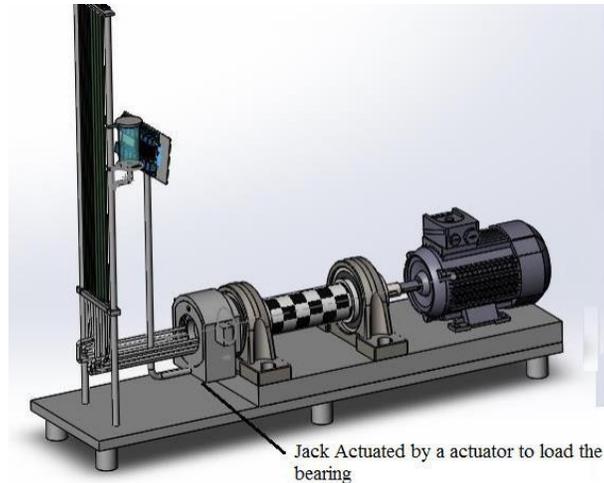
Figure 6.11 The concept design

Applying load by adding weights: The other conceptual design is applying the load to the bearing by adding weights manually. This design is developed by producing a design that could lift up the bearing from the bottom. The design would be metal bar fixed one end to the frame from inside with a rotating hinge and the other end of the rope. The rope is run through a pulley which is placed at a higher position where it helps the rope to rotate around it and run the rope to a lower part. The rope at the other end is attached to a weight hanger. Whenever the weight is added on the hanger the bar is lifted thereby lifting the bearing from the bottom since the one end is hinged to rotating end. This design could load the bearing from the bottom, but still, it may create an imbalance in loading. However, the design is simple and can be used with proper designing techniques. This design also eliminates the conventional loading method by the metal belt. This could eliminate the basic property of the apparatus which the device stand for.

6.8 Assembled apparatus

The figure shown below shows the new design of the journal bearing apparatus with all the components presented in the exploded view. The journal (shaft) is rotated by means of a motor. The motor shaft is fixed to the journal by means of a coupling. The apparatus should be able to run at different speeds to analyze the pressure of the oil at various speeds of the shaft. Hence, the project includes the task of controlling the speed of the motor. The motor speed is controlled by means of a variable frequency drive. Various kinds of the possible drives which can be used for the task has already been discussed in the earlier chapters, However, the process to control this VFD (variable Frequency Drive) has will discuss in the next chapter and also how to control this drive using a User Interface. The bearing when the motor is running at various speeds is subjected to loading. The load is applied to bearing by means of a metal belt as it was previously used by the existing system Therefore the new design includes the new loading system, which is explained in the sections of this chapter.
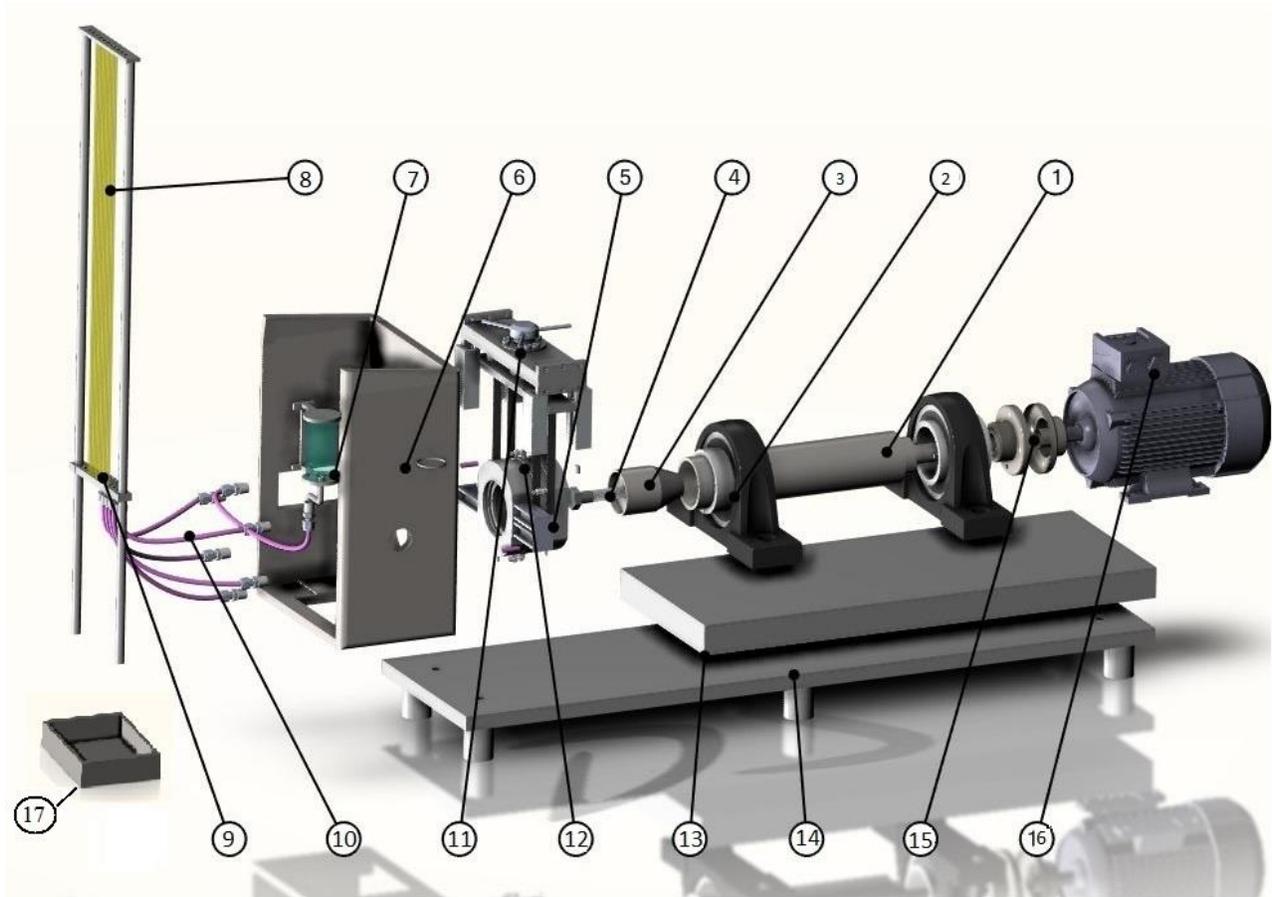
Figure 6.12 The assembled apparatus,1) Shaft, 2) Pillow block, 3) The dismantlable shaft, 4) Threaded bolt, 5) Support for the outer bearing to the frame, 6) Frame, 7) Oil tank, 8) Manometers, 9) Frame or stand, 10) Hoses (pipes), 11) Load applying screw, 12) Bearing, 13) Base plate for the shaft and the motor, 14) Base for the whole plate, 15) Coupling, 16) Motor, 17) Oil tray

6.9 Summary

In this chapter, the mechanical design of the apparatus is discussed. As per one of the main objective of the task is to modify the previous design of the without changing the measurement with several constraints, the conceptual design has been discussed in this chapter where the solution is provided according to the requirements of the design. This is continued with the modification of the shaft continued with the suggestion of the pillow blocks, coupling and the base plate for to the device. Further, the concept generation has been discussed as an alternative to the design. Finally, the mechanical design assembled has been discussed at the end. The next chapter deals with the simulations which are subjected on these mechanical will be discussed following the control system of the apparatus.

7 MECHANICAL DESIGN ANALYSIS

In this section, the design analysis of the mechanical parts has been generated on the bearing shaft and on the belt. The bearing shaft and belt are the main parts which are subjected to the load when the force is applied, hence the analysis is done in these parts. In the following sections, Analysis of the bearing shaft and the Belt, the parts are subjected to the maximum load. The analysis has been done by using the SOLIDWORKS software.

7.1 Analysis of the bearing shaft design

In the analysis of the bearing shaft design, the bearing subjected to the load at the end of the bearing shaft on the bearing. Assuming the maximum load applied on the bearing is 3000N. The table shows the properties assumed for the analysis of the bearing shaft design.

Table 7.1 Material properties of the bearing shaft analysis

No		
1	Name:	Alloy Steel
2	Model type:	Linear Elastic
3	Default failure criterion:	Max von Mises
4	Yield strength:	6.20422e+008 N/m^2
5	Tensile strength:	7.23826e+008 N/m^2
6	Elastic modulus:	2.1e+011 N/m^2
7	Poisson's ratio:	0.28
8	Mass density:	7700 kg/m^3
9	Shear modulus:	7.9e+010 N/m^2
10	Thermal expansion coefficient:	1.3e-005 /Kelvin

Table 7.2 Stress Diagram of the bearing shaft assembly shows the stress analysis of the bearing shaft. The analysis has done on assuming the force is applied on the whole surface of the journal bearing part. This analysis is done on this part to know the maximum and minimum stress acting on the part of the bearing. Since the design and the dimensions of the bearing shaft remain the same, the analysis is generated to learn the area of the material where the maximum and minimum stress acting is on the bearing. Assuming the maximum of 3000N is applied on the bearing, by the von Mises Stress criteria the maximum induced stress on the bearing is 2.8826e+006 N/m^2. Obtained by the FEA analysis from the Von Mises stress distribution

as shown in Figure 7.1, it can be noted that the von Mises stress is maximum the bearing edge and the value is 2.8826e+006 N/m^2 which is lower than the yield strength value 6.20422e+008 N/m^2. Hence the design is safe.

Table 7.2 Stress Diagram of the bearing shaft assembly

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.000161425 N/m^2	2.8826e+006 N/m^2

Figure 7.1 stress analysis diagram
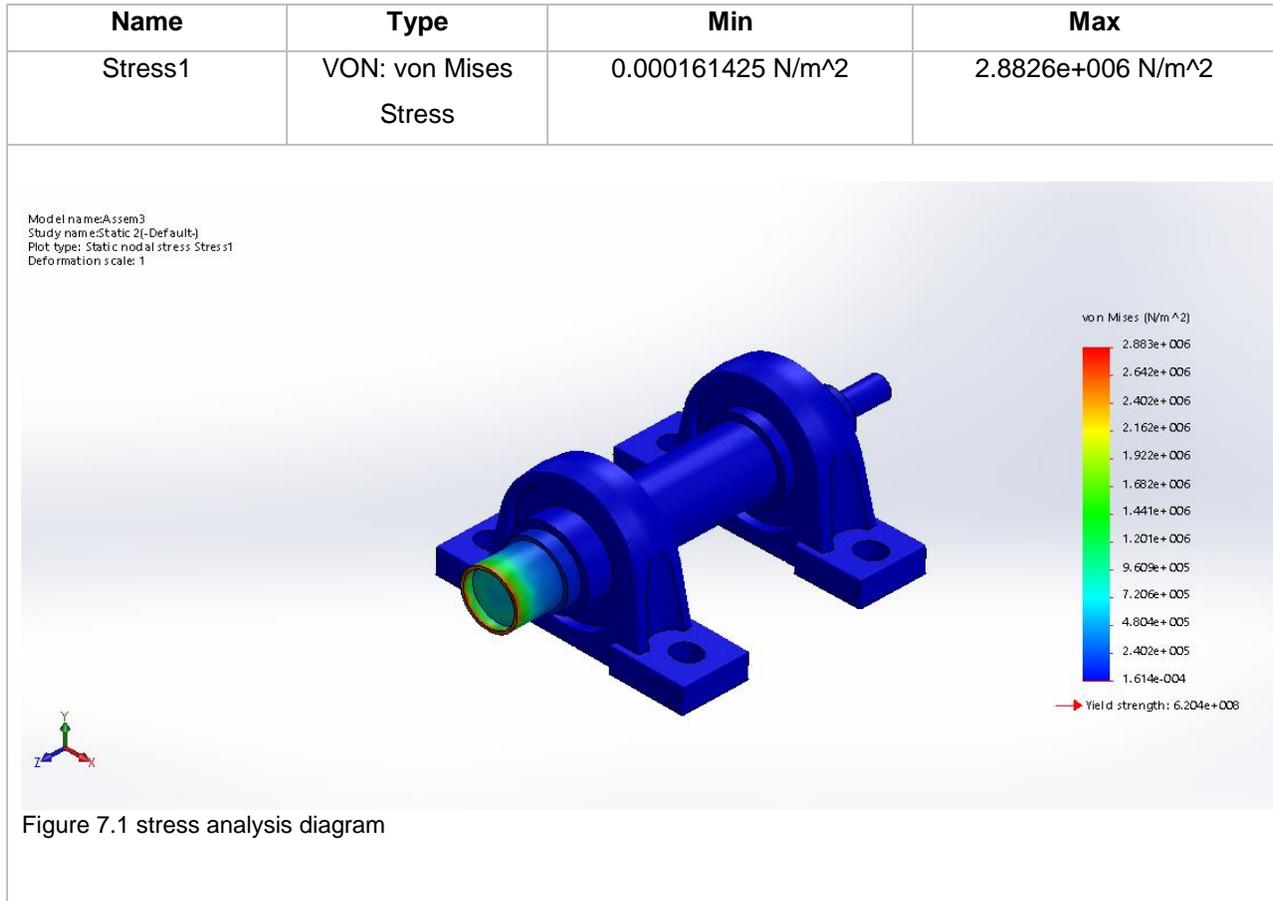
Table 7.3 Resultant Displacement Table shows the results of the bearing shaft deformation when the load is subjected on the part. The maximum deformation according to the analysis is 0.000405283 mm, when the part is subjected to the load of 3000N.

Table 7.3 Resultant Displacement Table

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm	0.000405283 mm
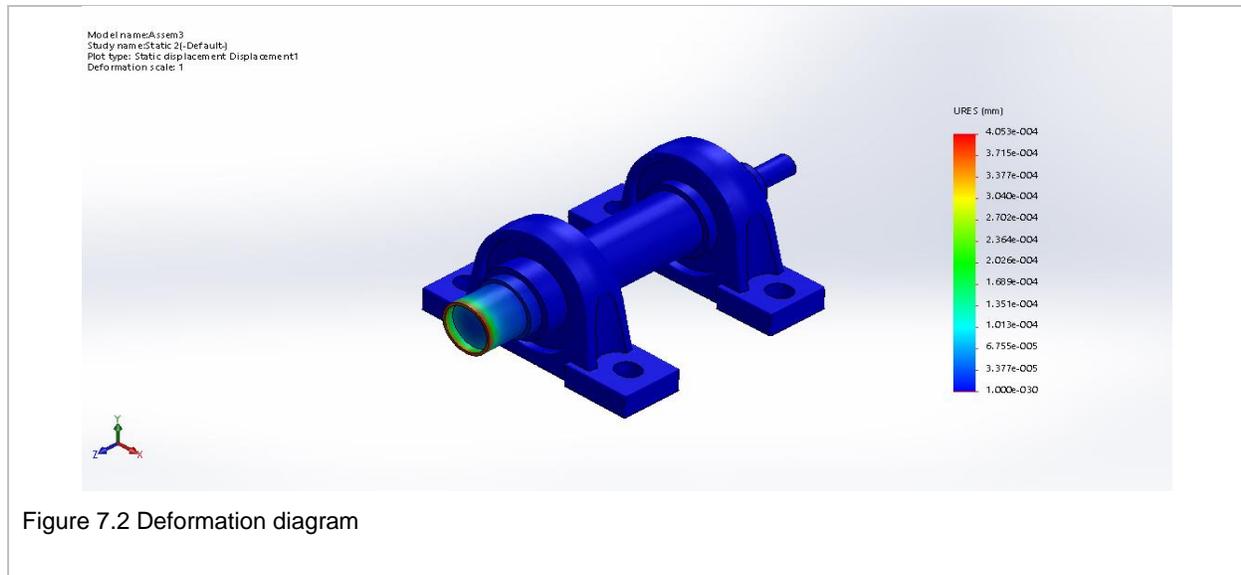
Figure 7.2 Deformation diagram

7.2 Analysis of the belt design

In the analysis of the belt design, the belt is subjected to the load at the bottom end where it lifts the outer bearing. When the force is applied by the rotating the screw the belt moves upwards by lifting and applying force on the inner bearing. Assuming the maximum load applied on the bearing is 100N. The Table 7.4 Properties of Belt model to be analyzed shows the properties assumed for the analysis of the belt design.

Table 7.4 Properties of Belt model to be analyzed

Model Reference	No	Properties	
Figure 7.3 Reference model: Belt	1	Name:	Stainless Steel (ferritic)
	2	Model type:	Linear Elastic Isotropic
	3	Default failure criterion:	Max von Mises Stress
	4	Yield strength:	1.72339e+008 N/m^2
	5	Tensile strength:	5.13613e+008 N/m^2
	6	Elastic modulus:	2e+011 N/m^2
	7	Poisson's ratio:	0.28
	8	Mass density:	7800 kg/m^3
	9	Shear modulus:	7.7e+010 N/m^2
	10	Thermal expansion coefficient:	1.1e-005 /Kelvin

Table 7.5 shows the stress analysis of the belt. The analysis has done on assuming the force is applied on the curved part of the stainless-steel belt. The analysis is done to understand the knowledge of the part of the

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belt where the loads are applied. In the design study, the forces are applied to the part where the stainless-steel belt lifts the outer bearing. Hence considering the weight of the bearing as the load applied on the belt, the design study is done. Assuming 100N as the force applying on the belt at the curved surface on it. By the von Mises Stress criteria, the maximum induced stress on the belt surface is 2.93159e+007 N/m^2. The von Mises stress distribution obtained by the FEA analysis can be seen in the figure. The von Mises stress is maximum at the center of the curve of the belt and the value, 2.93159e+007 N/m^2 is lower than the yield strength value 1.72339e+008 N/m^2, hence can be said that the design is safe.

Table 7.5 Stress analysis for belt

Name	Type	Min	Max
Stress	VON: von Mises Stress	39172.2 N/m^2	2.93159e+007 N/m^2

Model name: belts
Study name: Static 2 (-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 83.0898

von Mises (N/m^2)

2.932e+007
2.688e+007
2.444e+007
2.200e+007
1.956e+007
1.712e+007
1.468e+007
1.224e+007
9.798e+006
7.358e+006
4.919e+006
2.479e+006
3.917e+004

Yield strength: 1.723e+008
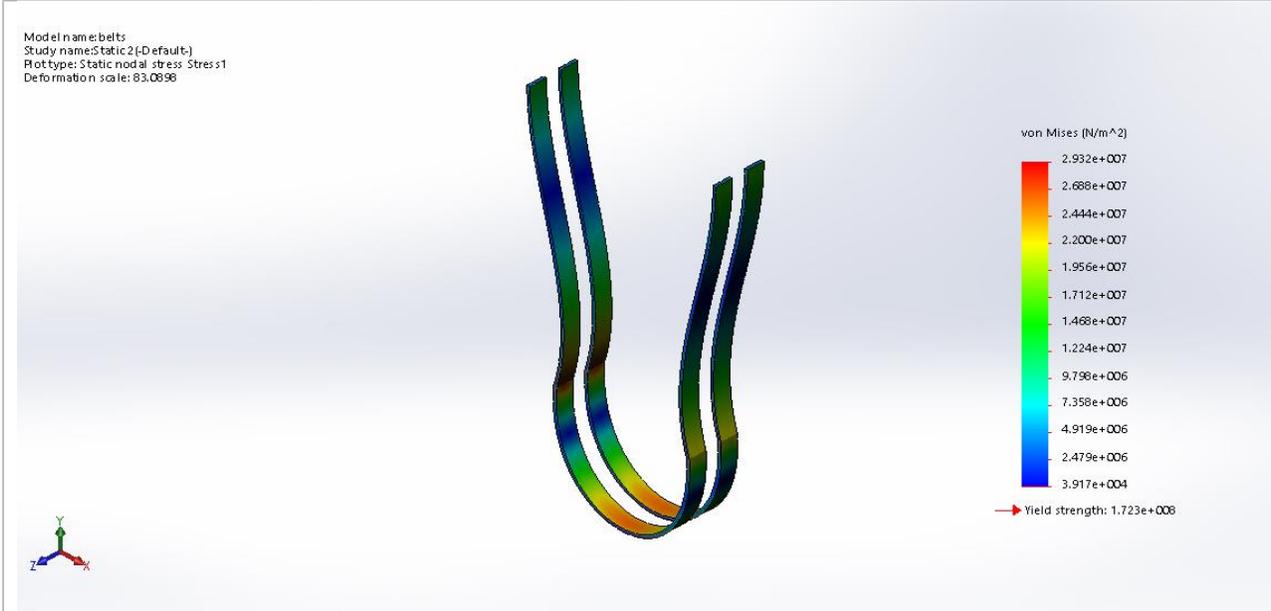
Figure 7.4 Resultant stress diagram of the belt

Table 7.6 Resultant displacement table of the belt shows the results of the belt deformation when the force is applied on the part. The maximum deformation according to the analysis is 0.27193mm, when the part is subjected to the load of 100N of the load at the curved part of the belt. The maximum displacement value is the part where is the red oval is marked and not the lower parts where the load is applied. Hence this part of the can add some material to increase the strength.

Table 7.6 Resultant displacement table of the belt

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm	0.271933 mm

Model name: belts
Study name: Static 2 (Default)
Plot type: Static displacement Displacement1
Deformation scale: 83.0898

URES (mm)

2.719e-001
2.493e-001
2.266e-001
2.040e-001
1.813e-001
1.586e-001
1.360e-001
1.133e-001
9.064e-002
6.798e-002
4.532e-002
2.266e-002
1.000e-030
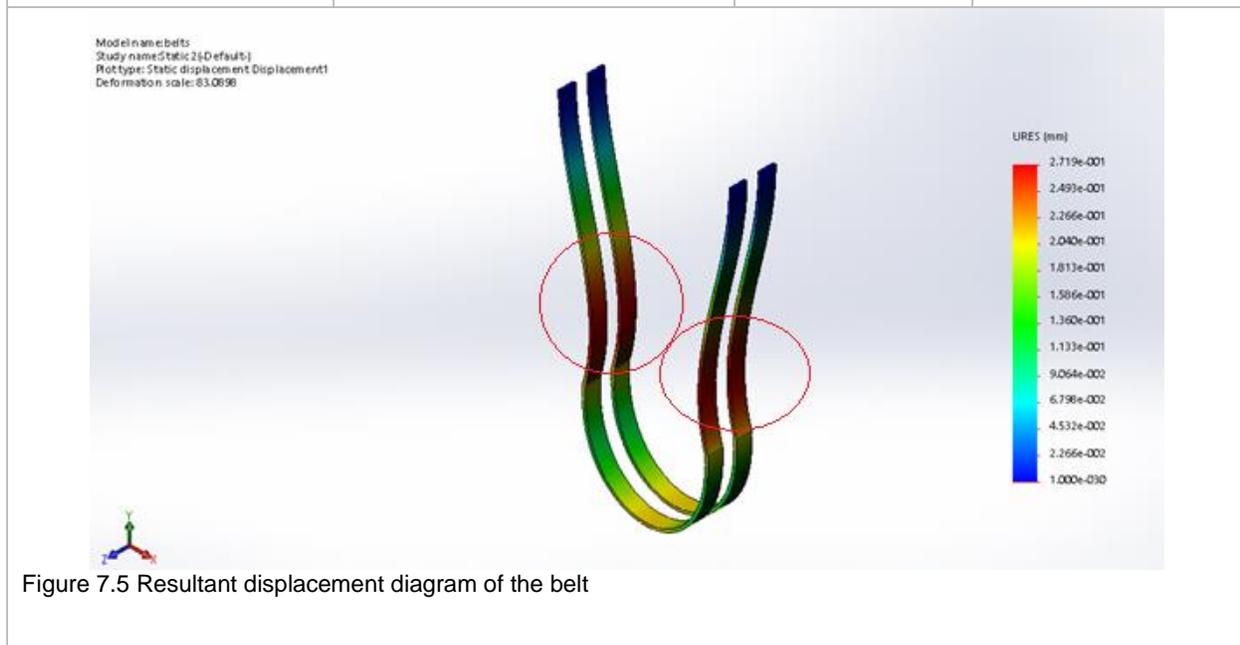
Figure 7.5 Resultant displacement diagram of the belt

7.3 Summary

In this chapter, the design study of the mechanical parts which has been subjected to the load has been discussed. In the first section, the design study of the bearing where it is subjected to the load applied by the belt when the force is applied by rotating the screw has been given. In the next section, the analysis has been done on the steel belt which applies force by lifting the bearing. The design study of these parts is important to understand the capacity to bear the external force in the working condition. In the next chapter, the control system is discussed to control these the apparatus.

8 CONTROL SYSTEM

The Load applied to the bearing and controlling the motor for the different speeds are the major goals of the controlling system in this project. The force is applied to the bearing by pulling the bearing using the screw mechanism through a belt. The pulling force applies load on the load cell in which the force is measured. There are many ways to configure the controlling and measurement system, where series of solutions are discussed below. Since there are numerous ways to control and measure the task, the goal of the task would be, to create, control and measure the task with reliability, monitor the task using a single Human Machine Interface, create a simple control system. Mentioned below are the control systems where some of them exist already. Some systems can be adapted to this task. The system which satisfies the prerequisites is adapted and involved in the task.

8.1 Controlling a 3phase a/c motor using LabVIEW and fieldpoint[33]

The method mentioned in this section is a National Instruments provided a solution where full voltage, nonreversing motor can be controlled by a control circuit which can start and stop a motor that turns in only one direction [36]. The main components of such a circuit are:

- The main circuit breaker to connect and disconnect the motor circuit from the feeding power lines
- A motor starter, consisting of a coil to open and close the three contacts that stop and stop the motor, and an overload device to open the circuit if the motor draws too much current

Three phase A/C motors are used in many industrial applications and can be found on many process floors. A motor control circuits, usually located in a special motor control center, start and stop A/C motors and protect motor integrity. Most industrial applications employ one control circuit for each motor [36]

The VI turns on a digital output of a Fieldpoint module if the Auto or Manual control is on. If the Auto control is on, the Manual control is turned off. When the VI writes to the output, it reads the signal on a digital input of a Fieldpoint module. This signal is used as feedback to indicate whether the motor should be running. If there is no signal coming back on the input, the VI waits for a second before turning the alarm on[32].
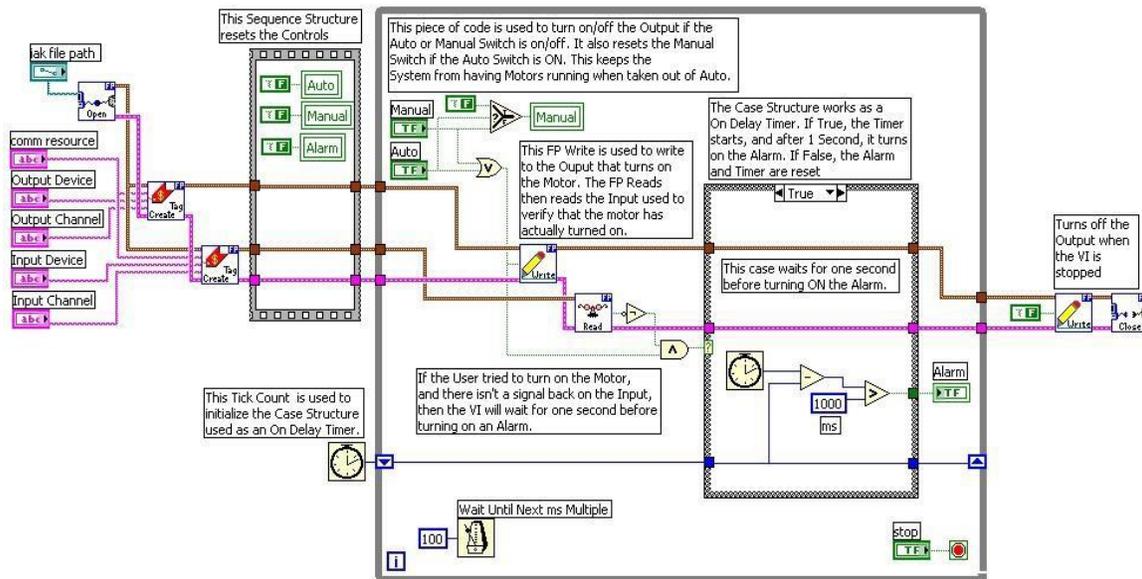
Figure 8.1 Block diagram for controlling the motor [32]

8.2 Controlling abb Acs 355 through LabVIEW
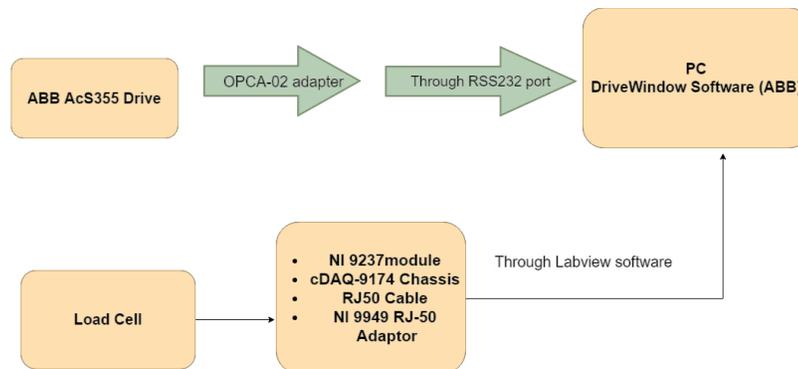
Figure 8.2 ABB ACS 355 with load cell schematic

The drive can receive start, stop and direction commands and reference values from the control panel or through digital and analog inputs. Embedded Fieldbus or an optional fieldbus adapter enables control over an open fieldbus link. A PC equipped with the DriveWindow Light 2 PC tool can also control the drive.
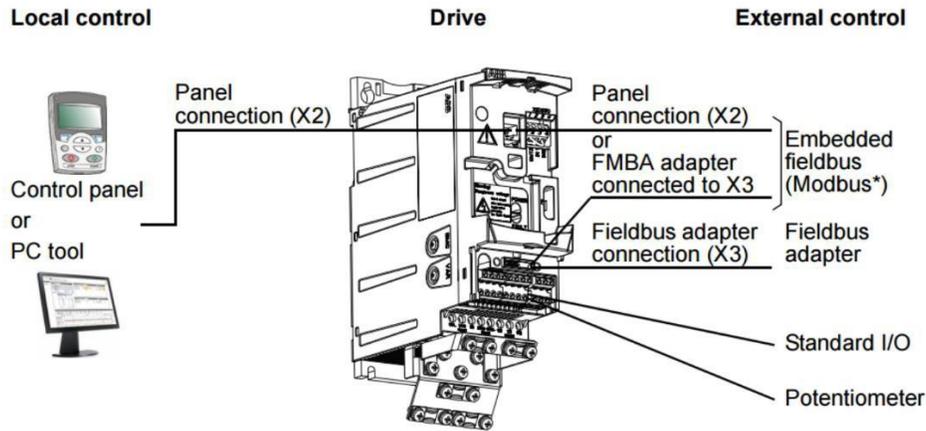
Figure 8.3 ABB ACS 355 Connections [37]

With SREA-01 Ethernet adapter module, it is possible to use Modbus TCP/IP with the Ethernet.

Figure 8.4 SREA-01 Ethernet adapter[38]

SREA-01 has three connectors: the screw terminal X1, RS-232 connector X2, and Ethernet connector X3

The drive can be connected to an external control system through a fieldbus adapter or embedded fieldbus. The embedded fieldbus supports Modbus RTU protocol. Modbus is a serial, asynchronous protocol. The embedded fieldbus can be connected with either EIA-485 (terminal X1 of the optional FMBA-01 Modbus adapter connected to drive terminal X3) or RS-232 (control panel connector X2). EIA-485 is designed for a multipoint application (a single master controlling one or more slaves). RS-232 is designed for a point-to-point application (a single master controlling one slave). [38]

The pin configuration of the RS-232 connector is shown below. The drive can be set to receive all of its control information through the fieldbus interface, or the control can be distributed between the fieldbus interface and other available sources[38].

The drive can receive start, stop and direction commands and reference values from the control panel or through digital and analog inputs. Embedded fieldbus or an optional fieldbus adapter enables control over an open fieldbus link. A PC equipped with the DriveWindow Light 2 PC tool can also control the drive[18].

ABB Software tools
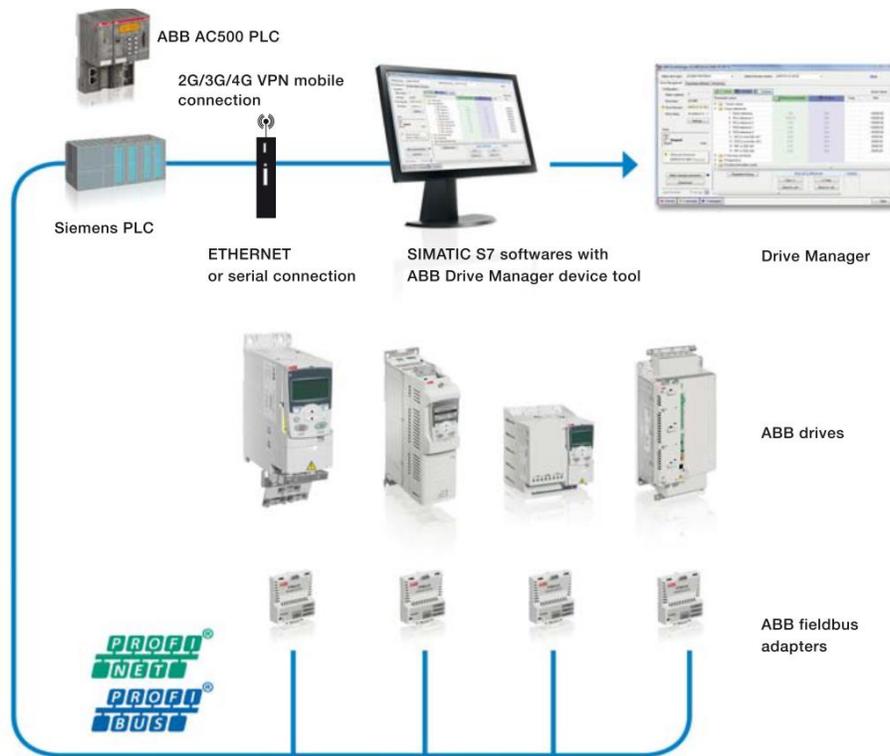
Figure 8.5 ABB Optional software tools [18]

8.3 Connecting LabVIEW to ABB drive with Modbus

LabVIEW becomes a powerful HMI/SCADA package for industrial control applications. It is able to control the drive through a Modbus.

Creating a Modbus master I/O server: A LabVIEW interface is created with Modbus addresses, called an I/O server. Communications settings (Address, IP address) are configured in the Modbus I/O server. Bind shared variables to Modbus Addresses through the I/O server: Address ranges are selected in the bound variables window. Then Modbus Addresses are written in the LabVIEW. The front panel is shown in the control and monitoring system chapter. With SREA-01 Ethernet adapter module, it is possible to connect the drive to the PC with the Ethernet.

8.4 Control system: SIEMENS

Siemens provides products and solutions with industrial security functions that support the secure operation of plants, solutions, machines, devices, and/or networks [34]. Siemens provides a solution for the

automation through its own kind of software and hardware tools. The Figure below shows the control system that can be incorporated to the journal bearing apparatus using the Siemens hardware and software tools. The control system consists of S7-1200 controller, Sinamics G120 Inverter, Siemens motor for controlling the speed of the motor and load cell, SIWAREX weighing module, and computer. The software tool includes STEP7 for the programming of the speed control of the motor, Siwatool v7 for acquiring data from the weighing module and Simatic WinCC for the Human machine interface.
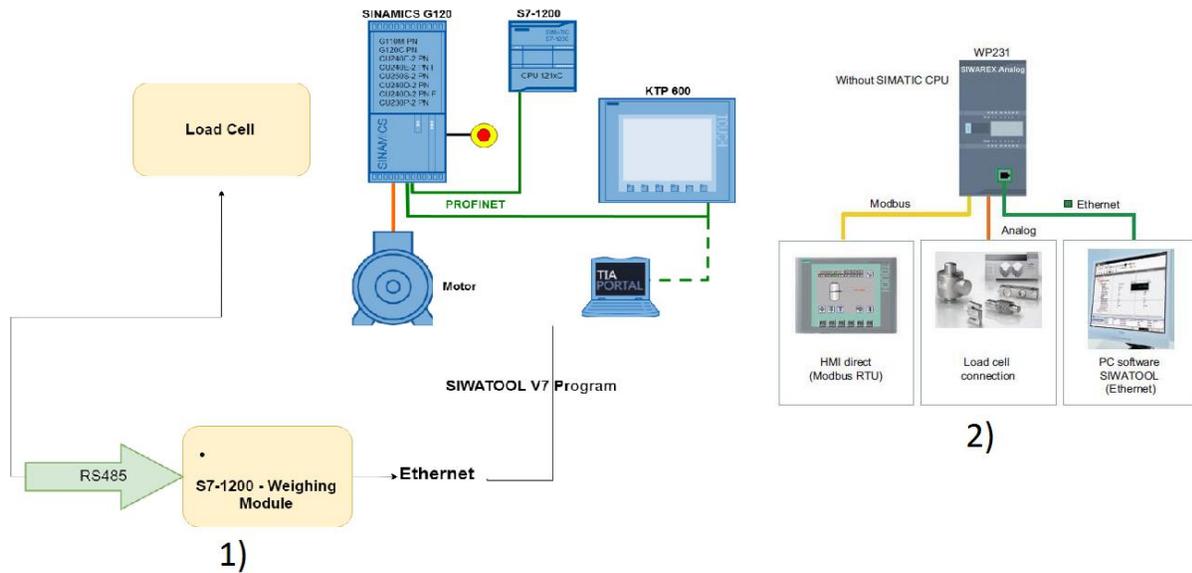
Figure 8.6 1) Control system, Siemens, 2) Load Cell Measurement[39]

8.4.1 The S7-1200 Basic Controller

The SIMATIC S7-1200 controller is modular and compact, versatile, a secure investment, and is perfectly suited to a whole range of applications. The S7-1200 CPUs with Safety Integrated handle both standard and safety-related tasks. A compact design with integrated IO, communication interfaces that meet the highest industry requirements and a range of powerful integrated technological functions make this controller an integral part of a comprehensive automation solution[40]

8.4.2 SINAMICS G120

SINAMICS G120 is a modular inverter system and is especially suited as a universal drive in the complete domain of industry and the trades for instance, in the automobile, textile, printing and chemical sectors for higher-level applications, e.g. in conveyor technology. Communication via fieldbus (PROFINET or PROFIBUS) with the safety-related PROFIsafe profile is already possible in the standard version[41].

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Figure 8.7 1) SIMATIC S7-1200 controller, 2) SINAMICS G120

8.4.3 The configuration of Sinamics G120[19]:

The following steps give the idea of configuring the Sinamics G120 with a lot of options of choosing depending on the requirements.

1. selecting the Power Module and power-dependent options
2. selecting the optimum Control Unit[24]

   Depends on the following requirements,

   - Encoder used for signal feedback,
   - Integrated positioning capability,
   - Integrated safety technology,
   - Number of inputs and outputs,
   - Type of communication/bus system,
   - Permissible combinations with Power Modules,
   - Optional shield connection kit is required for the particular Control Unit

3. optional system components and licenses[24]

   - Optional system components and licenses,
   - Optional additional Description Components.
   - Software for engineering and commissioning

8.4.4 Weighing module SIWAREX WP231

Figure 8.8 SIWAREX [42]

- SIWAREX WP231 is the first weighing module for SIMATIC S7-1200 and through this is programmable via the Totally Integrated Automation (TIA) Portal engineering platform. The ability to operate SIWAREX WP231 with or without SIMATIC PLCs offers the flexibility needed. The Ethernet and RS485 interfaces with Modbus protocol enable to integrate the weighing module into different control systems. SIWAREX WP231 offers four digital inputs and outputs and one analog output. All inputs and outputs are controllable via the SIWAREX module or via SIMATIC S7-1200. The high resolution of one million parts and the measuring rate of 10ms guarantee a reliable weighing in all of the applications. The module also offers extensive diagnostic functions for commissioning and operation like a trace of weight or monitoring of limit values the commissioning is either possible via the new SIWATOOL or directly via a connected HMI touch panel [43].

- The power supply, load cells, the RS 485, digital input/outputs and the analog output are connected via the screw connector of the weighing module. An RJ45 connector is used for the Ethernet connection. Function The primary task of SIWAREX WP231 is the measurement and conversion of sensor voltage into a weight value. Up to three interpolation points are used for the weight calculation. The signal can also be digitally filtered if required. [44]

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8.4.5 Load Cell

The bending ring load cell is particularly suitable for implementation in a container, conveyor, platform and roller table scales. The measuring element is a bending ring made of stainless steel. Two expansion measuring spirals are applied each to the upper and lower faces of the ring. Under the influence of the centrally acting load in the measuring direction, the bending ring is tilted, i.e. the diameter of the upper ring face is reduced and the diameter of the lower ring face is increased. This causes the bending ring (and the expansion measuring spirals installed with friction-locking) to be elastically deformed. This generates a measuring signal voltage that is proportional to the load. Load cells with a rated load of up to 13 t are equipped with integral overload

protection [42].

Figure 8.9 SIWAREX R RN [42], Rated load: 60 kg to 60 t Degree of protection: IP68 Sensor material (DIN): Stainless steel

8.4.6 Siemens software tools

1. SIMATIC STEP 7 (TIA Portal): PLC Programming: configuration and programming of SIMATIC controllers S7-1200, S7-1500, S7-300, S7-400, the S7-1500 Software controller as well as WinAC[45].
2. SIWATOOL V7 [44]: SIWATOOL V7 is a special program for commissioning and servicing and runs with Windows operating systems. The program enables the user to perform scale adjustment without requiring automation engineering skills. During servicing, the technician can use a PC to analyze and test the procedures in the scale. Reading the diagnostics buffer from the SIWAREX WP231 is extremely helpful when analyzing events. The following are just some of the tasks that can be carried out using SIWATOOL V7:

> ➢ Parameterization and adjustment of the scale
> ➢ Testing of scale properties
> ➢ Recording and analysis of weighing sequence.

It is also extremely helpful to analyze the diagnostics buffer which can be saved together with the parameters following reading out from the module. Trace mode is provided to optimize the weighing sequences in the SIWAREX WP231 weighing module. The recorded weight values and associated states can be displayed as trends using SIWATOOL V7 and MS Excel. [38]

3. SIMATIC WinCC[38]: SIMATIC WinCC is a supervisory control and data acquisition (SCADA) and human-machine interface (HMI) system from Siemens. SCADA systems are used to monitor and control physical processes involved in industry and infrastructure on a large scale and over long distances. SIMATIC WinCC can be used in combination with Siemens controllers. WinCC is written for the Microsoft Windows operating system. It uses Microsoft SQL Server for logging and comes with a VBScript and ANSI C application programming interface [46].

8.5 Control system from Rockwell automation

As Siemens, Rockwell Automation provides control system through its own set of products. Related to the task, the Rockwell automation has the following set of control system tools necessary for the task.Micrologix 1100 processor, Powerflex 525 drive, micro 800plc for Easy 8 weighing module (Hardy Process Solutions). Details of Micrologix 1100 and Powerflex 525 have been discussed in the earlier sections. Software tools used are Rslinx (used to provide a communication link between the computer, network, and controller), Rx logic 500/5000 (ladder programming for PLC), and Connected Components Workbench (Micro800).
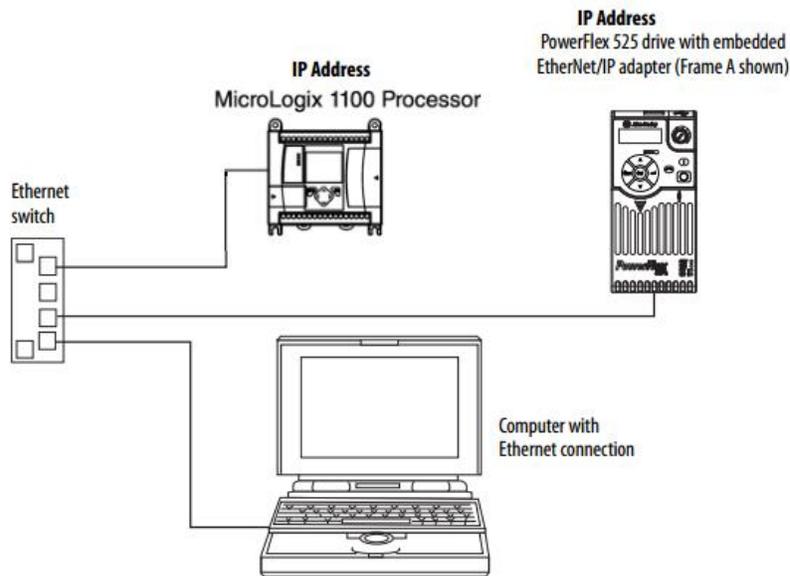
Figure 8.10 Controlling of the drive [47]

8.5.1 PowerFlex 525 Embedded EtherNet/IP adapters[47]

The EtherNet/IP adapter, embedded on the Main Control Board in PowerFlex 525 drives, is used for network communication. Since the EtherNet/IP adapter is embedded on the Main Control Board in the PowerFlex 525 drive, the only required step is setting its IP address and connecting it to the network. [47] There are two methods for configuring the embedded EtherNet/IP adapter's IP address: [47]

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• BOOTP Server

• Parameters

Configuring the adapter using BOOTP server: In the BOOTP/DHCP server window in the computer, Subnet mask, Gateway, Primary DNS, Secondary DNS, Domain name, IP address, Host Name, and description are filled. [47]

Configuring the I/0:

RSLinx classic: Using RS Linx the drives are configured Depending on the application of the task, selecting either the browse local or remote subnet option, and click OK. [47]

Adding the controller to the I/O configuration: To establish communications between the controller and drive over the network, should add the CompactLogix controller and it's embedded EtherNet/IP Bridge to the I/O configuration. Adding the controller to the I/O configuration Is done by in Logix5000, following several steps giving in the Manual [47]. Ladder logic program can be done in RS Logix 5000 for controlling the speed of the motor.

8.5.2 Easy 8 Micro800 Weigh Scale Module [48]

Hardy Process Solutions EASY 8 Weigh Scale Module (HI 2080WS) is for the Allen-Bradley Micro800 programmable controller. The EASY 8 reads, conditions and digitizes load cell sensor and strain gage signals, found its applications in process weighing. It is a single channel plug-in module. The hardy EASY 8 calculates and digitizes net and gross weight data from Hardy load cells sends data to the Allen-Bradley® Micro800 PLC. EASY 8 is a powerful weight processing module. [48]

8.5.3 Hardy HI HPLP Low Profile Load Cells

The Hardy HI HPLP ADVANTAGE Series are low profile load point systems designed to support loads where a traditional load cell won't fit. They are designed with electro-polished surfaces, and stainless steel or alloy steel construction making them low-maintenance in less than ideal environments. The load point provides users with a uniform, compact and economical solution across a wide range of load cell capacities - from 500 kg (1100 lbs.) through to 30,000 kg (66,000 lbs.).[49]

8.5.4 Connected Components Workbench software.

Connected Components Workbench, design and configuration software, offers controller programming, device configuration, and integration with HMI editor. [50]. For load cell measurement using EASY 8Weigh Scale Module (HI 2080WS) with Allen-Bradley Micro800 programmable controller, the programming is done in Connected Components Workbench. Configuring controller plugins is done in Connected Components Workbench through series of steps provided in the manual ([51]). After configuring User Defined Function Block (UDFB) is created followed by creating the ladder logic program.

8.6 User Interface

The user interface (UI), in the industrial design field of human–machine communication, is the platform where communication between and machines and humans occur. The main objective of the user interface is to have a productive operation and control from the human end of the machine whilst the machine at the same tome send back information that helps the operator to make a decision[52]. In this work, the main aim of the user interface is to control the speed of the motor using a personal computer and also to measure the load cell data. There are several ways to achieve the Human User Interface. As explained in the earlier sections, In the case of Siemens, User Interface can be achieved by Wicc. In this task, a demo HMI is created and is explained how the user can interface through Microsoft visual studio (advanced HMI) or through Lab view (National Instruments).

8.7 Summary

In this chapter, various of control systems have been discussed which can be adapted to control the apparatus. These control systems are discussed by considering the final control method which is through a personal computer and compatibility among the various manufacturers. In the first section controlling by LabVIEW and field point. In the next sections control system using the ABB ACS 355 drive and LabVIEW have been included. Following by the control system by SIEMENS and Rockwell automation have been discussed. Considering the cost reduction as one of the factors in this work, the control system which could satisfy the factor with other factors will be considered for this work. In the next chapter, the calculation have been done to find the pressure distribution at the various angles with flow simulations and the results for the same

9 CALCULATIONS AND SIMULATIONS

The mechanical design demonstrates the redesign requirements results of the mechanical system. Whereas the pressure distribution caused by the bearing while loading conditions are measured using the manometers. These manometers are connected to the hoses where the lubrication flow out of the bearing. The waste lubrication is collected in the oil tray which the lubrication oil can be reused. The pressure distribution of the oil can be explained using the principle of the journal bearing. The bearing runs with the geometric centers of the shaft and housing while carrying a load with a proper oil supply, just to establish a convergent flow. These are the regions where the large hydrodynamic pressures are setup where it supports the bearing surface while the bearing is under load[53].
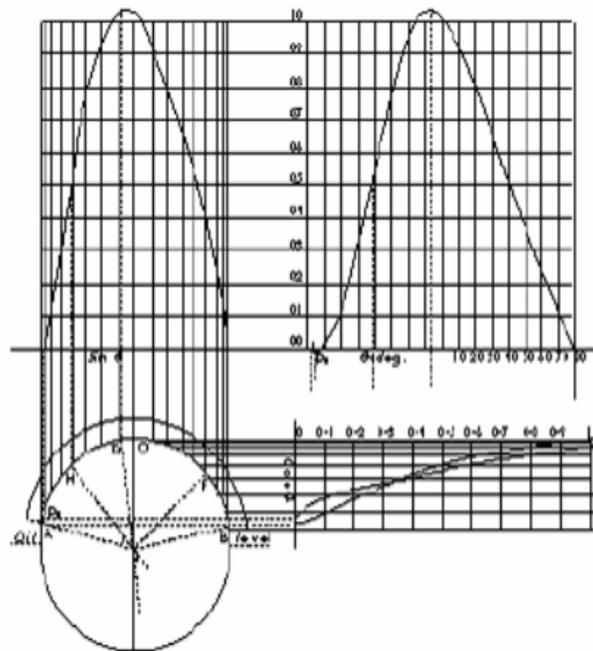
Figure 9.1 Oil Film Pressure Distribution [53]

According to Professor Osborn Reynold, oil is dragged when the shaft rotates and form a wedge-shaped film between the journal and journal bearing because of its adhesion to the journal and its resistance to flow. This action sets up the pressure in the oil film which thereby supports the load[53]. The figure shown beside is the wedge-shaped film shown by Reynolds which has to be an essential feature for an effective journal bearing[53].

In this apparatus, the manometers are connected to the measuring points around the circumference of the bearing shell. With which the pressure can be read with reference to the height of the columns. Figure 9.2 demonstrates the typical distribution of pressure in the journal bearing. By using the Reynolds equation, it is possible to find the pressure at different points. The Reynolds equation [54] to measure the 2D flow of the hydrodynamic journal bearing is given by,

$$\frac{\partial}{\partial x}\left(h^3 \frac{\partial p}{\partial x}\right) + \frac{\partial}{\partial z}\left(h^3 \frac{\partial p}{\partial z}\right) = 6\eta U \frac{\partial h}{\partial x}$$

<div align="right">(9.1)</div>

Where:

h – local oil film thickness,

η – dynamic viscosity of the oil,

p – local oil film pressure,

U – linear velocity of journal,

x- circumferential direction.

z - longitudinal direction.

Reynolds equation (9.2) [54] is also be used to find the pressure of the oil at different positions.

$$p = \frac{\mu U r}{c^2} \left[\frac{6\varepsilon \sin\theta \ (2 + \varepsilon \cos\theta)}{(2 + \varepsilon^2) \ (1 + \varepsilon \cos\theta)^2} \right]$$

<div align="right">(9.1)</div>

Calculating by using the above equations,

Where,

r = Radius of shaft, 30mm

U= Speed of shaft, 10995.6 mm/s

c = Clearance,

c/r = 0.001

c = 0.030 mm

ε= eccentricity, 0.05, from Raimondi- Boyd chart.,
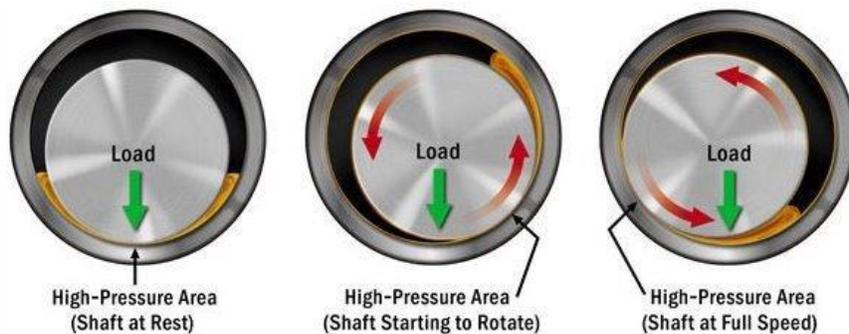
Figure 9.2 Typical Pressure distribution in the journal bearing [3]

Table 9.1 shows the Pressure distribution calculated at different angles of the bearing with different shaft speeds by using the equation 9.2. The pressure is calculated for 3000, 2000, 1000 and 500 rpm. The pressures are calculated by considering the values of eccentricity as 0.05, 0.035mm as for the clearance

and for the shaft radius of 35mm. By the table, it can be noted that there are negative pressures from the equation. The pressures will decline to an equal in the divergent zone and the negative value as that in the convergent zone. These negative pressures are non-physical and cannot occur in a real fluid. Instead, as the pressure begins to drop below atmospheric, the fluid will begin to cavitate and a gaseous phase will begin to fill the divergent region. This gaseous phase can be present in three forms: vaporous, gaseous, or a combination of the two making the flow two-phase. [55]

Table 9.1 Pressure distribution of oil at different angles of the bearing

No	θ	Pressure at different speed of the shaft in Mpa			
		P at 3000 rpm	P at 2000 rpm	P at 1000 rpm	P at 500 rpm
1	90	3.473	2.316	1.158	0.58
2	106.36	-1.543	-1.028	-0.514	-0.257
3	122.72	-0.793	-0.531	-0.265	-0.132
4	139.08	2.687	1.72	0.895	0.447
5	155.44	-3.766	-2.51	-1.255	-0.627
6	171.8	3.269	2.18	1.09	0.545
7	188.16	-1.154	-0.77	-0.384	-0.192
8	204.52	-1.258	-0.838	-0.42	-0.21
9	220.88	2.968	1.978	0.1	0.494
10	237.24	-3.737	-2.5	-1.245	-0.622
11	253.6	3.013	2.01	1.004	0.502
12	269.96	-0.753	-0.502	-0.251	-0.125

It can be noted that maximum pressure is the 90-degree angle at 3000 rpm which is 3.473Mpa, followed by the 171.8 degrees, 3.269Mpa, 253.6degree, 3.013MPa and 220.88degree, 2.968Mpa. These calculations are calculated for the 2-D flow. The 3-D flow simulation is discussed in the next section at various speeds of the shaft using SOLIDWORKS flow simulation, which will help to analyze the flow simulation in the apparatus. By the calculation, it can also be noted that the pressure values for 30mm bearing shaft at 3000 rpm are same as the pressure value for the 35mm bearing shaft at 3000 rpm. The graphical representation is shown in figure 9.3, where various degrees are represented on the X-axis and pressure in Mpa in the Y axis.
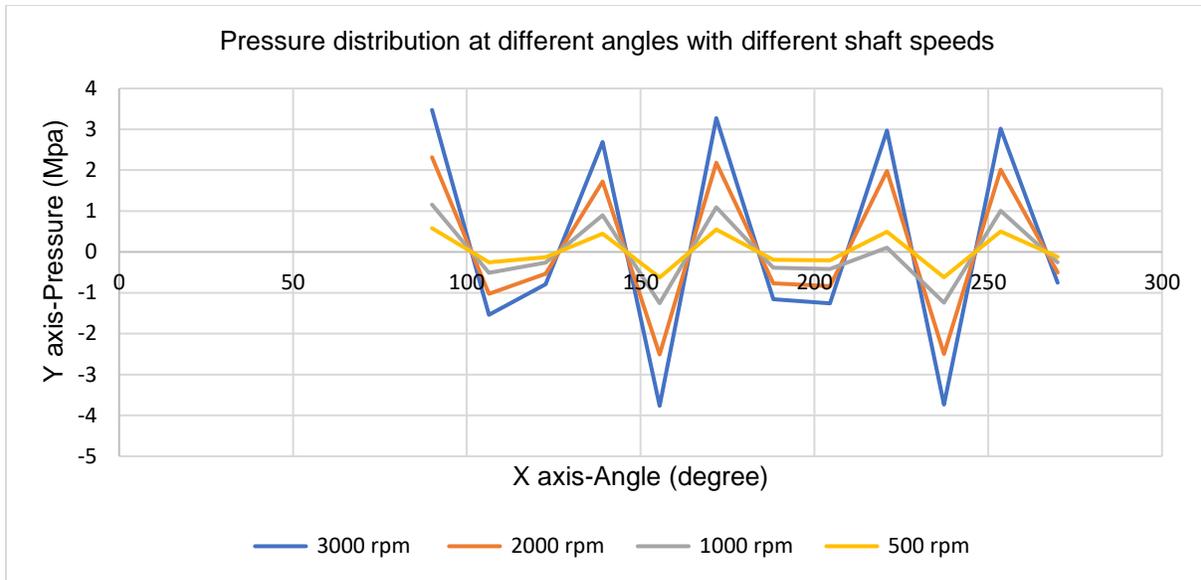
Figure 9.3 Graph of Pressure distribution at different angles different shaft speeds

Table 9.2 shows the Pressure distribution calculated at different angles for different eccentricity values by using the equation 9.2. The pressure is calculated for 3000rpm. The pressures are calculated by considering the values of eccentricities as 0.2, 0.4, 0.6, and 0.8. by taking 0.035mm as for the clearance and for the shaft radius of 35mm. It can be noted that maximum pressure is 110.425 Mpa which is occurring at 253.6 degrees of the bearing at the eccentricity value of 0.8, next 94.776 Mpa at 171.8 degrees and 81.254 at 90 degrees of the bearing. By the table, it can also be noted that the higher the value of eccentricity higher the pressure in the bearing. The graphical representation is shown in figure 9.4, where various degrees are represented on the X-axis and pressure in Mpa on the Y axis.

Table 9.2 Pressure calculated for different eccentricity

No	θ	Pressure calculated for different eccentricity			
		ε (0.2)	ε (0.4)	ε (0.6)	ε (0.8)
1	90	15.192	33.65	55.35	81.254
2	106.36	-5.065	-7.8	-8.99	-9.2
3	122.72	-4.045	-11.915	-31.304	-117.147
4	139.08	9.214	14.824	17.657	18.535
5	155.44	-15.02	-28.976	-40.645	-49.516
6	171.8	14.687	34.027	59.428	94.776
7	188.16	-3.76	-5.744	-6.584	-6.71
8	204.52	-6.33	-18.271	-46.054	-152.988
9	220.88	10.358	16.982	20.533	21.813
10	237.24	-14.51	-27.01	-36.546	-42.94

11	253.6	13.888	33.666	62.732	110.425
12	269.96	-2.4385	-3.706	-4.231	-4.3
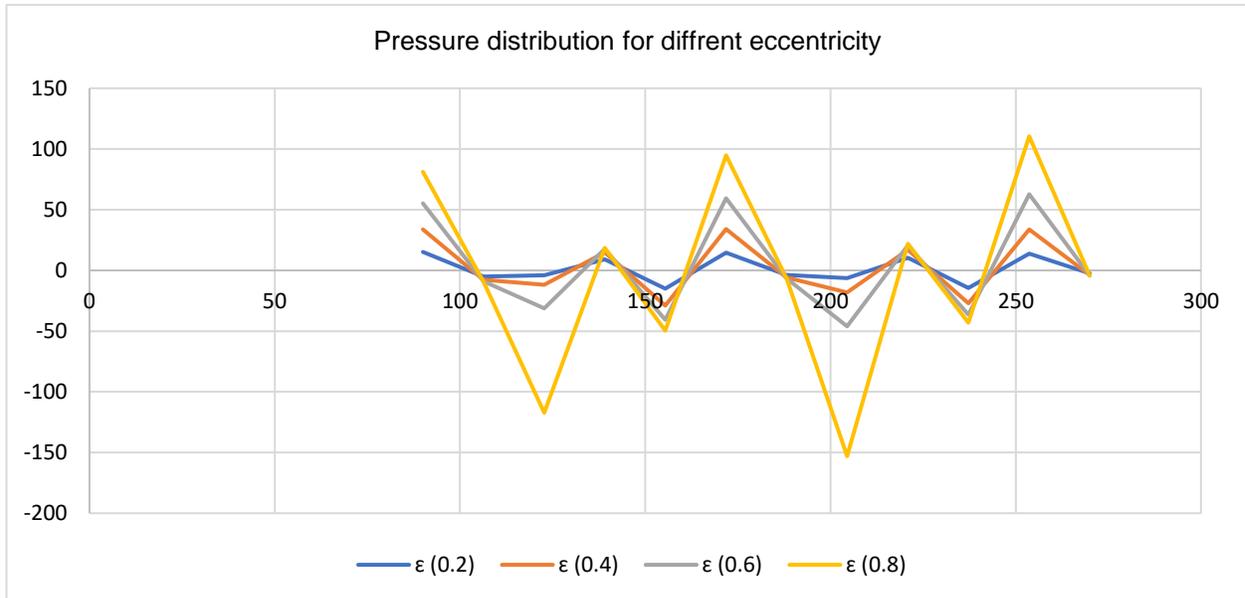
Figure 9.4 Pressure distribution for different eccentricity values

Table 9.3 shows the Pressure distribution calculated at different angles for different clearance values of the shaft and the bearing by using the equation 9.2. The pressure is calculated for the speed of 3000rpm of the 35mm radius shaft, eccentricity value of 0.8, and the clearance values of 0.05mm, 0.06mm, 0.08mm and 0.1mm. It can be noted that maximum pressure is 54.108Mpa which is occurring at 253.6 degrees of the bearing at the clearance value of 0.05mm, next 46.44Mpa at 171.8 degrees and 39.814Mpaat 90 degrees of the bearing. By the table, it can also be noted that the lower the value of clearance, higher the pressure in the bearing. The graphical representation is shown in figure 9.5, where various degrees are represented on the X-axis and pressure in Mpa on the Y axis.

Table 9.3 Pressure calculated for different clearance values

		Pressure calculated for different clearance (c) mm			
No	θ	P at 0.05mm clearance	P at 0.06mm clearance	P at 0.08mm clearance	P at 0.1mm clearance
1	90	39.814	27.648	15.552	9.953
2	106.36	-4.507	-3.1303	-1.76	-1.127
3	122.72	-57.402	-39.862	-22.422	-14.35
4	139.08	9.0822	6.30711	3.547	2.27
5	155.44	-24.263	-16.849	-9.477	-6.065

6	171.8	46.44	32.25	18.14	11.61
7	188.16	-3.288	-2.283	-1.284	-0.821
8	204.52	-74.964	-52.058	-29.282	-18.741
9	220.88	10.688	7.422	4.175	2.672
10	237.24	-21.04	-14.611	-8.219	-5.26
11	253.6	54.108	37.575	21.136	13.527
12	269.96	-2.107	-1.463	-0.823	-0.526
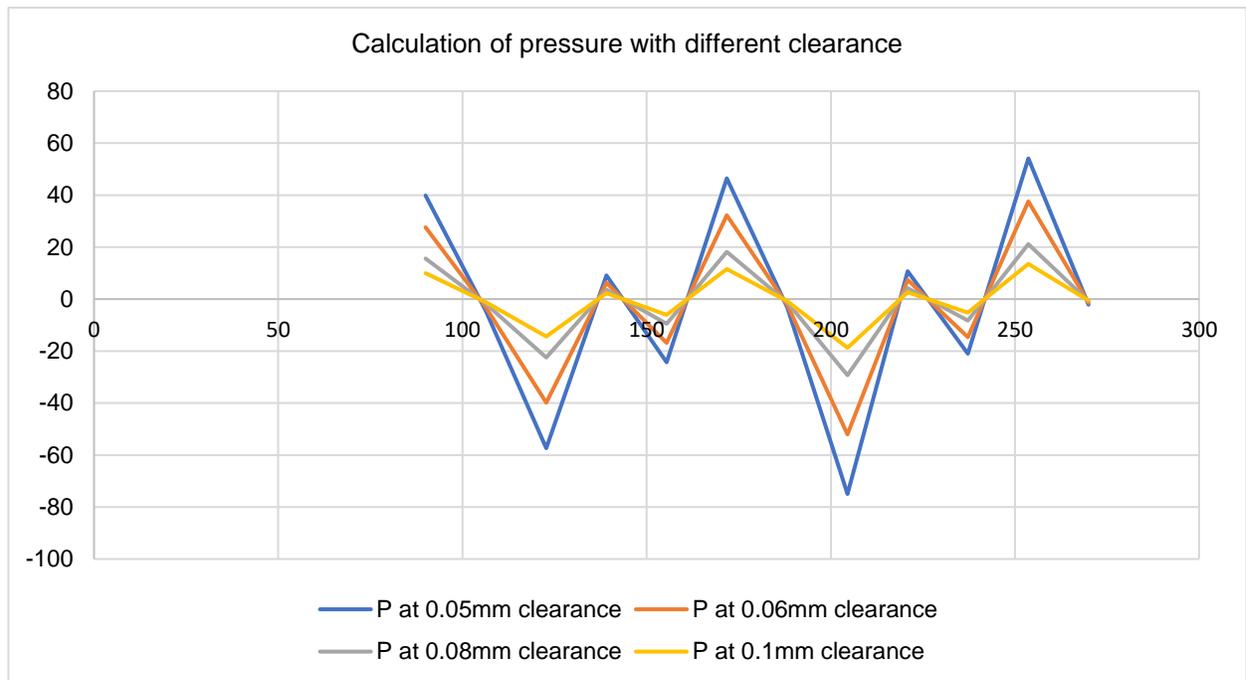
Figure 9.5 Calculation of pressure with different clearance

9.1 Flow simulation with 500rpm shaft speed

The flow simulation is generated considering the height of the inlet value from the oil tank with the free flow of the oil. simulation is carried considering the heat conduction in solids is off, with the flow type as laminar and turbulent and gravity on. The water is considered as the fluid for the simulation. taking the initial conditions as, static pressure 101325.00 Pa, temperature 293.20 K.
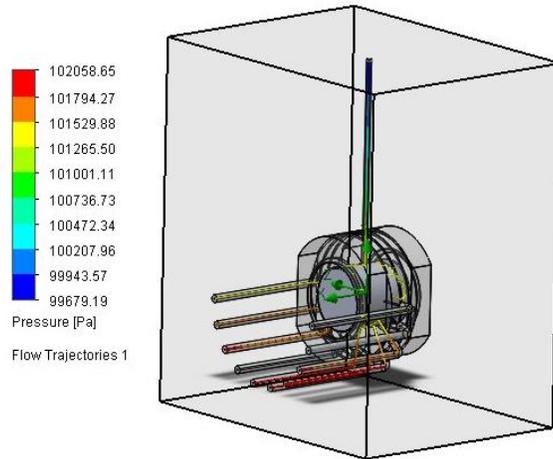
Figure 9.6 Pressure distribution of liquid at 500rpm shaft speed

In the figure above shows, the flow simulation results conducted on the journal bearing design with the one inlet value and 10 outlet valves. The flow is conducted when the bearing shaft is rotating at 500RPM, with the flow of liquid by gravity, from a height where the oil tank is situated. From the pressure flow diagram, it can be noted that the maximum pressure distribution is taken place in the seventh tubes from the front face of the figure when the shaft is rotating in the antilock wise direction. It can be noted that the minimum pressure is 99679.19Pa which is denoted by the red path and the maximum pressure is denoted by the red path where is the pressure value is 102058.65Pa. The density vs temperature, dynamic viscosity vs temperature graphs are given in the appendix.

Table 9.4 Simulation properties at 500 RPM

No	Name	Minimum	Maximum
1	Pressure [Pa]	99679.19	102058.65
2	Temperature [K]	293.2	293.2
3	Density (Fluid) [kg/m^3]	997.56	997.56
4	Velocity [m/s]	0	0.689
5	Velocity (X) [m/s]	-0.327	0.687
6	Velocity (Y) [m/s]	-0.498	0.191
7	Velocity (Z) [m/s]	-0.237	0.265
8	Temperature (Fluid) [K]	293.2	293.2
9	Shear Stress [Pa]	0	4.29
10	Relative Pressure [Pa]	-1957.13	422.33

9.2 Flow simulation with 3000rpm shaft speed

From the figure 9.4, the red circle shows where the maximum pressure takes place these are the outlet hoses where it carries the oil to the manometer. As the motor rotates the oil film is carried with the minimum pressure. The green circle showed the minimum oil pressure. In the similar passion, the simulation results for temperature, velocity, and fluid temperature can be seen. It can be noted that the minimum pressure is 99896.01 Pa which is denoted by the red path and the maximum pressure is denoted by the red path where is the pressure value is 102062.66 Pa. The flow simulation has been carried out on the 35mm radius shaft. The properties on which the flow simulation is carried on is given in table 9.5.
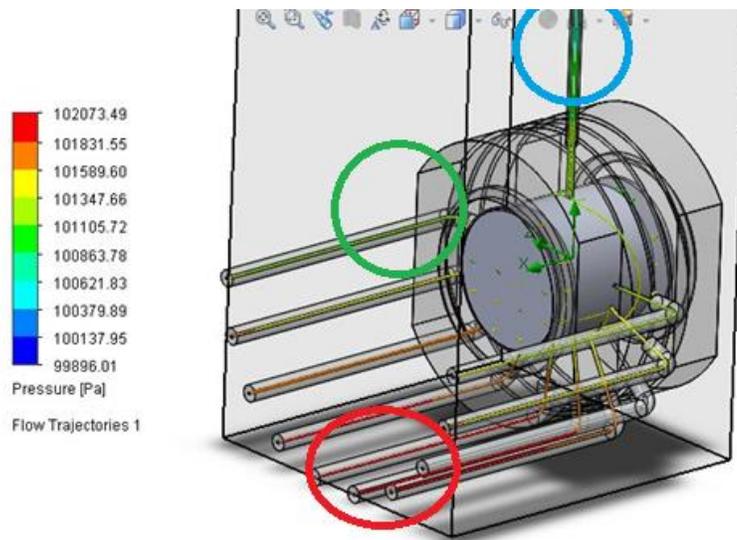
Figure 9.7 Flow simulation at 3000RPM

Table 9.5 Simulation properties at 3000 RPM

No	Name	Minimum	Maximum
1	Pressure [Pa]	99896.01	102062.66
2	Temperature [K]	293.2	293.2
3	Density (Fluid) [kg/m^3]	997.56	997.56
4	Velocity [m/s]	0	0.701
5	Velocity (X) [m/s]	-0.701	0.287
6	Velocity (Y) [m/s]	-0.47	0.167
7	Velocity (Z) [m/s]	-0.359	0.355
8	Temperature (Fluid) [K]	293.2	293.2

9	Vorticity [1/s]	0.1	951.19
10	Shear Stress [Pa]	0	7.13
11	Relative Pressure [Pa]	-1428.99	737.66

9.3 Pressure measurement system using sensor

Considering the fact that the pressure distribution can be monitored using the manometers. In the paper, EXPERIMENTAL STUDY OF HYDRODYNAMIC PRESSURE DISTRIBUTION IN OIL LUBRICATED TWO-AXIAL GROOVE JOURNAL BEARING [56] an attempt was made to measure hydrodynamic pressures by mounting the pressure sensor on the shaft surface The sensor used for the study is a flush type diaphragm pressure transducer. The pressure transducer is of Honeywell, made with a maximum pressure limit of 20 bars (300 psi). To amplify the output the signal, an inline amplifier is connected between the data acquisition board and the sensor. The leads of the sensor were connected to the amplifier through Mercotac electrical connector. The schematic of the measurement process is shown below [56]
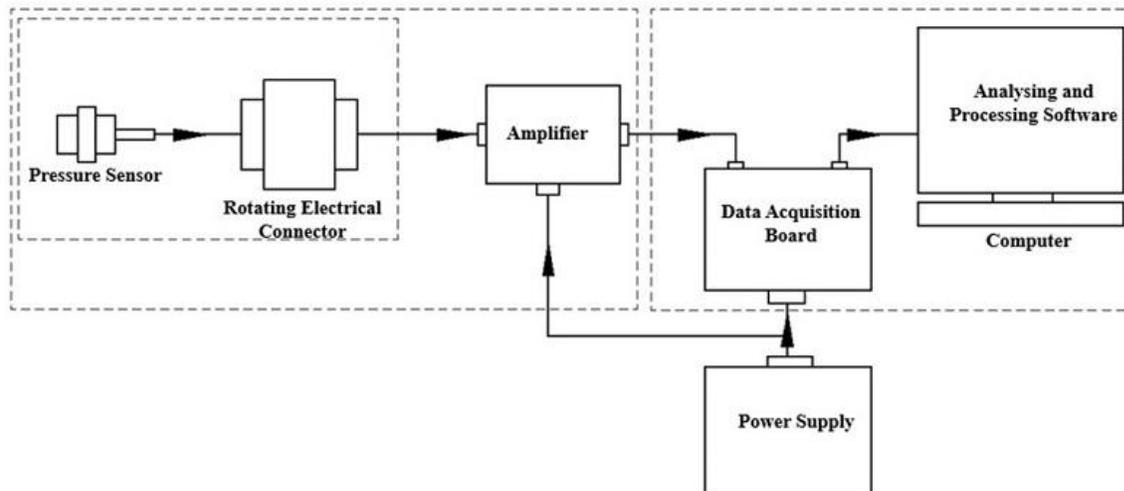
Figure 9.8 Hydrodynamic pressure measurement process [56]

9.3.1 Data acquisition system

As illustrated in the Schematic diagram above the last section of the measurement process is the data acquisition system comprising a Quanser Q8 data acquisition board and associated QUARC data

acquisition software. The sensor circuit was built using the built-in elements of QUARC software. The output can be monitored continuously during experimentation or could be saved as a data file for future processing provided by the QUARC software by communicating with MATLAB.

9.4 Chapter summary

In this chapter, the pressure distributions of lubrication oil calculations and simulations are discussed. The calculation to measure the 2D flow of the hydrodynamic journal bearing has been provided using the Reynolds equation. Using the Reynolds equation the pressure distribution for the various speed of the shaft, different eccentricity and for the different values of the clearance at different angles of the bearing. The graphical representation is also shown along with the table values. In the next sections, the 3D flow simulation with 500rpm shaft speed, 3D flow simulation with 3000rpm shaft speed has been carried on to measure the pressure distribution at various angles of the bearing. In the next section Pressure measurement system using sensor have been discussed.

10 MONITORING AND CONTROLLING SYSTEM

In this chapter attempt has been made to control the apparatus by using two kinds of the control system, the first section deals with the controlling and monitoring by using Microsoft visual studio human machine interface and next section deals with the control system through National Instrument's LabVIEW.

10.1 HMI by RXlogix500 and Microsoft visual studio

In series of the control systems mentioned above in the previous chapter, Control System from Rockwell automation is selected for the control system and Microsoft visual Studio as the Human Machine Interface. Since the ladder logic program, written using the RS logix500 Allen Bradley, Rockwell automation, is an open source ladder logic program software from the Rockwell automation. As mentioned in the earlier sections the drive selected is power flex 525, micrologix 1100 series program logic controller. Since the hardware is absent in the work, the program is run using the Rs Logix Emulate 500 which is open source as well from Allen Bradley, Automation. The driver is configured using RS Linx classic.

The below program shows ladder logic in RS Logix 500 platform, Micrologix 1100 PLC referred from the [57]. The figure in the appendix shows the main ladder in which the jump to a subroutine is created to operate the drive with various parameters like Stop Drive, Start Drive, Forward, Clear Faults, Write Frequency and Read Frequency.

10.2 HMI (Human Machine Interface)

The HMI created using the Microsoft visual studio, Advanced HMI Open source, using the ladder logic program the address is referred to the parameters in the HMI. The advanced HMI is supported with various Program Logic Controllers to interact.
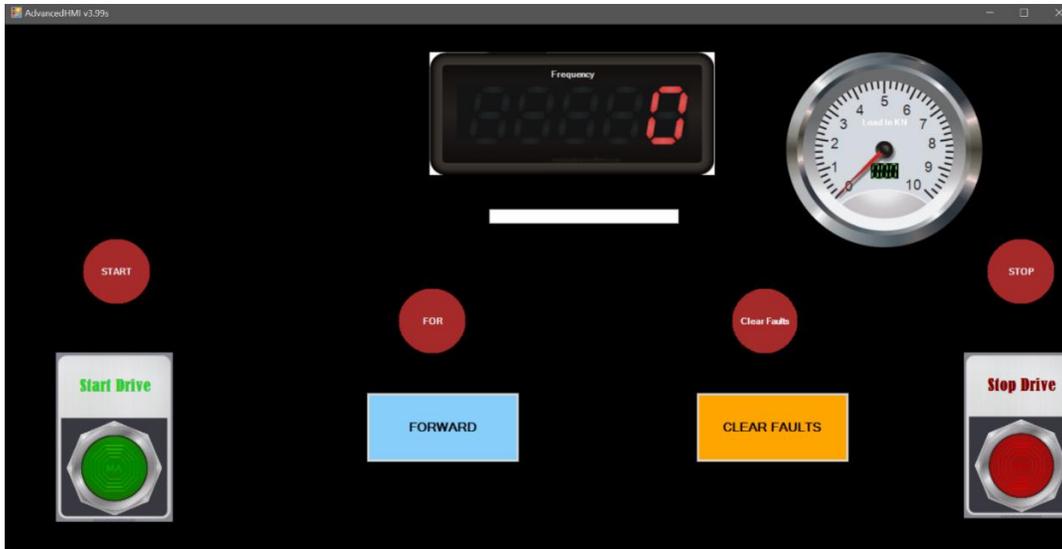
Figure 10.1 Demo HMI using Microsoft Visual Studio, Advanced HMI
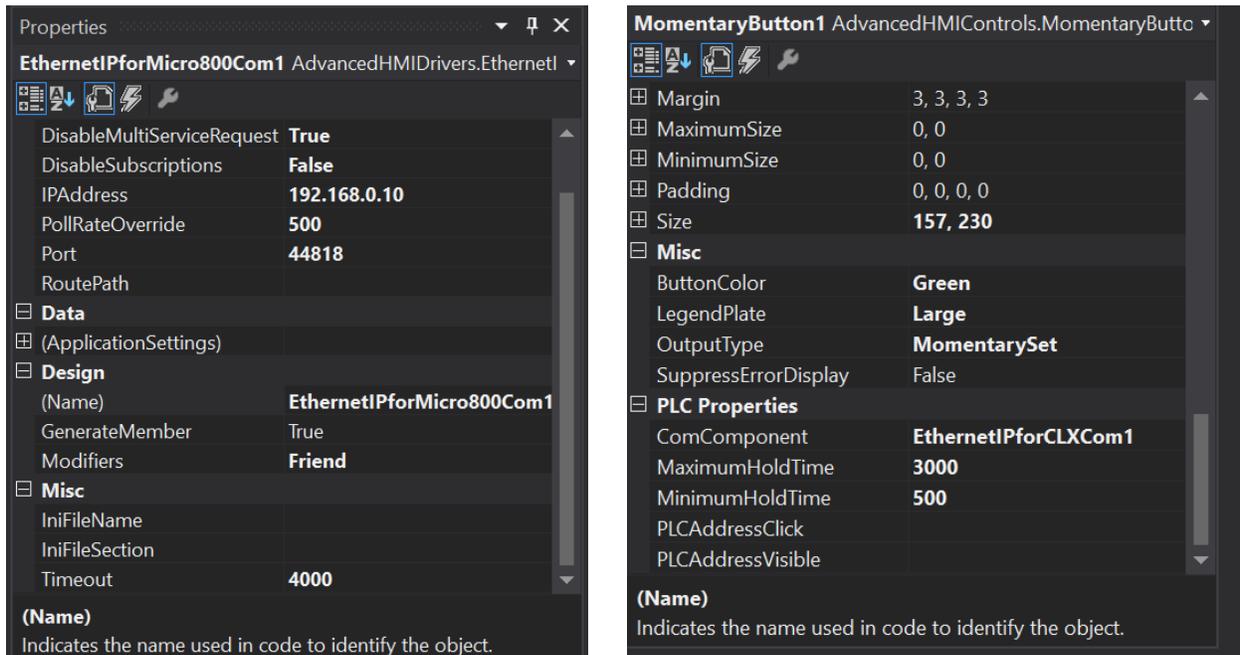
The above picture shows the example of the configuration of PLC and parameters into HMI, where the IP address of the PLC and parameters are given into the properties in the advanced HMI. The first picture is the Micro 800 PLC for weighing module and the second is for start Button.

10.3 Controlling and Monitoring system using LabVIEW

The measurement system can also be created using National Instruments, LabView. The below figure shows the front panel using LabVIEW. This is front panel taken IN reference to the work by Mehmet Deniz,

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MODERNIZATION OF THE LINEAR MOVEMENT TEST RIG.[28] As the parameters (ABB ACS 355) used is same as the task, the program can be used to control the speed of the motor. The drive control parameters are shown in the appendices (setting up communication through the embedded Modbus). The speed of the drive is setup using the buttons in the control panel which are in link with the reference speed
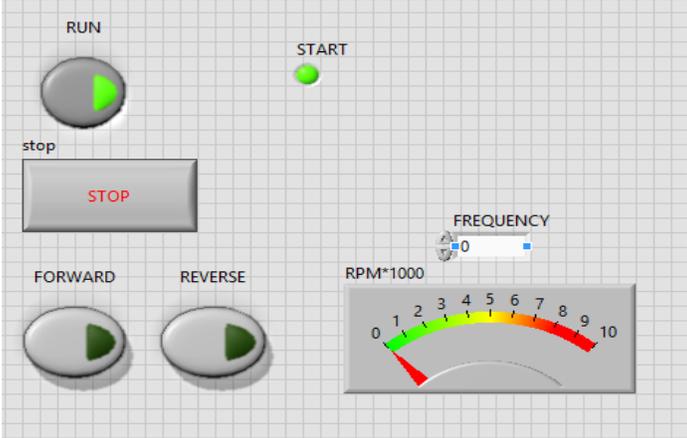
Figure 10.2 Front Panel using LabVIEW demo

10.3.1 Measurement of load cell in LABVIEW, NI

The figure 10.3 below shows the load cell data acquisition system using the NI 9237 DAQ system connected to the computer and monitored the load in Newton using the graph on the front panel. This is used with the above control panel where the control panel to monitor the apparatus.
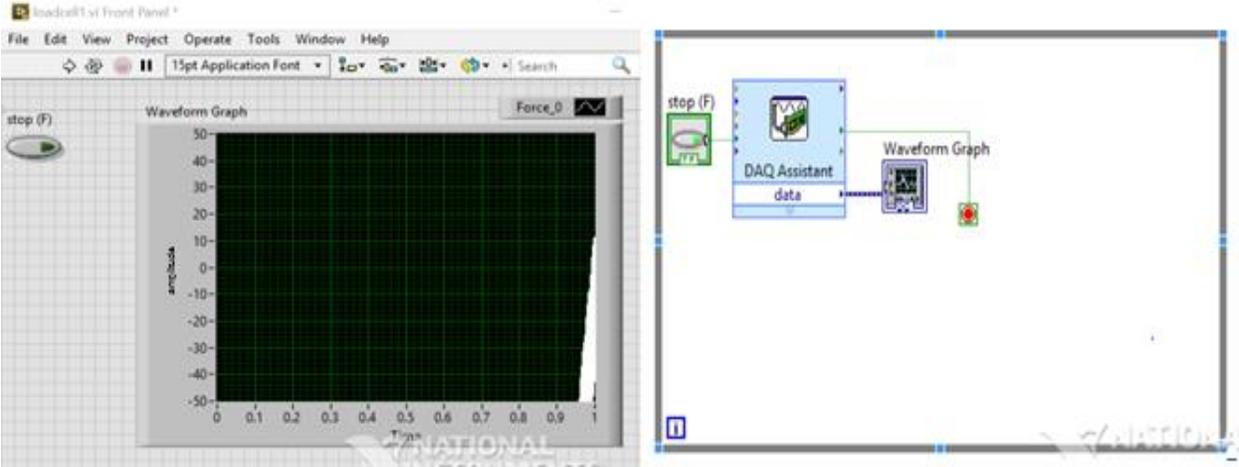
Figure 10.3 load cell measurement in LabVIEW

10.4 Summary

From the above two control systems, the user has the options to choose either one the control systems. As per manufacture, wise both ABB and Rockwell automation are industrially and internationally acclaimed manufacturers for their automation. Since both the software's have been used are student version, Microsoft visual studio is available with free versions as well. And the control system with LabVIEW eliminates a separate controller to control, by considering the factor of cost reduction can be one of the good choices.

11 SUMMARY IN THESIS LANGUAGE

The purpose of this task is to modernize a mechanical apparatus. To accomplish this solution, it is necessary to follow the idea without losing its traditional way of the mechanism. The apparatus itself is a laboratory machine for the university student to study the pressure distribution of oil at various points in a journal bearing. Hence work has higher significance to students at the industrial level applications and engineering. To accomplish this goal of modernizing the apparatus, the parts are procured and analyzed. The work started with the introduction explaining the problem statement, the significance, objectives of the task, along with conducting a background research and explaining the scope, deliverables of the task. The mechanical design requirements of the tasks were to design the missing parts of the device, redesigning the loading system and to redesign the shaft and bearing. The development involved the design of the measurement system along with monitoring system to monitor and control the device using a human-machine interface.

Thorough background research is exercised in the next chapter which included the design of a complete journal bearing apparatus paper, control system paper and others. In this chapter, it is concluded that there are numerous researches and papers that have been done on the journal bearing and the similar device. The market overview dealt with the devices available in the market. Three models were explained in the chapter, one with the market value. From this chapter, it could be summarized that the journal bearing apparatus are available from the market to buy. TM280 is produced by the Gunt, Hamburg with 12 measuring points, KMD 07 available in the market for 1500-2500 US $. Since one main objective of the work is to analyze the cost for the device it could be concluded that the device from this work would cost more than the devices available in the market. Since the mechanism of the operating the device is significant than any other device available in the market, the cost could be compromised.

Project design configuration: In this chapter, the device is divided into drive system, mechanical system, and monitoring and control system. The mechanical system dealt with the analyzing and suggesting of missing parts that need to introduced with into the system. Along with suggestion the loading system, bearing and the shaft were designed according to prerequisites. In the drive system, the motor and drives which were suggested to rotate the shaft are suggested and discussed. The controlling system dealt with the controlling of this drive through a human machine interface. From this chapter, it can be concluded that the various missing parts from the device are available in the market and can be redesigned according to the requirements. In the chapter, the design study of the mechanical parts, the parts which have been subjected to the load has been simulated and analyzed. The design study of the bearing and belt which are subjected to the load are simulated and by the conclusion, it can be concluded the designs are safe.

In the control system chapter, various control systems have been discussed which can be adapted to

control the apparatus. Some of the control systems can be adapted are controlling by LabVIEW and field point, the control system using the ABB ACS 355 drive and LabVIEW, the control system by SIEMENS and Rockwell automation. Considering the cost reduction as one of the factors in this work, the control system which could satisfy the factor with other factors will be considered for this work. In the chapter, the pressure distributions of lubrication oil have been calculated using the Reynolds equation for the 2D flow of the hydrodynamic journal bearing. The pressure distribution for the various speed of the shaft, different eccentricity and for the different values of the clearance at different angles of the bearing are discussed. The results for the same have been provided. From the calculations, it can be concluded that the that the higher the value of eccentricity and lower the value of clearance, higher the pressure in the bearing.

Conclusion: ABB ACS 355 drive can be used for controlling the speed of the motor. Where according to the necessities 3-phase induction motor or the synchronous servo motor can be used to drive the shaft. Honeywell load cell can be used to measure the force applied to the bearing using National Instruments DAQ board and the NI chassis. LabVIEW can be used as a human user interface to control the speed of the motor using a Modbus. It can also be used to monitor the load cell data.

Recommendations: During the next stages of development, these proposed designs, software and user interface configurations can be used and changed based on the results. The mechanical system can further developed by allowing to the finite element analysis, which will prove the strength of the loading system. The bearing can also be subjected to the final element analysis and check the strength of it. The friction sensors can be used to measure the friction forces and the hydrodynamic friction coefficients. The 3D flow analysis can be done with the several loading conditions.

12 SUMMARY IN ESTONIAN

Käesoleva töö eesmärk on kaasajastada mehaanilist seadeldist. Eesmärgi saavutamiseks oli oluline mitte unustada, kuidas mehhanismid traditsiooniliselt töötavad. Seadeldis ise on ülikooli õpilastele liuglaagris õli rõhu jagunemise õpetamiseks mõeldud laboriaparaat. Seetõttu on töö olulisem õpilastele, kes on seotud tootmise ja inseneerikaga. Masina moderniseerimiseks oli vaja laboratooriumist võetud vajaminevad osi analüüsida. Töö algab sissejuhatusega, mis selgitab probleeme, töö olulisust ja eesmärki koos üldise taustinfo ja saavutada tahetavate tulemustega. Ülesande eesmärk oli disainida puuduolevad osad ja redisainida laadimissüsteem, võll ja laager. Tulemuse saavutamiseks oli vaja disainida mõõtesüsteem koos jälgimissüsteemiga, mis jälgiks ja kontrolliks seadeldist HMI (Human-Machine Interface) vahendusel.

Järgmises peatükis tehti põhjalik taustauuring, mis käsitles liuglaagriga töötava seadme disaini artikleid, kontrollsüsteemi artikleid ja muud. Selgub, et eelnevalt on liuglaagriga töötavate ja teiste sarnaste seadmete teemal palju uurimustöid ja artikleid kirjutatud. Turu ülevaates vaadeldi seadmeid, mis on praegu turul kättesaadavad. Peatükis selgitati kolme erinevat mudelit. Peatüki kokkuvõtteks võib öelda, et liuglaagriga töötavaid seadmeid on võimalik turult osta. Näiteks seade TM280 12 rõhu mõõtmise punktiga, KMD 07 on saadaval 1500-2500 USD eest. Kuna töö üks peamisi eesmärke on teada saada käsitletava seadme turuhind, selgub, et see on kallim kui seadmed, mis on praegusel hetkel turul saada. Käsitletaval seadmel on mõned olulised erinevused võrreldes teiste sarnaste seadmetega ja selle tootmine maksab rohkem. Siiski ei ole hinnavahe peamiseks takistuseks. Projekti disainimise konfiguratsiooni peatükis jagati seade ajamsüsteemiks, mehaaniliseks süsteemiks, jälgimis- ja kontrollsüsteemiks. Mehaanilise süsteemi osas tegeleti seadmest puuduvate osade analüüsimise ja nende soovitamisega. Vastavalt antud soovitustele ja eeldustele disainiti laadimissüsteem, laager ja võll. Ajamsüsteemi osas tehti ettepanekuid ja arutatleti võlli ringi ajava mootori ja ajamite teemat. Kontrollsüsteemi osas tegeleti ajamite kontrollimisega HMI vahendusel. Sellest peatükist võib järeldada, et mitmed osad, mis on seadmest puudu on turul saada ja neid on võimalik ümber disainida vastavalt vajadusele. Ümber disainitud osad võib kontrolltulemuste põhjal lugeda ohututeks.

Kontrollsüsteemi peatükis arutletakse mitmete kontrollsüsteemide üle, mida oleks võimalik antud seadme kontrollimiseks kasutusele võtta. Mõned näited: kontrollimine LabVIEW ja field point poolt, kontrollsüsteem, mis kasutab ABB ACS 355 võlli ja LabVIEWd, kontrollsüsteem SIEMENSi ja Rockwell Automation poolt. Võttes arvesse kulude vähendamist, kui üht käesoleva töö tingimust, kasutatakse kontrollsüsteemi, mis täidab antud tingimuse ja sobitub teiste tingimustega. Antud peatükis on arvutatud määrdeõli rõhu jagunemine kasutades Reynoldsi võrrandit 2D voolu kohta hüdrodünaamilises liuglaagris.

Rõhu jagunemine erineb vastavalt võlli liikumise kiirusele. Arutletakse võlli ja laagri vahelise osa väärtuse üle laagri erinevate nurkade all. Arvutuste kaudu järeldub, et mida suurem on erinevuse väärtus ja väiksem vaheosa väärtus, seda suurem on laagri rõhk.

Kokkuvõtteks: ABB ajamit saab kasutada kontrollimaks mootori kiirust. Võlli ringi ajamiseks võime kasutada kolmefaasilist asünkroonmootorit või servomootorit. Laagrile rakenduva koormuse mõõtmiseks võib kasutada National Instruments DAQ paneeli ja NI teliku kaudu Honeywell koormusandurile saadetavat informatsiooni. LabVIEWd võib kasutada kui HMId kontrollimaks Modbusi vahendusel mootori kiirust. Samuti võib seda kasutada koormusanduril oleva informatsiooni jälgimiseks.

Soovitused: järgnevate arendusetappide ajal võib soovitatud disainid, tarkvara ja kasutajaliidese konfiguratsioone kasutada ja muuta vastavalt tulemustele. Mehaanilist süsteemi on võimalik edasi arendada toetudes FEAle (Finite Element Method), mis tõestab laadimissüsteemi tugevust. Laagri tugevust saab samuti FEA abil kontrollida. Hõõrdumise andureid saab kasutada hõõrdejõu ja hüdrodünaamilise hõõrdumise koefitsentide mõõtmiseks. 3D voolu analüüsi saab teha erinevaid raskusi rakendades.

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APPENDICES

# Appendix 1: The mechanical part and ladder logic program
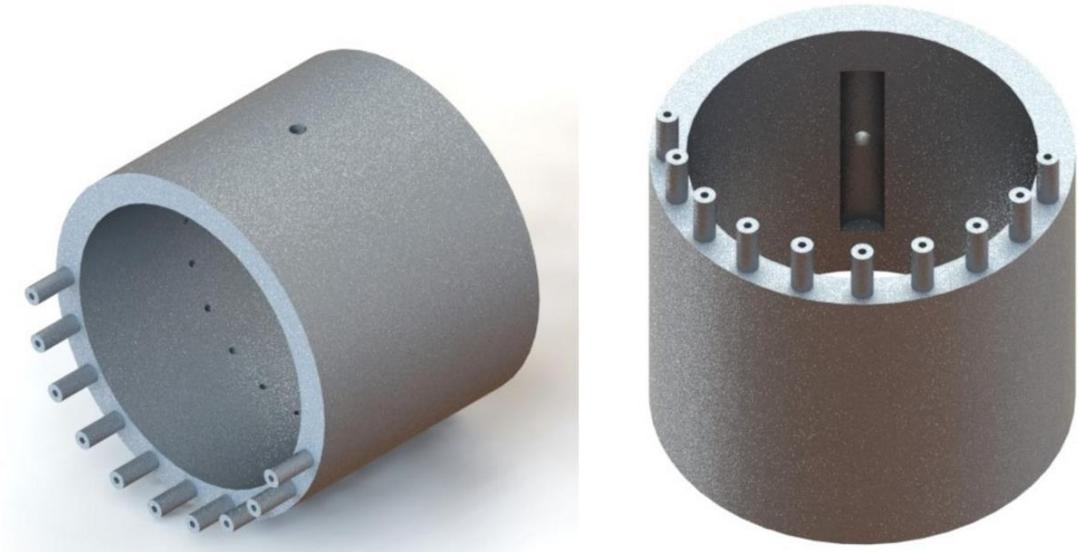
Inner Bearing

Existing Load gauge
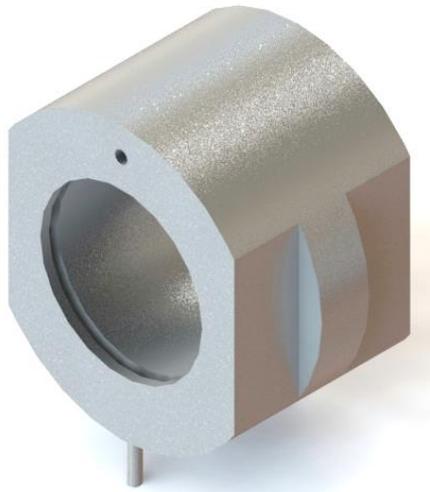
The outer existing bearing

The frame

Appendix 2 ABB ACS355 Technical details

Parameter	Setting for fieldbus control	Function/Information	Modbus register address	
CONTROL COMMAND SOURCE SELECTION			ABB DRV	DCU
1001 EXT1 COMMANDS	COMM	Enables *0301 FB CMD WORD 1* bits 0…1 (*STOP*/*START*) when EXT1 is selected as the active control location.		40031 bits 0…1
1002 EXT2 COMMANDS	COMM	Enables *0301 FB CMD WORD 1* bits 0…1 (*STOP*/*START*) when EXT2 is selected as the active control location.		40031 bits 0…1
1003 DIRECTION	FORWARD REVERSE REQUEST	Enables the rotation direction control as defined by parameters *1001* and *1002*. The direction control is explained in section *Reference handling* on page *323*.		40031 bit 2
1010 JOGGING SEL	COMM	Enables jogging 1 or 2 activation through *0302 FB CMD WORD 2* bits 20…21 (*JOGGING 1* / *JOGGING 2*).		40032 bits 20…21
1102 EXT1/EXT2 SEL	COMM	Enables EXT1/EXT2 selection through *0301 FB CMD WORD 1* bit 5 (*EXT2*); with the ABB drives profile *5319 EFB PAR 19* bit 11 (*EXT CTRL LOC*).	40001 bit 11	40031 bit 5
1103 REF1 SELECT	COMM COMM+AI 1 COMM*AI1	Fieldbus reference REF1 is used when EXT1 is selected as the active control location. See section *Fieldbus references* on page *320* for information on the alternative settings.	40002 for REF1	

| Parameter	Setting for fieldbus control	Function/Information	Modbus register address
1106 REF2 SELECT	COMM COMM+AI1 COMM*AI1	Fieldbus reference REF2 is used when EXT2 is selected as the active control location. See section *Fieldbus references* on page *320* for information on the alternative settings.	40003 for REF2

OUTPUT SIGNAL SOURCE SELECTION			ABB DRV	DCU
1401 RELAY OUTPUT 1	COMM COMM(-1)	Enables relay output RO control by signal *0134 COMM RO WORD*.	40134 for signal *0134*	
1501 AO1 CONTENT SEL	135	Directs the contents of the fieldbus reference *0135 COMM VALUE 1* to analog output AO.	40135 for signal *0135*	

SYSTEM CONTROL INPUTS			ABB DRV	DCU
1601 RUN ENABLE	COMM	Enables the control of the inverted Run enable signal (Run disable) through *0301 FB CMD WORD 1* bit 6 (*RUN_DISABLE*); with the ABB drives profile *5319 EFB PAR 19* bit 3 (*INHIBIT OPERATION*).	40001 bit 3	40031 bit 6
1604 FAULT RESET SEL	COMM	Enables fault reset through the fieldbus *0301 FB CMD WORD 1* bit 4 (*RESET*); with the ABB drives profile *5319 EFB PAR 19* bit 7 (*RESET*).	40001 bit 7	40031 bit 4
1606 LOCAL LOCK	COMM	Local control mode lock signal through *0301 FB CMD WORD 1* bit 14 (*REQ_LOCALLOC*)	-	40031 bit 14
1607 PARAM SAVE	DONE SAVE...	Saves parameter value changes (including those made through fieldbus control) to permanent memory.	41607	
1608 START ENABLE 1	COMM	Inverted Start enable 1 (Start disable) through *0302 FB CMD WORD 2* bit 18 (*START_DISABLE1*)	-	40032 bit 18
1609 START ENABLE 2	COMM	Inverted Start enable 2 (Start disable) through *0302 FB CMD WORD 2* bit 19 (*START_DISABLE2*)	-	40032 bit 19

Setting	When COMM ≥ 0	When COMM ≤ 0
COM M+AI1	COMM(%) · (MAX-MIN) + MIN + (AI(%) - 50%) · (MAX-MIN)	COMM(%) · (MAX-MIN) - MIN + (AI(%) - 50%) · (MAX-MIN)

Maximum limit is defined by parameter 1105 REF1 MAX / 1108 REF2 MA.
Minimum limit is defined by parameter 1104 REF1 MIN / 1107 REF2 MIN.

Setting	When COMM ≥ 0	When COMM ≤ 0
COM M*AI1	COMM(%) · (AI(%) / 50%) · (MAX-MIN) + MIN	COMM(%) · (AI(%) / 50%) · (MAX-MIN) - MIN

Maximum limit is defined by parameter 1105 REF1 MAX / 1108 REF2 MA.
Minimum limit is defined by parameter 1104 REF1 MIN / 1107 REF2 MIN.

Modbus mapping

The following Modbus function codes are supported by the drive.

Function	Code Hex (dec)	Additional information
Read Coil Status	01 (01)	Reads discrete output status. The individual bits of the control word are mapped to coils 1...16. Relay outputs are mapped sequentially beginning with Coil 33 (eg, RO1 = Coil 33).
Read Discrete Input Status	02 (02)	Reads discrete input status. The individual bits of the status word are mapped to inputs 1...16 or 1...32, depending on the active profile. Terminal inputs are mapped sequentially beginning with input 33 (eg, DI1 = Input 33).
Read Multiple Holding Registers	03 (03)	Reads the contents of registers in a slave device. Parameter sets, control, status and reference values are mapped as holding registers.
Read Multiple Input Registers	04 (04)	Reads multiple input registers. The 2 analog input channels are mapped as input registers 1 and 2.
Force Single Coil	05 (05)	Writes a single discrete output. The individual bits of the control word are mapped to Coils 1...16. Relay outputs are mapped sequentially beginning with Coil 33 (eg, RO1 = Coil 33).
Write Single Holding Register	06 (06)	Writes to a single register in a slave device. Parameter sets, control, status and reference values are mapped as holding registers.
Diagnostics	08 (08)	Provides a series of tests for checking the communication between the master and the slave devices, or for checking various internal error conditions within the slave. The following subcodes are supported: 00 Return Query Data: The data passed in the request data field is to be returned in the response. The entire response message should be identical to the request. 01 Restart Communications Option: The slave device serial line port must be initialized and restarted, and all of its communication event counters cleared. If the port is currently in Listen Only Mode, no response is returned. If the port is not currently in Listen Only Mode, a normal response is returned before the restart. 04 Force Listen Only Mode: Forces the addressed slave device to Listen Only Mode. This isolates it from the other devices on the network, allowing them to continue communicating without interruption from the addressed remote device. No response is returned. The only function that is processed after this mode is entered is the Restart Communications Option function (subcode 01).
Force Multiple Coils	0F (15)	Writes multiple discrete outputs. The individual bits of the control word are mapped to Coils 1...16. Relay outputs are mapped sequentially beginning with Coil 33 (eg, RO1 = Coil 33).
Write Multiple Holding Registers	10 (16)	Writes to the registers (1 to approximately 120 registers) in a slave device. Parameter sets, control, status and reference values are mapped as holding registers.
Read/Write Multiple Holding Registers	17 (23)	Performs a combination of one read operation and one write operation (function codes 03 and 10) in a single Modbus transaction. The write operation is performed before the read operation.

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Appendix 3: Laboratory Manual

PRESSURE DISTRIBUTION IN JOURNAL BEARING EXPERIMENT

Introduction

A test rig is an apparatus or equipment used for measuring the performance of any mechanical equipment. Test rig can be placed in the laboratory for studying the pressure distribution of the journal bearing [1]. The main objective of the Journal bearing apparatus is to learn the pressure distribution of oil in a journal bearing at various points and at various speeds.

1) shaft
2) Pillow block
3) The dismantable journal
4) Threaded Bolt
5) Support for the outer bearing to the frame
6) Frame
7) oil Tank
8) Manometers
9) Frame or stand supporting manometers
10) Hoses (pipes)
11) Load applying Screw
12) Bearing
13) Base plate for the shaft and the motor
14) Base for whole plate
15) coupling
16) Motor
17) Oil Tray
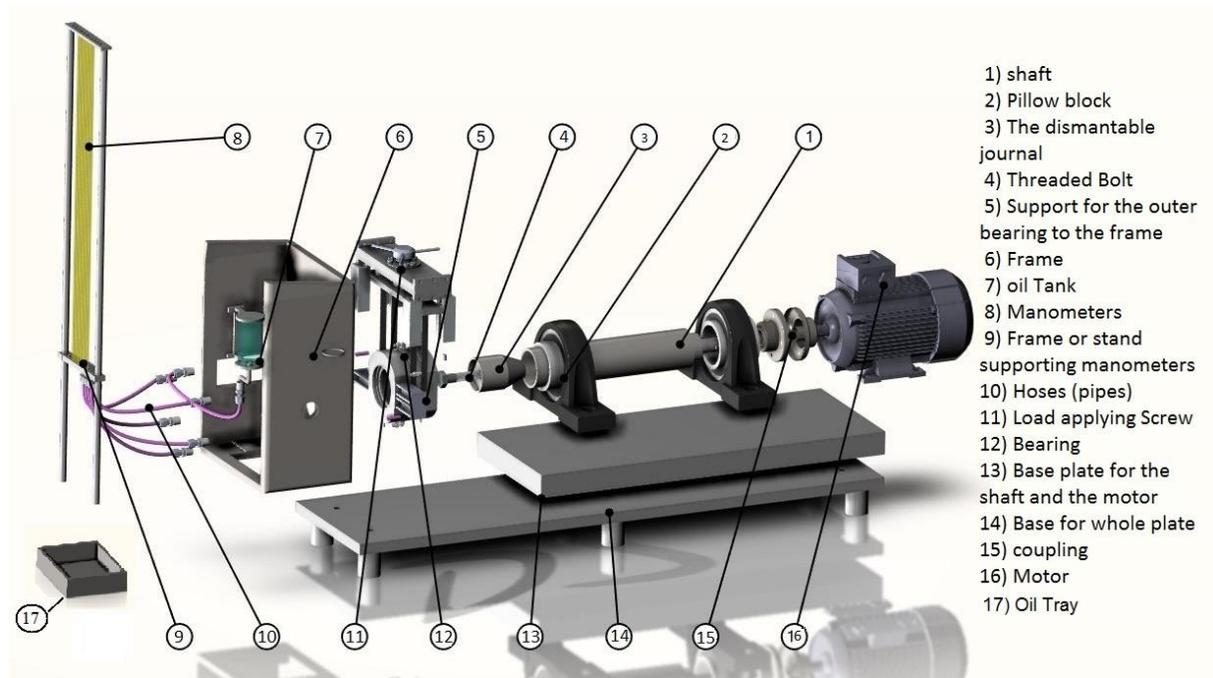
Figure A3.1 Journal bearing apparatus

Pressure distribution can be calculated by using the following parameters Equation (A3.1), (A3.1), (A3.1) [58]

$$(P - P_0) = \left[-\frac{12\pi\mu\varepsilon \, r^2 N}{c^2} \right] \left[\frac{(2 + \varepsilon\cos\theta)\sin\theta}{(2 + \varepsilon^2)(1 + \varepsilon\cos\theta)^2} \right] \qquad \text{(A3.1)}$$

$$(P - P_0)_{max} = (-K) \left[\frac{(2 + \varepsilon\cos\theta_1)\sin\theta_1}{(1 + \varepsilon\cos\theta_1)^2} \right] \qquad \text{(A3.2)}$$

$$K = \frac{12\pi\mu\varepsilon\, r^2 N}{c^2 (2 + \varepsilon^2)} \qquad\qquad \text{(A3.3)}$$

r = Journal radius, (in)

c = Radial clearance, (in)

μ = Oil viscosity at operating temperature, (reyn)

ε = Eccentricity ratio (= e/c)

θ1 = Location of maximum film pressure

N = Journal speed (RPS)1

P0 = Ambient or oil supply pressure (psi)

P = Hydrodynamic pressure at position θ

Procedure:

- Switch on the PC
- Open the LabVIEW software
- Run the program
- Measure the pressure at various points by checking on the manometer by varying the speed of the motor
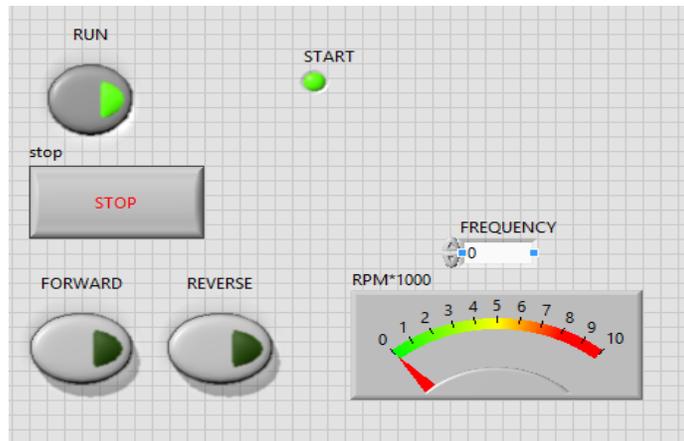
Figure A3.2 LabVIEW HMI panel

Experiment no 1: Measure the pressure distribution for various speeds with 0 load condition

Table A3.1 pressure measurement at various speed of the shaft

No	Speed of the motor in rpm	Pressure in Mpa
1	500	
2	1000	
3	2000	
4	3000	

Experiment no 2: Measure the pressure distribution for various speeds by varying load condition

Procedure: Rotate the screw at the head of the frame where the belt forces the bearing to lift by applying force on the shaft. By varying the speed to measure the pressure distribution at different points of the bearing.

Table A3.1 pressure measurement at various speed of the shaft by applying force

No	the speed of the motor in rpm	the load applied in newton	Pressure measured in Mpa
1	1000		
2			
3			
4			
5	2000		
6			
7			
8			
9	3000		

10			
11			
12			

Appendix 4: Calculations, Flow simulations results and graphs
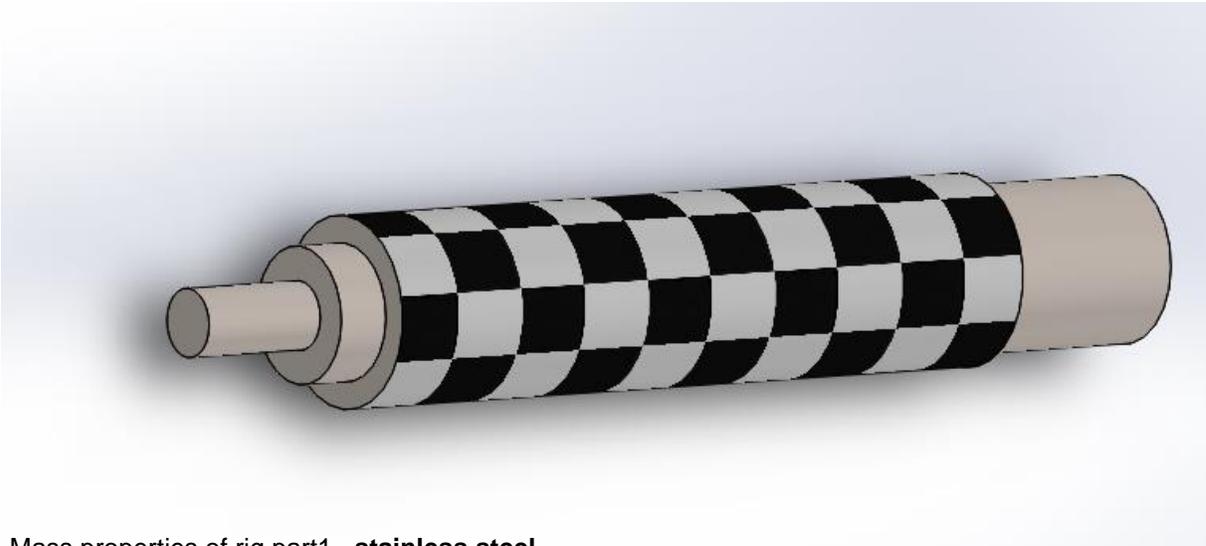
Mass properties of rig part1   **stainless steel**

Density = 0.01 grams per cubic millimeter

Mass = 10152.95 grams

Volume = 1291723.94 cubic millimeters

Surface area = 88310.17 square millimeters

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

      Ix = (0.00, 0.00, 1.00)   Px = 5851483.87

      Iy = (0.00, -1.00, 0.00)   Py = 103430614.93

      Iz = (1.00, 0.00, 0.00)   Pz = 103430614.93

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

      Lxx = 103430614.93   Lxy = 0.00   Lxz = 0.00

      Lyx = 0.00   Lyy = 103430614.93   Lyz = 0.00

      Lzx = 0.00   Lzy = 0.00   Lzz = 5851483.87

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

      Ixx = 600455797.79   Ixy = 0.00   Ixz = 0.00

      Iyx = 0.00   Iyy = 600455797.79   Iyz = 0.00

      Izx = 0.00   Izy = 0.00   Izz = 5851483.87
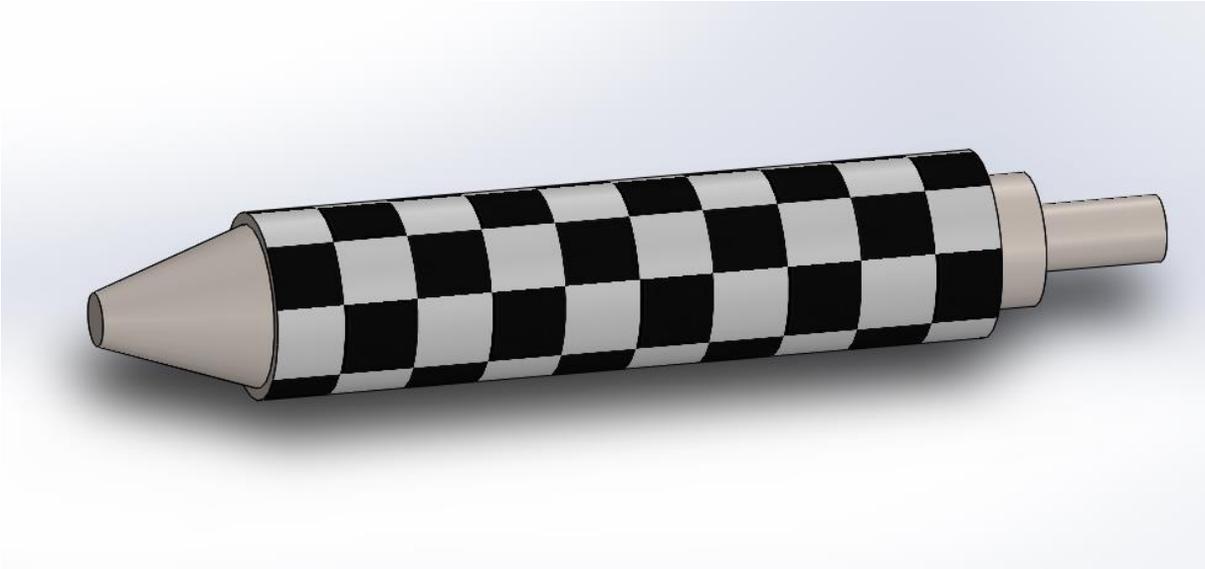
Mass properties of rig part1

Density = 0.01 grams per cubic millimeter

Mass = 9600.42 grams

Volume = 1221426.89 cubic millimeters

Surface area = 81579.83 square millimeters

Center of mass: (millimeters)

    X = 0.00

    Y = 0.00

    Z = 211.99

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

    Lxx = 88006896.75   Lxy = 0.14   Lxz = 3.23

    Lyx = 0.14   Lyy = 88006897.88   Lyz = 1.41

    Lzx = 3.23   Lzy = 1.41 Lzz = 5470702.38

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

    Ixx = 519438216.54   Ixy = 0.14   Ixz = 7.62

    Iyx = 0.14   Iyy = 519438217.68   Iyz = 3.33

The power of motor

    Izx = 7.62   Izy = 3.33   Izz = 5470702.38

$$P = T \cdot \omega = T \cdot \frac{\pi \cdot n}{30} = 0{,}1822775 \cdot \frac{3{,}14 \cdot 3000}{30} \approx 57{,}2673 \, \text{W. Or } 0.05726 \text{kw}$$
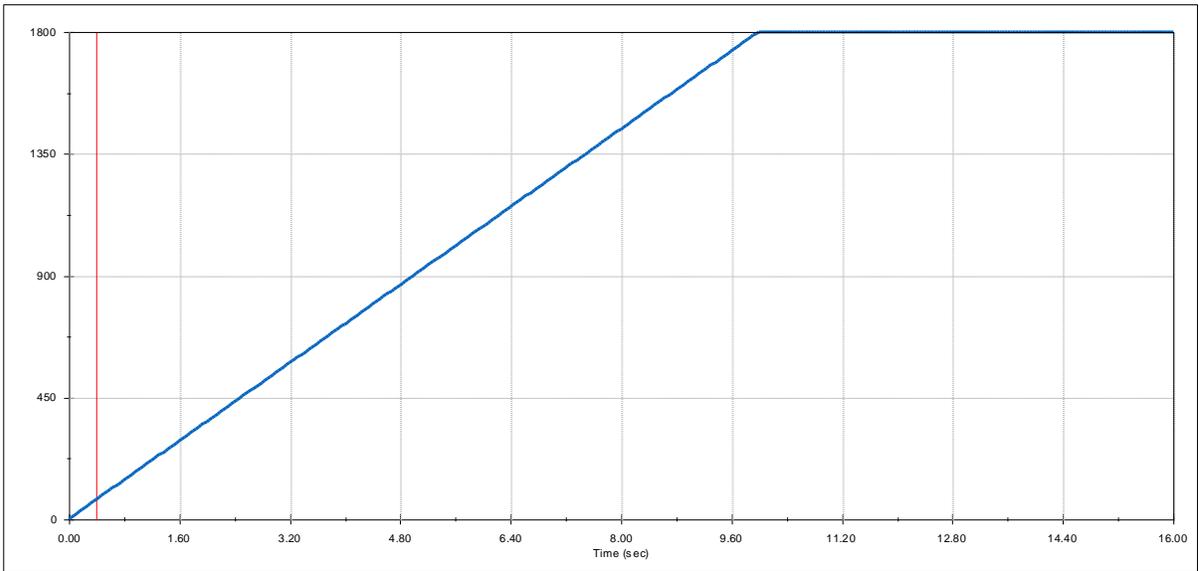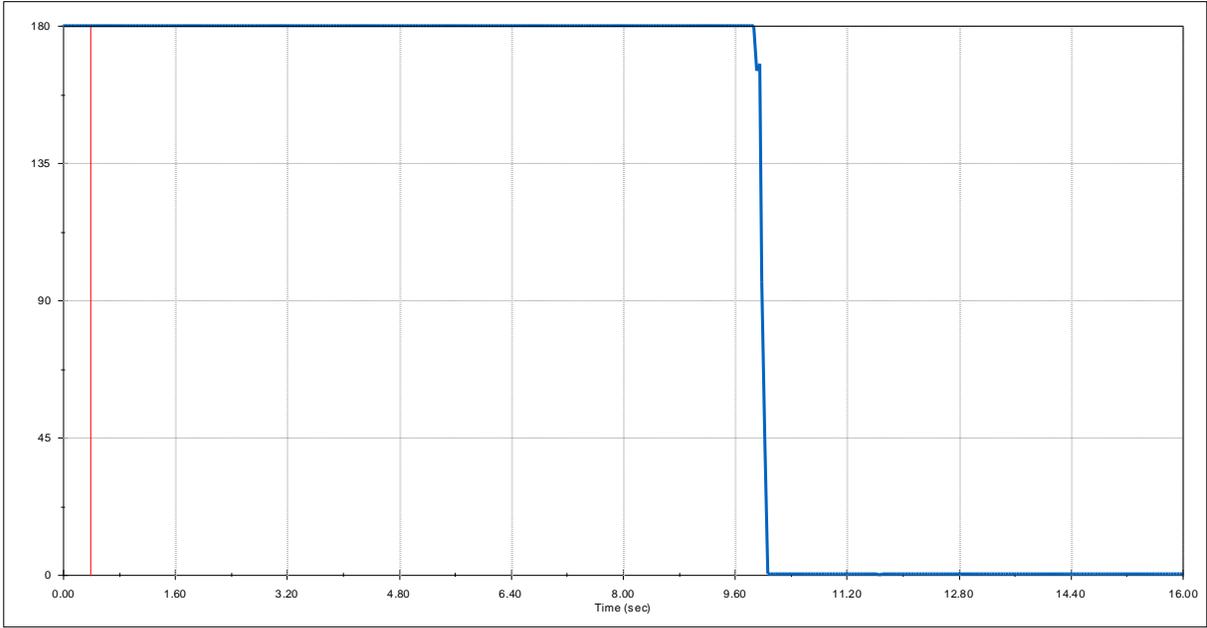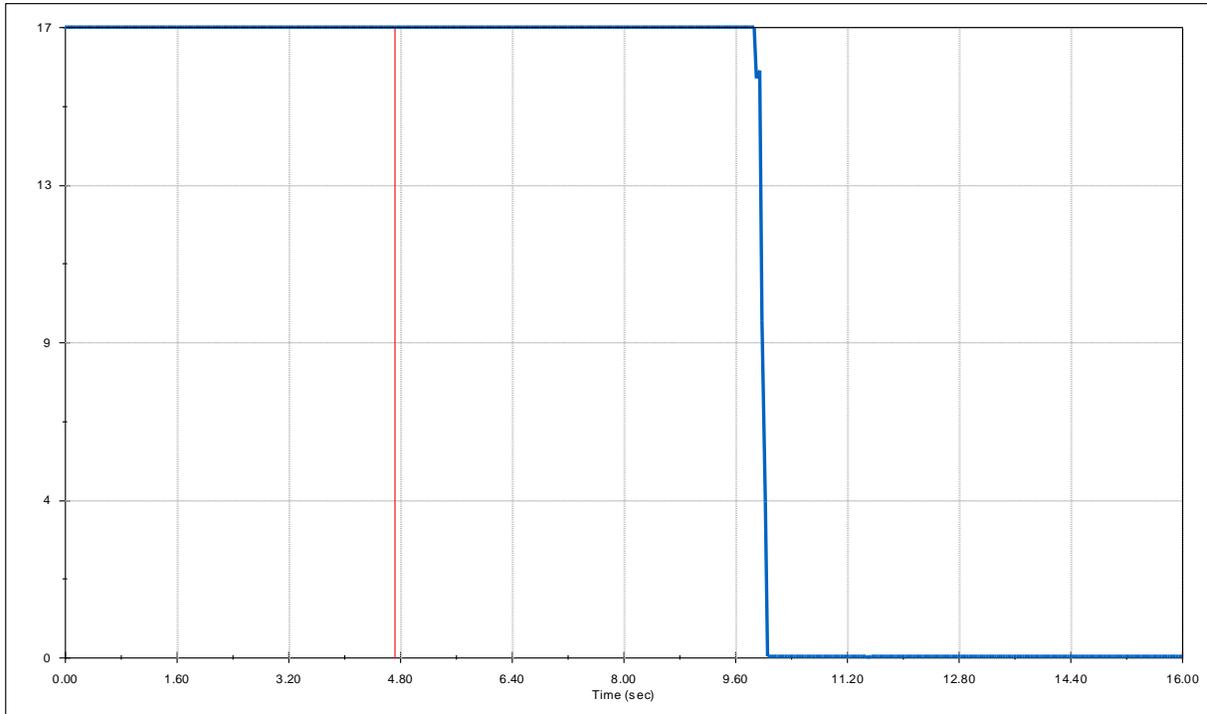
Engineering Database

**Liquids**

Water

Path: Liquids Pre-Defined
Density
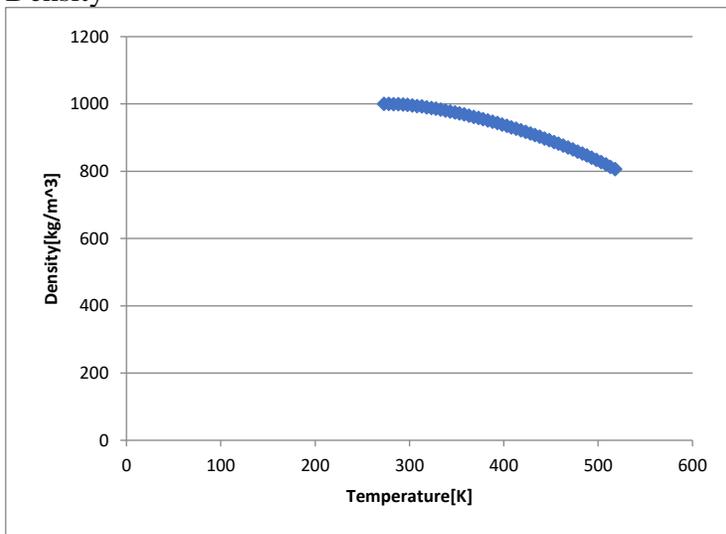
## Dynamic viscosity
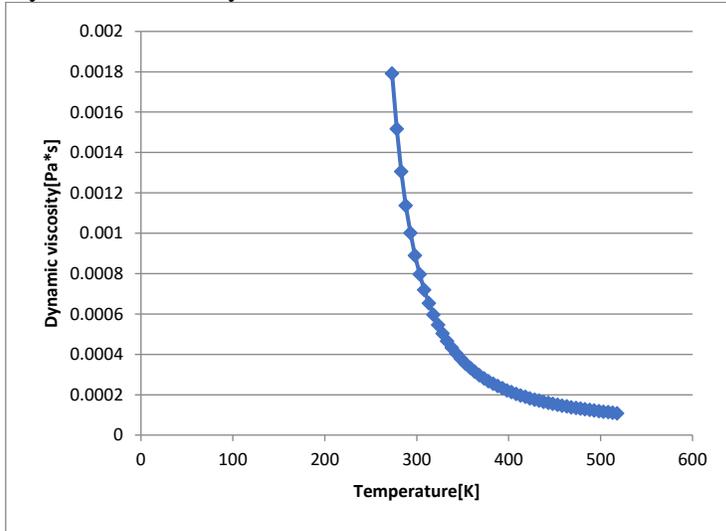
## Specific heat (Cp)
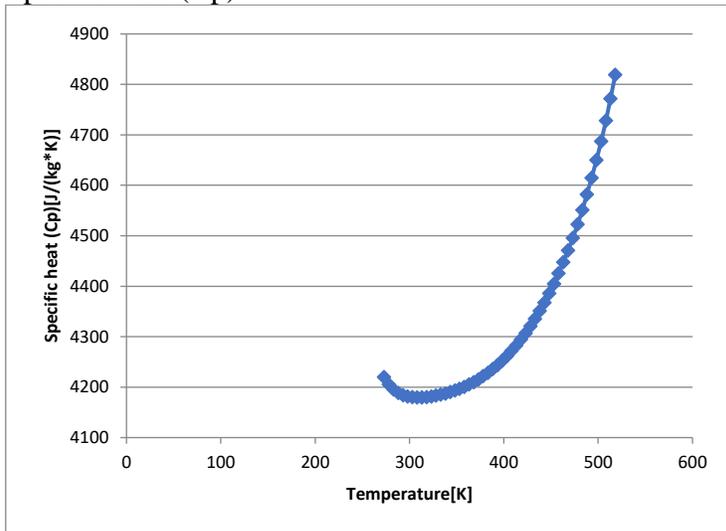
Thermal conductivity
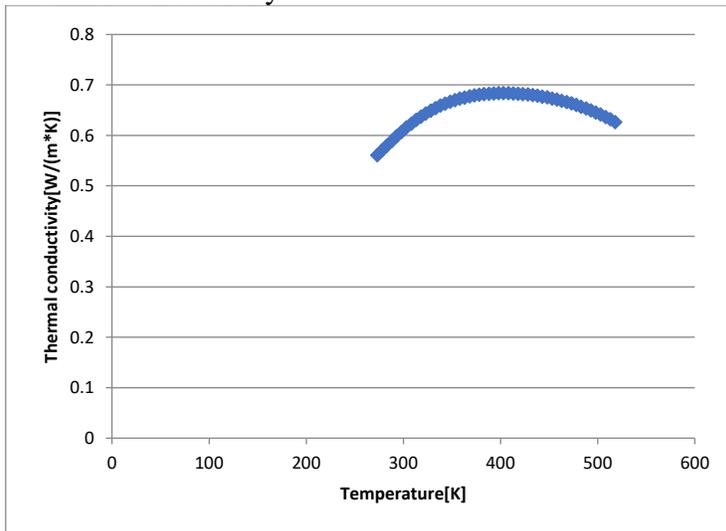
Cavitation effect: Yes

Temperature: 0 K
Saturation pressure: 0 Pa