



TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING

Department of Electrical Power Engineering and Mechatronics

MODERNIZATION AND DESIGN OF BALL BEARINGS APPARATUS

Veerelaagrite katseseadme konstrueerimine ja moderniseerimine

MASTER THESIS

Student:	Anilkumar Nagavelli
Student code:	A146461
Supervisor:	Leo Teder

Tallinn, 2017

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material.

All works, major viewpoints and data of the other authors used in this thesis have been referenced.

“.....”2017

Author:

/signature /

Thesis is in accordance with terms and requirements

“.....” 2017

Supervisor:

/signature/

Accepted for defense.

“.....”2017

Chairman of theses defence commission:

/name and signature/

TUT Department of Mechatronics

MASTERS THESIS SHEET OF TASKS

Year: 2017 semester: Vth

Student: Anilkumar Nagavelli (A146461)
Curricular: Mechatronics
specialty: Mechatronics
Supervisor: Leo Teder (Teaching assistant)
Advisor: Priit Põdra (Associate Professor)

MASTERS THESIS TOPIC:

(In English): Modernization and Design of Ball Bearing Apparatus.

(In Estonian): Veerelaagrite katseseadme konstrueerimine ja moderniseerimine.

Assignments to be completed and the schedule for their completion:

No.	Description of the Tasks	Timetable
1.	Device structural scheme and functional specification.	2 Weeks
2.	Design of device transmission and Loading system.	2 weeks
3.	Design of the device friction moment measuring system.	2 weeks
4.	Design of device control system.	2 weeks
5.	Thesis report completion and recommended by the supervisor.	2 Weeks

Solved engineering and economic problems: Description of the structure of Ball Bearing setup and designing, measurement methodology and research torque bearing when the load changes, the rotational speed and the level of lubricating oil.

Language of the thesis: English

Application is filed not later than:

Deadline for submitting the theses:

Student Anilkumar Nagavelli signature: date.....

Supervisor signature: date.....

Confidentiality requirements and other conditions of the company are formulated as a company official signed letter.

Contents

Figures	6
Table	7
EESSÕNA	9
1. INTRODUCTION	1
1.1 Current problem	2
1.2 Chapter summary	3
2. EXISTING DESIGN OF BALL BEARING APPARATUS.....	4
2.1 Motor.....	5
2.2 Literature review	7
2.3 Study problem	7
3. MARKET OVERVIEW	8
3.1 Ball Bearing Test Rig.....	8
3.2 Ball Bearing Test Rig -BSPIL-DYN-04058.....	9
3.3 Brake Lining Friction Test Rig	10
4. MATHEMATICAL CALCULATIONS	11
5. PROJECT DESIGN CONFIGURATION	16
5.1 Modernize system	16
5.1.1 Outcomes	18
5.1.2 Grounds.....	18
5.2 Shaft Designing	19
5.3 Coupling.....	21
5.4 Oil Supply	22
6. MOTOR.....	24
6.1 DC motor.....	24
6.2 Servo Motors.....	24
6.3 Stepper Motor.....	24
6.4 AC motor.....	25
6.5 Three Phase Induction Motor	25
7. DRIVES.....	27
7.1 ABB machinery drives	27
7.1.1 Machine interfaces	28
7.1.2 Software tools.....	29
7.2 Delta Drive	30
8. LOADCELL	31
8.1 Compression Load Cells and Compression Force Sensors	32

9. PHOTOGATE SYSTEM.....	34
9.1 Vernier Photogate.....	34
10. MEASUREMENT SYSTEM	36
10.1 Loadcell.....	36
10.1.1 Bridge Measurement	36
10.1.2 Configuring a Bridge Measurement.....	37
10.1.3 cDAQ-9174.....	38
10.2 Photogate.....	40
10.3 Speed Control of Three Phase AC Induction Motor	44
10.3.1 Variable Frequency Drives	45
10.3.2 Precautions for Using PLC Functions	45
SUMMARY	54
KOKKUVÕTE.....	56
REFERENCE	58
Appendix 1	60

Figures

Figure 1. Block Diagram [1].....	1
Figure 2. Device structural scheme and functional specification	3
Figure 3. Schematic diagram o Ball bearing Apparatus [1].....	4
Figure 4. Loading system and Friction reading [1].....	5
Figure 5. Existing and current Ball bearing apparatus	6
Figure 6. Ball Bearing Test Rig [3]	8
Figure 7. Ball Bearing Test Rig BSPIL-DYN-04058 [4]	9
Figure 8. Brake Lining Friction Test Rig [5].....	10
Figure 9. Measuring friction torque [6]	12
Figure 10. Kinematic diagram of the laboratory setup and the bearing load circuit [1]	12
Figure 11. Project design	16
Figure 12. Loading system	17
Figure 13 Project subsystem configuration	18
Figure 14. Shaft with pillow blocks.....	19
Figure 15. Bearing box Oil Level Inlet and Outlet [22].....	22
Figure 16. Marelli - IE2 3ph B3 Foot Mount AC Motor[12]	26
Figure 17. ACS355 - Ratings, types, voltages and prices[14]	27
Figure 18. Machine interfaces [13].....	28
Figure 19. Control connections [14].....	29
Figure 20. Software tools [13]	29
Figure 21 Delta VFD Ratings [29]	30
Figure 22 VFD-007CP43A-21 - Variable Frequency Drives [29].....	30
Figure 23. Load cells [16].....	31
Figure 24. Miniature Button Load Cell [17].....	32
Figure 25. Dimensions of Button load cell [17]	33
Figure 26. Photogate setup [19].....	34
Figure 27. Specifications of Photogate [19]	35
Figure 28. NI Compact DAQ and NI 9237 Bridge Module [23]	36
Figure 29. Device Terminals [23].....	37
Figure 30. Load Cell data acquisition system	38
Figure 31. DAQ-9174 Compact DAQ 4-Slot USB Chassis [24].....	39
Figure 32. Lab view Output Panels	39
Figure 33. Photogate Sensor [25]	41
Figure 34.NI myDAQ Features [27].....	42
Figure 35.LabVIEW Photogate Front Panel and Block diagram.....	42
Figure 36. myDAQ connects the PC to Photogate sensor	43
Figure 37 Hardware PLC – VFD Communication [30].....	45
Figure 38 Communication protocols[33].....	46
Figure 39 PLC Program.....	47
Figure 40 speed control of AC motor [31].....	48
Figure 41 Configuring Modbus Master I/O Server.....	49
Figure 42 Select Modbus Addresses to Bind to Shared Variables.....	50
Figure 43 NI OPC Servers 2012 Displaying Simulated PLCs.....	51
Figure 44 Network architecture	51
Figure 45 Actual network configuration.....	52
Figure 46 LabVIEW Motor Control Circuit Front Panel.....	53

Table

Table 1. Friction coefficients of standard bearings	11
Table 2. Description of the bearings	14
Table 3. The values of the coefficients	14

FOREWORD

In English:

This thesis was written for my Master degree in Mechatronics at the Tallinn University of Technology. The work was executed at the Tallinn University of Technology. And, the work consists of the laboratory apparatus and Modernizing, mechanical, data communication, Sensors and software field integration. The purpose of this modernization work is to design a test rig for investigation of friction of materials and machine components and, the description of the structure of laboratory setup, measurement methodology and research torque bearing when the load changes, the rotational speed and the level of lubricating oil.

I would like to thank the following people, without whose help and support this thesis would not have been possible. First, I like to show my gratitude to the people of departments of Mechatronics. My supervisor Leo Teder for his suggestions, encouragements, and guidance in writing the thesis and approaching the different challenges during the thesis. My sincere thanks to him for motivating me to write till the end of the work. He was always helpful and helped me with my doubts and confusion in the case. I would also like to thank Priit Põdra for his support, vision, and help. Finally, I would like to thank my parents, my friends and my girlfriend for their constant support during the time I studied.

EESSÕNA

In Estonian:

See lõputöö on kirjutatud minu magistrikraadi jaoks Tallinna Tehnikaülikoolis. Töö oli teostatud Tallinna Tehnikaülikooli juures. Töö koosneb laboritehnika, selle kaasajastamisest, mehaanikast, andmesidest, andurite ja tarkvara integratsioonist. Eesmärk on katsepingi kaasajastamine, sellega seonduvalt uuritakse erinevate materjalide takistust muutuval koormusel ja antud laboriseadmete koostu üldiseid andmed. Samuti on eesmärgiks uurida veerelaagri väändemomenti koormuse, nurkkiiruse muutumisel ja vajaliku määrdeaine kogust.

Ma tahaksin tänada järgmisi inimesi ilma kelle abi ja toeta selle lõputöö võimalik olnud. Esmalt ma tahaksin tänada inimesi Mehhatroonikainstituudist. Sooviksin tänada oma juhendajat assistant Leo Tederit tema ettepanekute, julgustuse ja suunamise eest lõputöö kirjutamisel ja erinevate probleemide lahendusvõimaluste otsimisel. Siirad tänusõnad minu motiveerimise eest kuni lõputöö valmimiseni. Ta on olnud alati abivalmis ja aidanud mind keerulistel hetkedel. Samuti sooviksin avaldada tänud dotsent Priit Põdrat oma abi ja nägemuse eest mida ta on pakkunud lõputöö lahendamisel. Ma tahaksin tänada oma vanemaid, sõpru ja tüdrukut nende pideva toetuse eest.

1.INTRODUCTION

Modernization of existing ball bearings' friction measuring device is described in this thesis. The device in question has a variable speed transmission, screw operated loading system and the friction measuring system based on the bearing unit rotation angle due to friction. The bearing unit has a possibility to change the lubricating oil level.

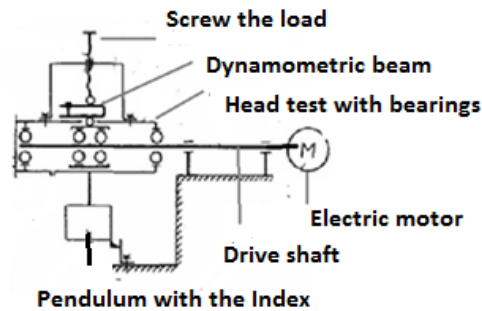


Figure 1. Block Diagram [1]

The device to be designed is based on the existing old friction moment measuring device DM28M. And, Resistance to rotation of the rolling bearing dependent on the size and design of the bearing, the accuracy and quality of manufacturing of working surfaces, load, rotational speed, amount and lubricating properties of the oil lubrication method, the temperature of the bearing assembly. This lab sets depending on the load torque, speed, and level of the lubricating oil. With increasing load, the friction forces on the contact areas of the rolling elements increase, respectively, and increased torque.

$$M = 0.5 * \mu * F * d \quad 1.1$$

Where, μ - friction coefficient

$$\mu = \frac{Fn}{Nf} \quad 1.2$$

F_n – friction force, N;

N_f – normal force, N.

F - radial and axial components of the loads

d - Inner diameter of the bearing or shaft diameter

1.1 Current problem

Main purpose of this modernization work is to design a test rig for investigation of friction of materials and machine components and, the description of the structure of laboratory setup, measurement methodology and research torque bearing when the load changes, the rotational speed and the level of lubricating oil. And, in this our problem is measuring the loading system and friction moment in the electronic measurement. All these devices are control by computer. We don't have perfect installation machine and the thesis having few problems like,

1. Design of the device transmission from the motor power $\approx 0,75$ kW. The speed of the device shaft must be variable in the limits of $(500 \dots 3000) \text{ min}^{-1}$.
2. The bearing unit design with bearing loading system and measuring in the electronic measurement and registration of radial load redesigning;
3. Design of the device friction moment in the electronic measurement system;
4. Design of an overall concept of device control and test data measurement using a PC.

A ball bearing, its carries a load by placing the rolling elements like balls between two bearing rings. And, it's having the bearings and shafts of rotating axes. It can accommodate radial and axial loads applied to the shaft and fixed against the longitudinal displacement axis. It's providing them at the same time free to rotate. It's, distinguish between two types of bearings, those are sliding and rolling.

Below the Device structural scheme and functional specification are explained, like chapters are divided into parts and the tasks are included. The Device structural parts are loaded and friction, Drive, sensors, Motor and control system monitoring software has been presented.

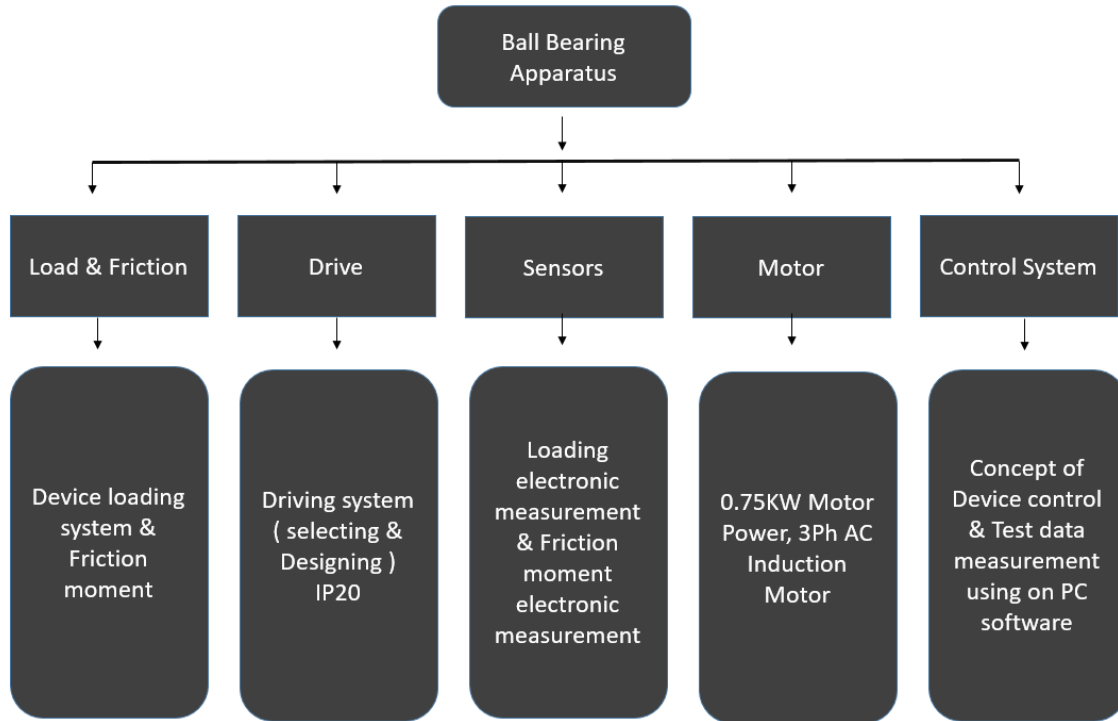


Figure 2. Device structural scheme and functional specification

1.2 Chapter summary

This paper exposes the results of the study of the conclusions that reflect the behavior of the torque on the rotational speed, the radial load and the amount of lubricating oil. Set by plotting and the relative value of individual components of the angular momentum: Having a thick resistance of the lubricating oil during its excessive level, in the absence of friction load and the friction that occurs when a load operation. Make also concluded that a consistent experimental value of the reduced coefficient of friction bearings investigated with reference data. In this process, we are explaining about modernizing mechanical parts, data communications, sensors and software etc. No simulation in real time but measuring the loading and friction moment system and monitoring all devices in PC.

2. EXISTING DESIGN OF BALL BEARING APPARATUS

The Ball bearing device Laboratory work is performed on the DM-28M installation for measuring the torque of standard rolling bearings with an inner diameter. In this existing machine having very old mechanical parts for installation and procedure is different, however the existing ball bearing apparatus principles are following like,

The installation consists of the following units:

- Induction motor 3-phase, 0.75kW power
- Drive system
- The drive shaft
- Test head with four bearings (Bearing Box)
- The force measuring device and the pendulum and Loading system.

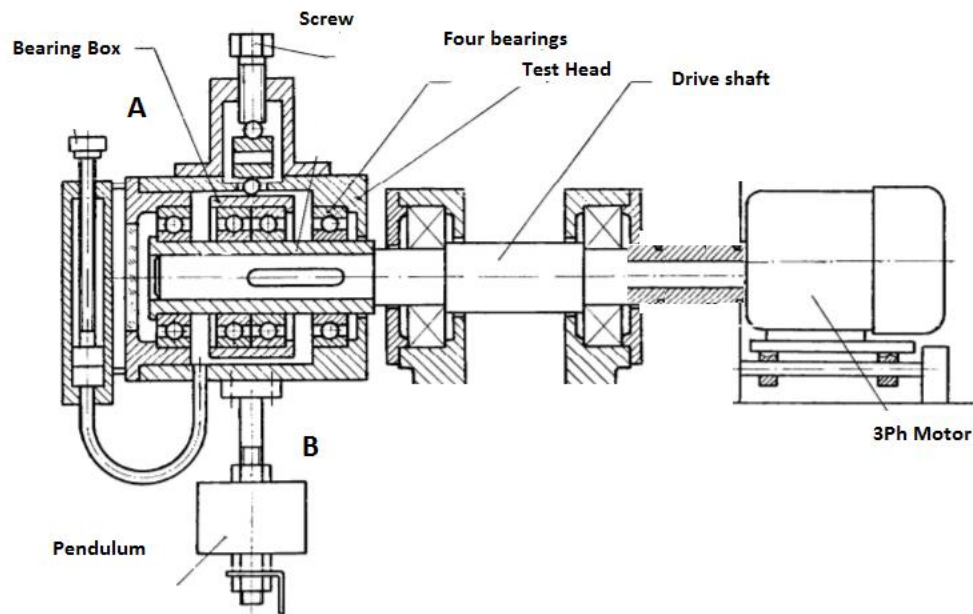


Figure 3. Schematic diagram o Ball bearing Apparatus [1]

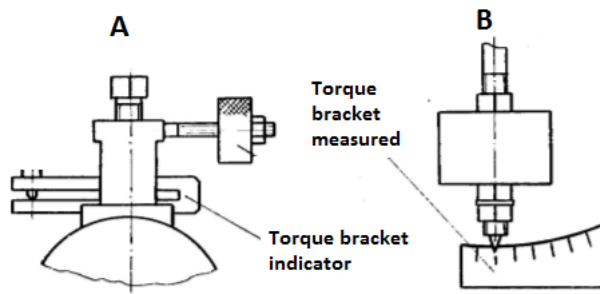


Figure 4. Loading system and Friction reading [1]

Above schematic diagram showing the existing machine mechanical parts and its dividing into two systems. Those are Loading system and Friction measuring system. About loading system and finding friction values are shown in other chapters.

2.1 Motor

Normally, AC motors are mostly preferred in industrial applications now days. Because these are low costs and durability. These are driven by alternating current (AC). These motors have a stationary stator and inside rotor. Stationary stator has coils to produce a rotating magnetic field with alternating current, and the yield shaft associated with within rotor for producing a second rotating magnetic field [2]. The properties of a given motor. [2]

Mains frequency 50Hz 3 phase supply, 0.75kW 3ph 4 Pole AC Motor for 230V or 400V.

The electric motor drives the shaft at the end of which the test head is mounted with bearings. All four-bearing are in one bearing box and rotates with the shaft. On the two-outer bearing, mounted head enclosure, and two medium – steel. By rotating the screw load force Q transmitted through the centering balls and a torque bracket on clip with two medium-sized bearings. These bearings are clamped like in the bearing box while simultaneously loaded and the reaction force of both end bearings. Thus, each bearing four identical radial load generated

$$Fr = Q / 2 \quad 2.1$$

$$Q = 2Fr \quad 2.2$$

Where, Q = force,

Fr = radial load

Here, Q the Force and the load generated by the screw. And, it's determined by the magnitude of the elastic deflection and the Torque bracket by a dial gauge to the calibration curve. These calibration curve sets to the proportional relationship between the amount of deflection and the value of the load Q . In this, inclusion of the electric motor is

carried out by transfer switch and then clicking on the "Start" button. Normally, the required speed of the drive shaft created (when $n = 1000 \text{ rev / min}$).

Occurring in rolling torque is transmitted to the head, body which is held against rotation at the bottom mounted weight (pendulum) and deflected by a certain angle depending on the torque. Count torque is carried out on a scale, is graduated in Nm. The required level of lubricating oil in the bearings mounted with oil and oil level control is carried out visually through the glass roof of the head.

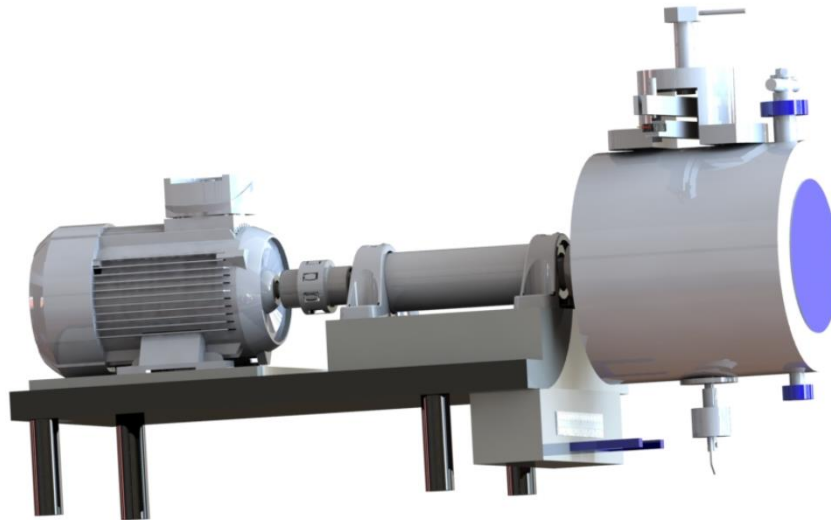


Figure 5. Existing and current Ball bearing apparatus

2.2 Literature review

In this, Moment of friction in rolling bearings paper they determine the topic in two objectives. Those are - Determination of the moment of friction in rolling bearings and Determination of the reduced coefficient of friction in rolling bearings. The main source of losses in the rolling bearings is the resistance to rolling of the rolling elements on the treadmill rings, depending on the load on the bearing, its dimensions, material properties of bearing components, etc.

In addition, the losses caused by friction of the rolling elements of the separator, friction bearing parts of lubrication, hydraulic resistance in the lubricant, etc. Determination of the total loss is difficult. In the present study determined the total friction torque. The main component of the losses in the bearing, depending on the pure rolling. They are using DM28 system. It's advantage of the ball bearing system but we changed so many things like loading system, Friction losses and angle, Oil system etc.

And, another paper they used same process system for the friction properties of ball bearing. But, in that the experimental results are the tribological parameters: moment of friction and coefficient of friction have been studied under lubricated conditions, with motor and transmission oil at various normal loads. Device "DM 28M" used for measurement of moment of friction in ball bearings. The device consists of casted housing with mounted driving shaft. A bearing (measuring) box is connected to the end of the shaft, where the four ball bearings (two in the middle and two at the end), which are tested, are located. Single-row steel ball bearings (Designation 308, GOST 8338-57) were used, with bore diameter of 40 mm, outside diameter of 90 mm and width of 23 mm. Experimental results show the variation of the moment of friction with the temperature of oil in the bearing, in regime without normal load, for motor oil M-63/14 without and with additive. The values are measured every 2 min with overall duration of 10 min.

In this they determine the Dependence of the coefficient of friction on load for motor oil M-63/14 without and with additive. Finally, these paper is helpful to finding the coefficient of friction and how much load should have applied and finding the friction angle purpose.

2.3 Study problem

According to existing machine and background research, we should control the speed and finding the torque bearing. And, it's very old machine very old mechanical parts for installation and procedure is different. What is the way for easy installation and process for redesign system and manly focus on the loading system and friction moment system? These systems how to measure in computer. And, oils supply in bearing box oil lubrication, does not require that a particular level. But in the box, it could be maintained for proper bearing load, because oil levels are not properly like do not reach critically low or high points then its effectiveness.

3. MARKET OVERVIEW

3.1 Ball Bearing Test Rig

This product developed by the SWARG systems and instruments, the apparatus consists of a shaft driven by motor to which the bearing to be tested is fixed. In this process, the load is applied to bearing through the lever arrangement. By using the special parallelogram loading attachment transmits the load to the bearing under test & at the same time, permits the measurement of friction torque. The torque is measurements by torque arm and dead weights and the number of revolutions is counted by a revolution counter. Finally, after the completion of the test, the radial clearance can be measured. Thus, the bearing can be tested for load test, endurance test as well as friction test. [3]



Figure 6. Ball Bearing Test Rig [3]

Specifications

1. Bearing, Mounting Fixture – Consists of a set of bearing races for bearings from 6201 to 6204 with parallelogram loading attachment.
2. Drive motor – 1 HP, 3000 RPM AC motor.
3. Lever & spring balance for applying the load, maximum loading capacity 10000 N.
4. Electronic revolution counter with digital indicator.

3.2 Ball Bearing Test Rig -BSPIL-DYN-04058

This product developed by B.S. PYROMATIC RTDELS PVT LTD. And, the specifications are below. [4]

Specifications

1. Bearing, Mounting Fixture – Consist of a set of bearing races for bearings from 6201 to 6204 with parallelogram loading attachment.
2. Drive motor ½ HP, 6000 RPM DC motor
3. Lever and spring balance for applying the load, maximum loading capacity 10000N
4. Electronic revolution counter with digital indicator.
5. Torque arm with dead weights for measurement of friction torque
6. Fixture for measuring bearing radial clearance.



Figure 7. Ball Bearing Test Rig BSPIL-DYN-04058 [4]

3.3 Brake Lining Friction Test Rig

This product developed by Eternal Engineering Equipment (p.) Ltd. And, the ranges of the experiments are shown below. [5]

Range of experiments

- 1) For the Friction Test for Brake lining and clutch plates: In this test specimens, shall be tested on this Test Rig. This machines may be on the scale dynamometer type using constant torque. The description of test method that may be adopted for the determination of the coefficient of friction are as given below.
- 2) And, Normal Test: In this test for the first cycle of normal test with the test machine shall be conducted 20 minutes with a load of 3.515 kg/cm on the samples. During the first few minutes of the cycle the surfaces of the test pieces shall be normalized by rubbing action on the surface so as to obtain uniform surface giving total contact with the friction disc. And, the average value of the coefficient of friction shall be Calculated.
- 3) Coefficient of Friction is calculated by following the Formula [5]

$$\text{Coefficient of friction} = \frac{\text{Output Torque}}{\text{Input Torque}} = \frac{W \times L}{F \times r_m} \quad 3.1$$

U = Coefficient of friction, W = Load (kg), L= Length of arm in (meter),

F= Force measured by load cells at (kg), r_m = mean radius of friction material in (mtr.)



Figure 8. Brake Lining Friction Test Rig [5]

4. MATHEMATICAL CALCULATIONS

Performance order work calculations

Average values of the reduced friction coefficients of standard bearings

Bearing Type	Bearing type Coefficient of friction f (Radial, Axial load)	Bearing type Coefficient of friction f (Load)
Radial single-row, ball	0,001 0,002	0,002 ... 0,003
Radial Ball Spherical double row	0,002 0,004	-----
Row Angular Contact	0.002 0.003	0.0025 0.004
Tapered roller radial Thrust	0,004 ... 0,008	0.01 ... 0.02

Table 1. Friction coefficients of standard bearings

Where, μ - friction coefficient

$$\mu = \frac{Fn}{Nf} \quad 4.1$$

Fn – friction force, N;

Nf – normal force, N. $\mu = \frac{0.25}{2000} = 0.001$ and $\mu = \frac{0.75}{4000} = 0.002$

If we know the friction coefficient, then

$$\mu = \text{Tan}\phi = \sin\phi/\cos\phi \quad 4.2$$

And = $\text{Tan}^{-1}\mu$

Then we know the value of friction angle.

The friction coefficient is the tangent of the friction angle.

Friction Torque (M)

$$M = F \cdot f \cdot d/2 \quad 4.3$$

Where, M = Friction torque

F = Radial and Axial load

f = coefficient of friction

d = Inner diameter

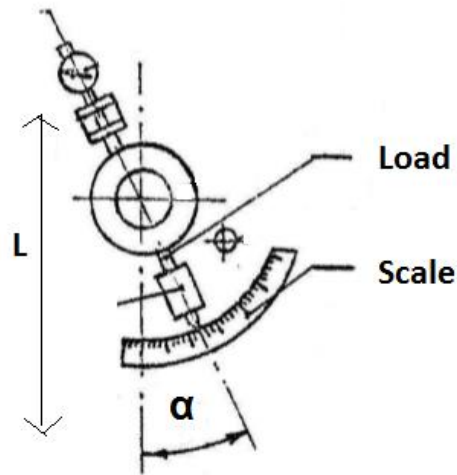


Figure 9. Measuring friction torque [6]

Or Measuring friction torque M

$$M = P \cdot L \cdot \sin \alpha$$

4.4

Where, P = weight of mass

L = length

α = Angle

Radial loads $F_r = 0.25, 0.5, 0.75$ and 1.0

At the same time and force values for the load of the screw corresponding to the values F_r , i.e.,

$$Q = 2F_r.$$

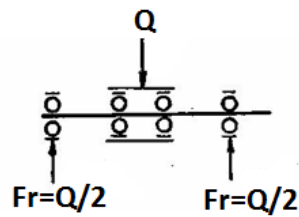


Figure 10. Kinematic diagram of the laboratory setup and the bearing load circuit [1]

$Q =$ Force, each bearing having four identical radial loads generated $Fr = Q/2$

$N = 500$ to 3000 rev/min

Rolling torque is transmitted to the head, body which is held against rotation at the bottom mounted weight (Pendulum) and deflected by certain angle depending on the torque.

Counting torque is carried out on a scale (NM). If necessary to achieve the zero position of the pendulum movement corresponding. To reduce the 'values of experimental torque bearings has to work under pre-load of about 4 ... 5 minutes at a speed of $n = 2000$ rev / min. Including the motor, load bearing force (0,5 ... 0,75) [Fr] and after a specified time, work to remove the load and switch off the motor. Make sure that the indicator needle and the pendulum back to the zero position.

Enable the motor ($n = 2000$ rev / min) and pendulum perform counting total moment ΣT_o rotation at no load with the submission of the results. Without turning off the engine, consistently produce a number of Q_i loads on the bearings, taking each time the value ΣT_{vr} torque recordings. And, Remove the load on the bearings to zero and turn off the motor. Make sure that the pendulum and indicator hand force measuring device back to its initial (zero) position.

Perform measurements and torques ΣT_o , ΣT_{vr} at $n = 3000$ and 1000 rev / min in the same order. At the end of the experimental part of the work to calculate torques attributable to one bearing, no-load current values T_0 and radial load T_{vr} .

Therefore, $T_o = \Sigma T_o / 4$, and $T_{vr} = \Sigma T_{vr} / 4$.

For one of the rotational speed (at the discretion of the teacher) and the minimum and maximum levels of oil to calculate the coefficient of friction of the bearing shown on the dependence obtained from the formula:

$$f = 2T_{vr} / Fr \cdot D \quad 4.5$$

Where in the T_{vr} - the torque of the bearing is N mm; Fr - the current value of the radial load, N; and d - the inner diameter of the bearing, mm. According to experimental data, $T_o = f(n)$ and $T_{vr} = f(n)$ for the radial load $Fr = 0.75$ [Fr] or $Fr = 1.0$ [Fr] for the minimum and maximum oil levels.

From the analysis of dependence of conclusions that reflect the behavior of the torque on the rotational speed, the radial load and the amount of lubricating oil. Set of plotting n relative values of individual components of the angular momentum. Excessive levels, in the absence of friction load and the friction that occurs when a load operation. Make also concluded that some consistent experimental values of the reduced coefficient of friction bearings investigated with reference data.

Kinematic diagram of the laboratory setup and the bearing load diagram (Above Figure 10).

Charts dependencies $T_o = f(t)$ and $T_{vr} = f(t)$, $T_{vr} = f(F_r)$ and $f = f(F_r)$

Brief description of the bearings used for the test in a laboratory

The main bearing options	Bearing Type		
	Ball radial light series	Thrust tapered radial light series	Spherical light series
Conditional Designation of bearing	208	7208	1208
Inner bearing diameter d, mm	40	40	40
The outer diameter of the bearing D, mm	80	80	80
Permissible radial load [Fr], N	4000	5000	2000

Table 2. Description of the bearings

Type ball bearing	Initial contact angle	Values of coefficients
Radial	0	0.0007
Angular contact	26	0.0010
Persistent	36	0.0010
Spherical	90	0.0010

Table 3. The values of the coefficients [7]

Therefore, $Q = 2F_r$

$F_r = Q/2$, where Q = Force and F_r = radial force

Loads are 4000N, 5000N and 2000N

Radial loads are 0.25, 0.5, 0.75 and 1.0

Inner Diameter d = 40mm

Average of friction coefficients $f = 0.002, 0.004, 0.001$

Speed n = 1000 rev/min, 2000 rev/min and 3000 rev/min

To one of the rotational speed and the minimum and maximum levels of oil calculate reduced bearing friction coefficient dependence obtained from the formula:

$$f = 2T_{vr} / Fr \cdot d \quad (1) \quad 4.6$$

Where in the T_{vr} - the torque of the bearing is N.mm; Fr - the current value of the radial load, N; and d - the inner diameter of the bearing, mm.

$$\begin{aligned} T_{vr} &= f \cdot F \cdot d/2 & 4.7 \\ &= 0.002 \cdot 0.25 \cdot 40/2 \\ &= 0.01 \text{Nm.} \end{aligned}$$

And,

Minimum speed 1200rpm and Maximum speed is 3000rpm

$$1200\text{rpm} = 125.66 \text{ rad/sec}$$

Mass = 6kg

$$R = 33$$

$$I = mr^2/2 = 6 \cdot 33^2/2 = 3.267 \cdot 10^{-3} \text{ kgm}^2$$

$$T = I \cdot E$$

$$E = 2\pi n/60t = (2 \cdot 3.14 \cdot 1200)/60 \cdot 10s \quad E = 12.56 \text{ rad/s} \quad T = 3.267 \cdot 10^{-3} \cdot 12.56 = 0.41 \text{Nm}$$

$$P = T \cdot W = (0.41 \cdot 3.14 \cdot 2 \cdot 1200)/60 = 51.496 \text{w}$$

$$P = 0.0514 \text{kW.}$$

According to calculations we get approximately near to get 0.75kW depends upon motor speed and other mathematical calculations.

5. PROJECT DESIGN CONFIGURATION

In this picture shows the design and Experimental determination of friction loss in rolling bearings research into the relationship between friction torque in the various types of load, rotational speed and the level of liquid lubricants.

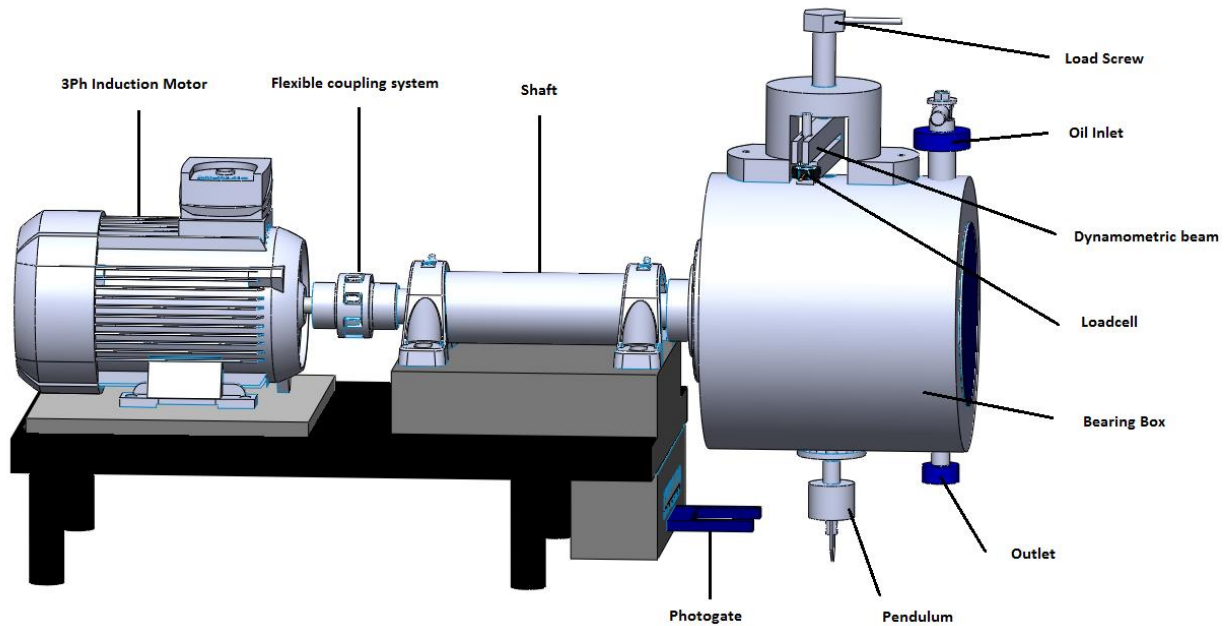


Figure 11. Project design

5.1 Modernize system

Compare with existing machine, new modernize system having few mechanical parts are redesigned and in this system for measuring purpose loading system and friction moment measuring for using sensors like loadcell and photogate. And, we changed the belt drive system. We are directly connected to the motor why because Direct drive is better than belt drive. Belt drives were used to isolate the motor from the main spinning container for friction reduction and shock. Now that there are better dampers and shock absorbers on the main container direct drives are more efficient. Direct drive motors reduce the potential failure rate by eliminating the most unreliable component, and may allow a slightly higher capacity drum. But the likely cost of a motor or drum replacement may be higher, and repair a little more difficult if things go wrong. Frankly, modern machines are so cheap and so much more reliable than even a decade ago I would not be making purchasing decisions on this sort of factor, just on normal domestic criteria like cost, quality, and user features. And, this is the procedure for project design configuration.

The motor drives the shaft at the end of which the test head is mounted with bearings. All four-bearing impaled on a steel sleeve and rotates with the shaft. On the two-outer bearing, mounted head enclosure, and two medium- steel ferrules mean inside.

By rotating the screw load force Q transmitted through the centering balls and a torque bracket on clip with two medium-sized bearings. These bearings are clamped to the hub while simultaneously loaded and the reaction force of both end bearings. Thus, each bearing four identical radial load generated $Fr = Q / 2$.

Force the Q , the load generated by the screw is determined by the magnitude of the elastic deflection. Torque bracket measured Load cell to the calibration curve. The calibration curve sets the proportional relationship between the amount of deflection δ and the value of the bracket load Q .

The inclusion of the motor is carried out by transfer switch to "Drive" and then clicking on the "Start" button. The required speed of the drive shaft is created on belt permutation stage corresponding. (Motor speed 500 to 3000 RPM min)

Occurring in rolling torque is transmitted to the head, body which is held against rotation at the bottom mounted weight (pendulum) and deflected by a certain angle depending on the torque. Count torque is carried out on a scale, it is graduated in Nm. The required level of lubricating oil in the bearings mounted by one tube on the bearing box with oil and oil level control is carried out visually through the glass roof of the head.

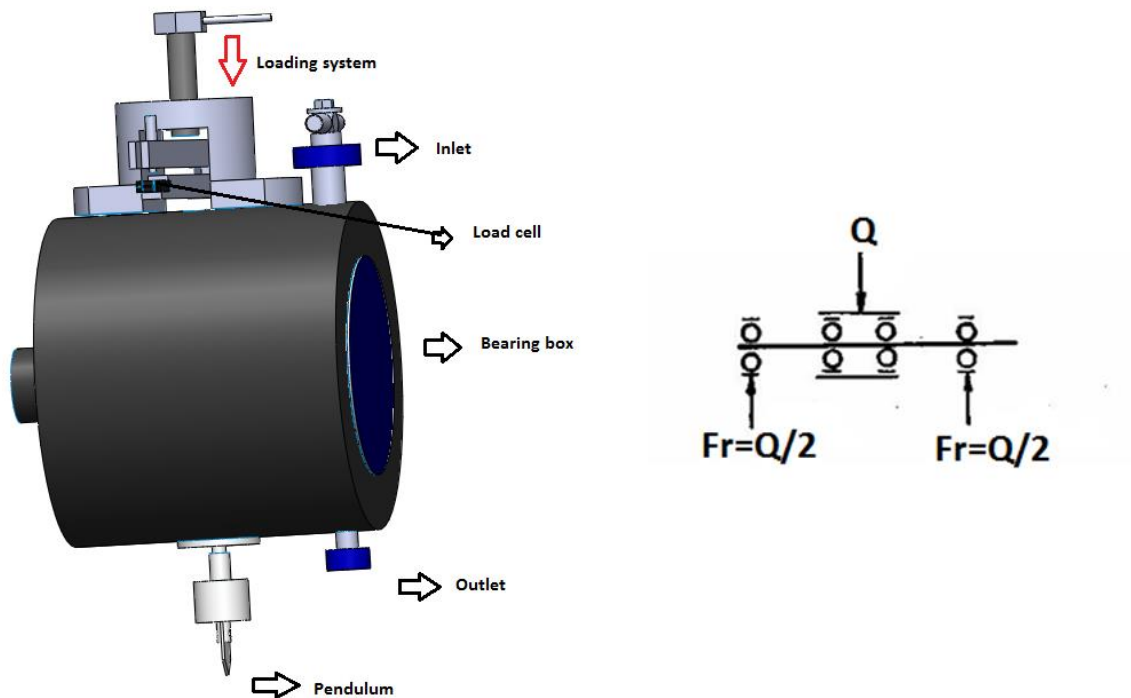


Figure 12. Loading system

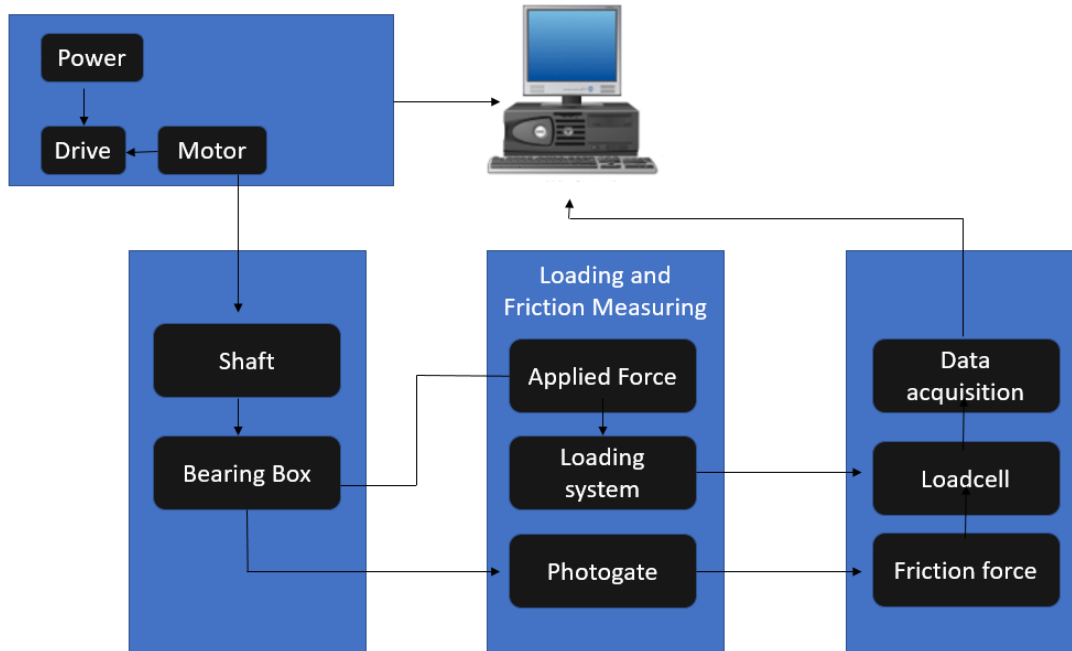


Figure 13 Project subsystem configuration

5.1.1 Outcomes

From the above project configuration system explaining about all the designs of an overall concept of device control and test data measurement using a PC. And, in this explained step by step process in below regarding loading and friction measuring system, drive system and software. Mainly, we can expect from this system results of the friction torque bearing system and all the designs are monitoring and controlling by PC. By using the LabVIEW HMI and how this software working and measuring the overall system are expected.

Coming to real data outcomes, results of the loading measuring system by using the loadcell sensor and how it works, measuring and controlling in PC. Friction moment system, period of the pendulum or momentum of the pendulum can measure by using the photogate sensor and controlling in PC. Mainly speed controlling process, using delta PLC programming and output results are monitoring and controlling in LabVIEW HMI. These are the main data outcomes.

5.1.2 Grounds

In this, existing DM-28M machine having the old mechanical parts and main reasons for the all devices have mechanical system, control system and measuring system. Firstly, coming to motor according to our mathematical calculations power 0.75kW and explained below motor chapter in detail. Shaft and coupling system are useful for the easy to installation and finding the results. Coming to loading system and friction moment system have to measure in the electronic measurement system by using software. In existing model, mainly we can consider the bearing box, its working principle and reason for the finding torque bearing.

And, all devices information in detailed step by step process explained below chapters.

5.2 Shaft Designing

A long, limit part or area shaping the handles of a mechanical assembly, the body of a bolt, or practically identical. A shaft is a rotating machine part, by and large circuitous in cross range, which is used to transmit power, beginning with one section, then onto the next, or from a machine which produces energy to a machine which absorbs power. The different individuals, for example, pulleys and apparatuses are mounted on it.

Shafts are by and large shaped by hot rolling and completed to size by cold drawing or turning and grinding.

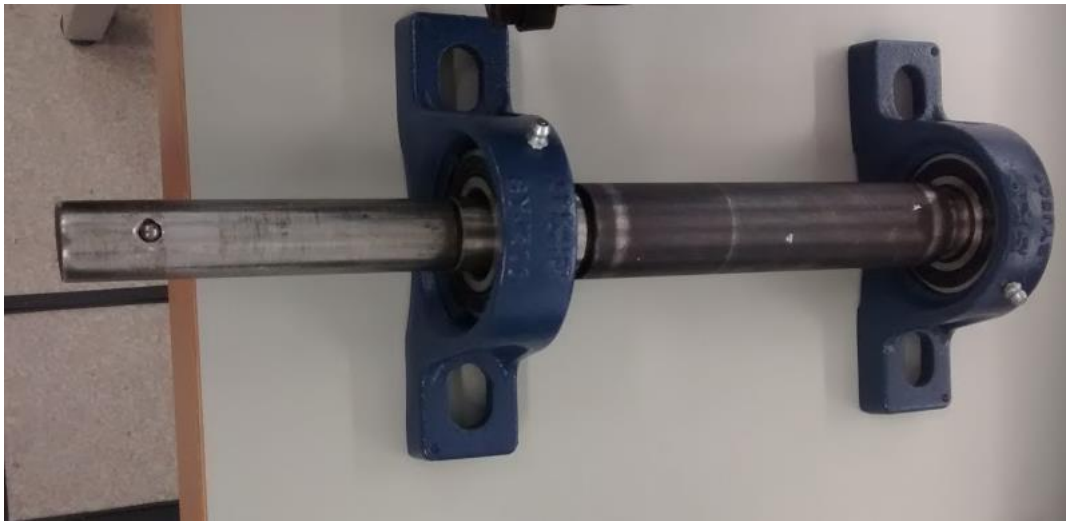


Figure 14. Shaft with pillow blocks

Standard sizes

Machine shafts

Up to 30 mm steps of 1

10 mm steps of 2

165 mm steps of 1

125 mm steps of 1

Total length 340 mm shaft.

A shaft is the segment of a mechanical device that transmits rotational motion and power. It is integral to any mechanical system in which power is transmitted from a prime mover, for example, an electric motor or a motor, to other rotating parts of the system.

Because of the simultaneous occurrence of torsional shear and normal stresses due to bending, the stress analysis of a shaft practically dependably includes the utilization of a combined stress approach. The recommended approach for shaft plan and analysis is distortion energy theory of failure. Vertical shear stresses and direct normal stresses because of axial loads may likewise happen. On short shafts or on parts of the shafts where no bending or torsion occurs, such stresses may be dominant.

Tangential Force [20]

$$W_t = T / (D/2) \qquad 9.1$$

Where,

P = power being transmitted in HP

N = rotational speed in RPM

T = Torque on the gear in lb*in

D = pitch diameter of the gear in inches

Design Stresses for Shafts

- In a given shaft, several different stress conditions can exist at the same time.
- For any part of the shaft that transmits power, there will be a torsional shear stress, while bending stress is usually present on the same parts.

5.3 Coupling

A coupling is a device used to interface two shafts together at their ends with the end goal of transmitting power. Couplings don't regularly allow disconnection of shafts during operation, in any case, there are torque restricting couplings which can slip or separate when some torque limit is exceeded. The main role of couplings is to join two pieces of rotating equipment while allowing some level of misalignment or end development or both. By careful selection, installation and maintenance of couplings, substantial savings can be made in reduced maintenance costs and downtime.

Types of coupling system

In this coupling system, they have different type of systems are there, case Sleeve or Muff coupling, Clamp or Split-muff coupling, Tapered shaft lock, Hirth, Flexible, Beam Coupling, Bush pin type flange coupling etc. [21]

In this machine, utilizing Flexible coupling system because A flexible coupling exists to transmit power (torque) starting with one shaft then onto the next; to compensate for minor amounts of misalignment; and, in specific cases, to give protective functions such as vibration dampening or acting as a “fuse” in the case of torque overloads. Hence, these reasons, industrial power transmission regularly calls for flexible rather than rigid couplings.

At the point when the time comes to specifying replacements for flexible couplings, it's human nature to take the simple way and simply find something similar, if not identical, to the coupling that failed, maybe applying a few oversized fudge factors to be conservative. Too often, however, this practice invites a repeat failure or costly system damage.

The wiser approach is to start with the assumption that the previous coupling failed because it was the wrong type for that application. Setting time opportunity to decide the correct kind of coupling is worthwhile even if it only verifies the previous design. Yet, it may lead you to something very surprising that will work better and last more. An alternate coupling design may also extend the life of bearings, bushings, and seals, preventing fretted spline shafts, minimizing noise and vibration, and cutting long-term maintenance costs.

5.4 Oil Supply

The level of the lubricating oil maintaining in bearing box and I designed for oil supplying like one inlet and one outlet process. In couple of special cases, the one thing that oil-greased up machines have in like manner is a box. Despite its size, shape and limit, a few support practices would be recommended for every such machine.

Level in Control

One of the key responsibilities in examination and support is checking and keeping up the level. A drop extending a support level in a limit of bearing box may achieve amount required supply of oil. Right when oil drops underneath the base level in a wet box application, the machine can be famished of the starved measure of oil to keep it running truly and dependably. Stuffing the vault can in like way be damaging.

Level Out Control

Oil levels change for different reasons. Reducing in volume is regularly brought on by spillage. Incessant structure best offs are a decent pointer that spillage is going on. This is a tremendous issue from the cost of oil use, and also in the potential risk to prosperity and nature. Top-offs should be taken after to alert such issues.

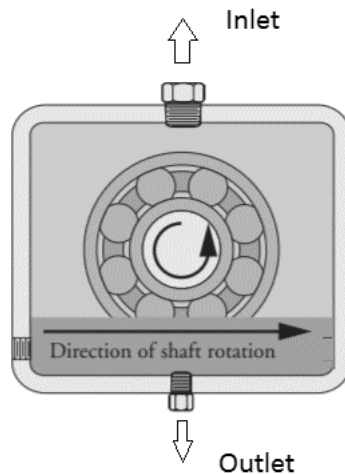


Figure 15. Bearing box Oil Level Inlet and Outlet [22]

Constant level lubrication

Constant level oilers are keeping up a predetermined oil level in bearing box, it's important for proper lubrication. In the event that the oil level was to below the minimum level, then depleted oil would be consequently expanded by utilizing level sensor and it goes to unique level. With the utilization of steady level oilers. And, maintenance efficiencies can be increased while minimizing maintenance costs, and the loss of production time. Presently a day's greater part of constant level oilers is customizable and taking into account use in many applications. Regularly,

constant level oilers are mounted in favor of the equipment because facing the direction of shaft rotation. In my bearing box oilers consider the base mounting, of the oil box.

In most cases, these constant level oilers are strong to the outside atmosphere to work properly. For the most part oilers are vented to the atmosphere, particularly in harsh, dirty environments, etc., are permitted to enter the lubricating oil. These contaminants are in the types of moisture and particulate which are extremely damaging to the oil and equipment life. The exchange of air between the oil box and oiler is at the oilers base, which is mounted specifically to the oil box.

Maintaining Proper Level:

In bearing box oil lubrication, does not require that a particular level. But in the box, it could be maintained for proper bearing load, because oil levels are not properly like do not reach critically low or high points then its effectiveness. [22]

Low Level

In this low-level process, the bearing box won't get enough lubricant oil essential for proper quality. Without enough oil to prevent friction, thermal runaway can happen rapidly to a steel bearing. If the temperature of the bearing increases, the ball and race are extended and which makes a much more tightly fit. In the event that more temperature considerably more, and cycle process continuous to rapid and failure. Furthermore, in this low level of oil will influence to a wide range of oil splash lubrication. If suppose direct contact, then there will be insufficient film quality and rings are will most likely be unable to get more or enough oil to satisfy lubricate the bearings.

High Level

In this high-level process, if shaking of the lubricant will happen accelerating the oxidation rate because of unreasonable air and raised temperatures. It's a very common mistake to trust that more is better and particularly when it's coming from oil bearing box lubrication. In the event that a lot of oil can influence the operation of oil rings and direct bearing contact. Furthermore, another result of high lubricant levels is leaking seals. In the event that the oil level is too high, the ring will become under oil and no longer sling the oil.

6. MOTOR

Selection of motor

For selection of motor, different type of choices we have now days and that can be utilized for giving motion to the system. These include servo motor, stepper motors, DC motors, and AC motors. And, every motor has advantages and disadvantages in a few viewpoints.

6.1 DC motor

A DC motor is any of a class of electrical machines that converts direct current electrical power into mechanical power. The most widely recognized sorts depend on the forces produced by magnetic fields. Almost a wide range of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current flow in part of the motor. Most types produce rotary motion; a linear motor directly produces force and motion in a straight line. DC motors were the first type widely used, since they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, utilizing either a variable supply voltage or by changing the quality of current in its field winding. Small DC motors are used in tools, toys, and appliances.

The universal motor can work on direct present yet is a lightweight motor utilized for versatile power apparatuses and machines. Larger DC motors are utilized as a part of electric vehicles, elevator and hoists, or in drives for steel rolling mills. [8]

6.2 Servo Motors

A servo motor is a rotary actuator that considers exact control of angular position. It consists of motor coupled to a sensor for position input. It also requires a servo drive to finish the system. The drive utilizes the feedback sensor to precisely control the rotating position of the motor. This is called closed-loop operation. By running the framework closed-loop, servo motors give a high-performance alternative to stepper and AC induction motors. [9]

6.3 Stepper Motor

Stepper motors are DC motors that move in discrete steps. They have multiple loops that are organized in gatherings called "phases". By energizing every stage in arrangement, the motor will turn, one step at a time. With a PC controlled stepping you can achieve very precise positioning and/or speed control. Therefore, stepper motors are the motor of decision for some accuracy movement control applications. Stepper motors come in a wide range of sizes and styles and electrical qualities. [10]

Stepper motors good for Positioning, Speed Control, Low Speed Torque And, limitations are Low Efficiency, limited High Speed Torque and No Feedback.

6.4 AC motor

An AC motor is an electric motor driven by an alternating current (AC). The AC motor normally consists of two fundamental parts, an outside stationary stator having coils provided with alternating current to create a rotating magnetic field, and an inside rotor attached to the output shaft delivering a second rotating magnetic field. The rotor magnetic field might be delivered by permanent magnets, reluctance saliency, or DC or AC electrical windings.

Less generally, linear AC motors work on comparable standards as rotating motors, however have their stationary and moving parts arranged in a straight-line arrangement, creating linear motion instead of rotation. [11]

In this AC motor having two types of motors. Therefore,

1. Synchronous Motors.
2. Asynchronous Motors (Induction Motor).

6.5 Three Phase Induction Motor

A three-phase induction motor runs on a three phase AC supply. 3 phase induction motors are extensively used for various industrial applications because of their following advantages-

- They have very simple and rugged (almost unbreakable) construction
- They are very reliable and having low cost
- They have high efficiency and good power factor
- Minimum maintenance required
- 3 phase induction motor is self-starting hence extra starting

Motor or any special starting arrangement is not required.

They also have some disadvantages

- Speed decreases with increase in load, just like a DC shunt motor
- If speed is to be varied, we have sacrificed some of its efficiency

Marelli - IE2 3ph B3 Foot Mount AC Motor



Figure 16. Marelli - IE2 3ph B3 Foot Mount AC Motor[12]

Brand: Marelli

Range: MAQ Three Phase IE2 Aluminum, 0.75kW (1HP) 4 Pole 230V/400V 3ph B3 Foot Mount AC Motor - MAQ80MB4. [12]

Price: £75.00

Parameters

Marelli - High Efficiency 80 Frame 0.75kW 3ph 4 Pole Foot Mounting AC Motor for 230V or 400V x 50Hz 3 phase supply. Use with any Variable Frequency Inverter Drive having 1ph or 3ph input and 3ph output, or a fixed frequency mains supply at 50Hz.

Full Load Current - 3.1A at 230V, or 1.8A at 400V.

Power Factor is 0.76 when mains connected at 50Hz.

Efficiency is 79.8% at full load, 79.6% at 75% load and 76.3% at half load.

This motor, we are using in this system because its having less cost and high efficiency.

7. DRIVES

Selection of drives

We have different type of drives in the market now days for speed control and therefore,

7.1 ABB machinery drives

The ABB machinery drives are intended to be fast drives to install, parameter-set and commission. In this manner, saving hours of designing work. They are very conservative and practical. Outfitted with front line insight and safety capability the drives are designed specifically to meet the production and performance needs of system integrators, original equipment manufacturers (OEMs) and panel builders, and additionally the requirements of end clients in a wide scope of uses.

In the ABB machinery drives portfolio, ACS355 represents the micro drive range; meeting prerequisites like conservative size, being improved for a lower power range, cost-effectiveness, and ease of use. By picking an ABB machinery drive, machine developers not just get all the clever things inside the drive, additionally everything outside it: the whole worldwide ABB. This means a full range of products and services designed to support their business. [13]

It is very easy to select the right drive.

This is how you build up your own ordering code using, the type designation key.

1. Start with identifying your supply voltage
2. Choose your motor's power and current rating
3. Select your drive's ordering code
4. Choose your options and add the option codes to drive's ordering code.

380/480 V, 3-phase supply voltage

Nominal	Output current	Max output	Frame	Fuse A	Heat dissipation	Cooling requirements	Type (code shown is IP20)	IP20 list price without control panel*	IP66 list price with control panel**
kW	A	A		Type gG	W	m ³ /h			
0.37	1.2	2.1	R0	10	35	*Nat Vent	ACS355-03E-01A2-4	£189	£400
0.55	1.9	3.3	R0	10	40	*Nat Vent	ACS355-03E-01A9-4	£199	£402
0.75	2.4	4.2	R1	10	50		ACS355-03E-02A4-4	£218	£417

Figure 17. ACS355 - Ratings, types, voltages and prices[14]

Options are available in ACS355

Input and output chokes

Brake chopper resistors (all drives in the ACS355 range have an integral chopper)

1st. Environment EMC filters

Footprint style

Low leakage EMC filters < 30 mA leakage

Flash Drop, programming in the box without power

Fieldbus modules

NEMA kit allows installations to be neater and provides mechanical support for land cables-

An extensive range of user interfaces is available.

7.1.1 Machine interfaces

The plug-in Fieldbus modules convey availability to major automation systems. A single twisted pair cable avoids large amounts of conventional cabling, thereby reducing costs and increasing system reliability. [13]

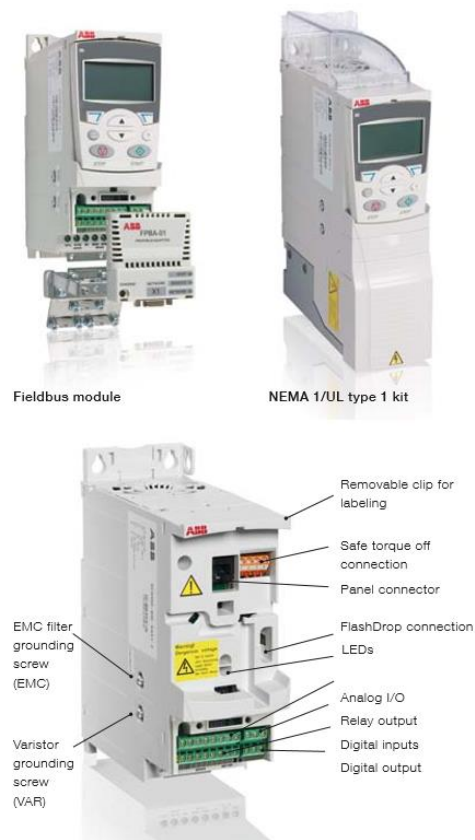


Figure 18. Machine interfaces [13]

ACS355 – User interfaces are

Assistant control panel (+J400)

Basic control panel (+J404)

Panel cover

Relay extension module (+L511)

Potentiometer (+J402)

Flash Drop

Fieldbus interfaces

24V “live keypad” options

Drive Window Light PC tool

NEMA 1 kit

Panel mounting kits, IP54 and IP66

Typical control connections:

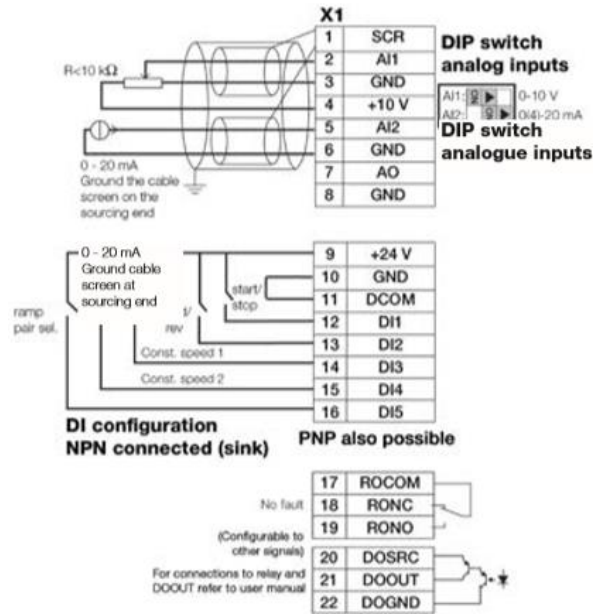


Figure 19. Control connections [14]

7.1.2 Software tools

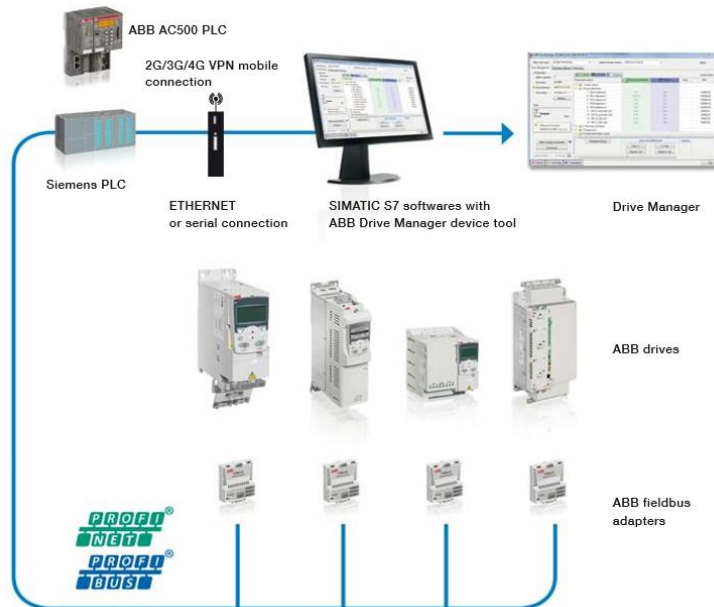


Figure 20. Software tools [13]

7.2 Delta Drive

The VFD-007CP43A-21 VFD Variable Frequency Drive joins power and execution into one complete, cost-effective package. This drive controls a 0.7kW (1HP) AC Motor and is equipped with a 3-step V/F curve response which conforms input voltage to achieve maximum efficiency in variable torque applications such as pumps, air blowers and HVAC drives. Momentary power loss restarts, flying starts, and auto-acceleration/deceleration are all additional features designed specifically for the varying load changes of our application requires. Sensor less Vector Control offers fast reaction to shifting load changes and increases motor performance. [29]

Item	Input voltage	Max Power (HP)	Rated Current (A)	Installation Type	IP Rating
VFD-007CP43A-21	323-528	0.00		Wall-Mount	IP20

Figure 21 Delta VFD Ratings [29]



Figure 22 VFD-007CP43A-21 - Variable Frequency Drives [29]

The main features are

- Open-Loop Speed Control
- Will Work with Most 3 Phase AC Motors
- Sensor less Vector Control
- Multi-Segment V/F Control Curve and Soft Start Greatly Improve Efficiency
- Built-in BACnet and MODBUS. Various Optional Communication Cards Such as ProfiBUS-DP, DeviceNet, MODBUS TCP, Ethernet-IP and CANopen.
- Detachable LCD Keypad. User-friendly Interface
- Fire Mode and Bypass Functions Provide Safe Operation in an Emergency etc.

Delta VFD connections are shown in Appendix and it will have used to control the speed of AC 3ph Induction motor by using the PLC program and we will be measuring in LabVIEW (monitoring).

8. LOADCELL

A Load cell is a transducer that is utilized to make an electrical signal whose magnitude is straight forwardly relative to the force being measured. The different types of load cells include hydraulic load cells, pneumatic load cells and strain gauge load cells. Load is a term every now and again utilized as a part of designing to mean the drive applied on a surface or body. It is a word that will not be generally utilized here, except in the normal utilization of 'load cell' which is a usually utilized term for different types of force measurement transducer, and in the term overload for a force exceeding the rated capacity of a force measurement system. [15]

A load cell is a device that is utilized to measure weight or force. At the point when a force is connected to it in a particular way, a load cell creates an output signal that is relative to the applied force. Strain gauge load cells are at the heart of the majority part of weighing and force measurement devices delivered today. One end of a load cell is typically supported on an inflexible structure while the other end supports a load getting gadget through which the load or force is connected. Load cells can be utilized separately or in combinations in weighing devices, as dictated by the geometry of the object to be weighed. Different kind of Loadcells is there, example.

Strain gauge load cells, Canister type load cell, S-beam load cell, Canister load cell, Compression disk load cell, Rocker column load cell, Double-ended shear beam and Single-ended beam.

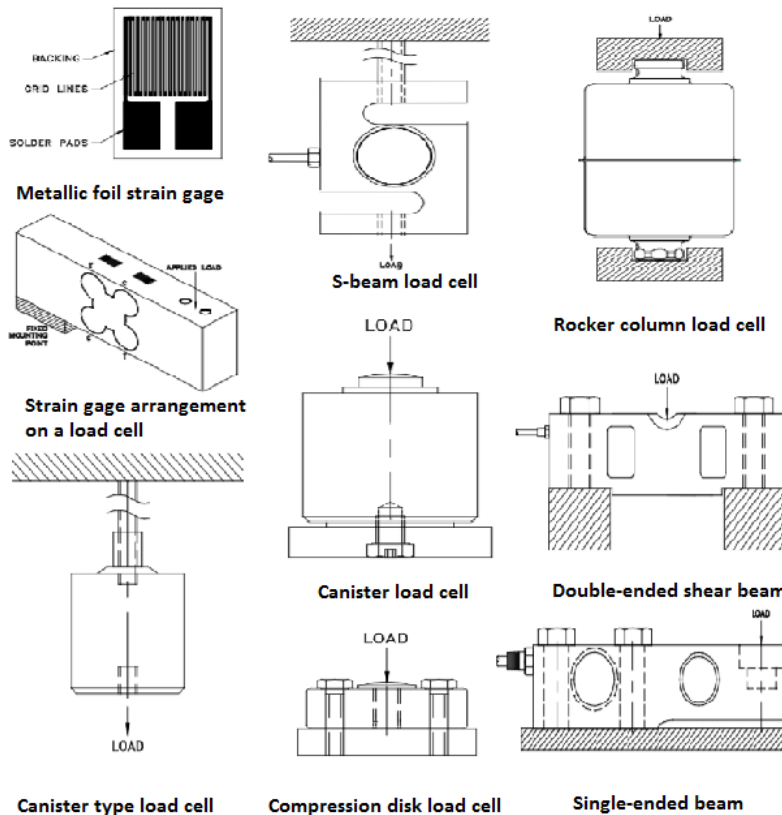


Figure 23. Load cells [16]

8.1 Compression Load Cells and Compression Force Sensors

This section shows our range of compression load cells and compression force sensors intended for the measurement of compressive loads, weights and forces. Our determination of compression load cells offers ranging from 0-25 grams for 0-1500 tons. In this design like single button load cell.

Button Load Cell

The miniature button load cells are designed for the measurement of compressive forces where space is a limiting factor. Its compact size means it can be fitted into the smallest of spaces and is regularly retrofitted, while the M3 threads in its base make settling the load cell in position a basic assignment.



Figure 24. Miniature Button Load Cell [17]

It is suited for both force measurement and weighing applications alike. It is utilized as a part of numerous mechanical procedure measurement applications for checking and control purposes. [17]

Key Features:

- Capacities 0-100N to 20kN
- Sealed to IP65
- Only 30mm in Diameter and 12mm in Height
- Integral Load Button
- Output 2mV/V nominal (1.5mV/V on 0-100N)
- Accuracy

Dimensions (mm):

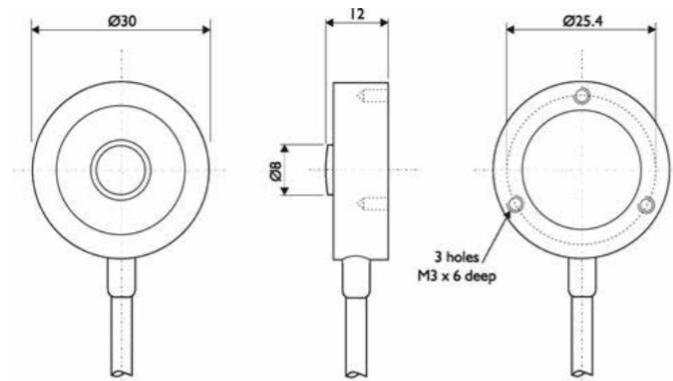


Figure 25. Dimensions of Button load cell [17]

Options:

- Full Range of Mounting Options Available
- Special Sizes Available on Request
- Other Ranges Available on Request
- Different Temperature Compensation Ranges Available
- Shunt Calibration Facility
- High Temperature Versions
- Vacuum Application Versions
- TEDS (Transducer Electronic Data Sheet)
- TEDS Allows Plug & Play with TEDS Enabled Instrumentation.
- USB Versions (via DSC-USB)
- Single or Multi-Channel PC-Based Monitoring & Data Logging System
- Wireless Version.

Loading mechanism

Loading mechanism is used to create radial load on the bearings of the subjects. When rotating keys, cylinder screws load through dynamometric bracket effect on race and through it the two-medium bearing. At the same time in extreme bearings raises equal and oppositely directed reactive conditions. Thus, each bearing has power

$$Fr=Q/2$$

Where Q is the load.

9. PHOTOGATE SYSTEM

The photogate system comprises of two photogates that can be joined to a photogate timer and integrated into any Visual Scientific analyze. Each photogate has an infrared light that sparkles on a sensor. At the point when objects pass through the photogate, the infrared light is blocked and data is sent from the sensor to the photogate timer. The photogate timer has a few settings, or modes, that can be utilized to calculate the time of an oscillatory system, the number of times a photogate was blocked, or the time an object takes to pass through one or both photogates. Such data can be utilized to calculate the velocities and accelerations of variety of objects. [18]

In this pendulum motion, examine two parts of pendulum movement. And, investigate the relationship between pendulum length, pendulum mass, and the period of oscillation. At that point figure out if mechanical energy is conserved as the pendulum swings.



Figure 26. Photogate setup [19]

9.1 Vernier Photogate

The Vernier Photogate is utilized for speed and acceleration measurements of objects passing through the gate. The object blocks an infrared beam as it passes. Motion information can be resolved in software from the timing of beam blocking.

1. The diameter of a ball rolling through a photogate, determine the speed of the ball from the ratio of the diameter to the time the gate is blocked by the ball. This requires just a single gate, yet the gate must be positioned carefully so the light beam intersects the middle of the ball.
2. Utilizing two photogates situated at a known separation, decide the speed of an object from the time interval between the breaking of the principal beam to the breaking of the second. This mode is known as pulse timing.
3. Set up a pendulum so that the bob swings through the photogate. The time interval from one block to the third block yields the pendulum period.

Specifications

Power requirements	5 VDC at 40 mA
Infrared source	Peak at 880 nm
Output is high and LED off for unblocked gate	
Output is low and LED on for blocked gate	

Figure 27. Specifications of Photogate [19]

The sensor has an infrared LED emitter on one arm and a photo transistor on the other arm. A question obstructs the infrared beam as it passes. Motion information can be determined in software from the timing of beam blocking. [19]

10. MEASUREMENT SYSTEM

10.1 Loadcell

A load cell is a transducer that converts mechanical force into electrical signals. There are many different types of load cells that operate in various ways, yet the most generally utilized load cell today is the strain gage load cell. As their name implies, strain gage load cells utilize a variety of strain gages to measure the deformation of a structural member and convert it into an electrical signal.

10.1.1 Bridge Measurement

Most strain gage measuring solutions provide an option to measure quarter-, half-, and full-bridge configurations. Consider an example, shown below in Figure, of an NI Compact DAQ system with an NI 9237 four-channel simultaneous bridge module.

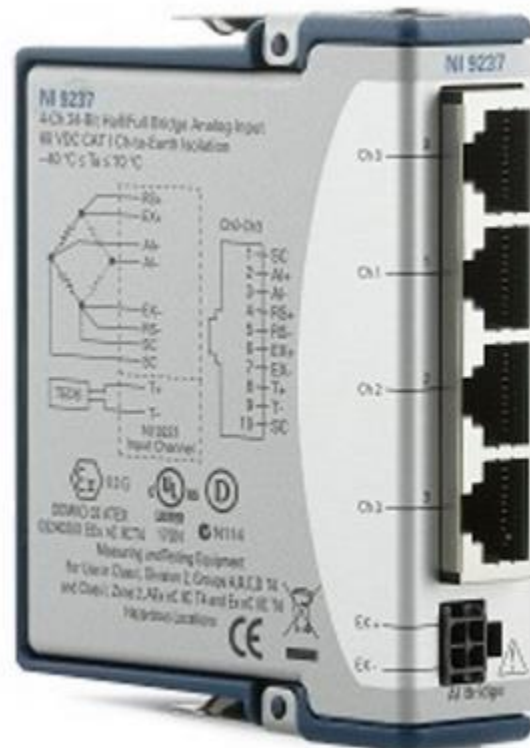


Figure 28. NI Compact DAQ and NI 9237 Bridge Module [23]

Step-by-step instructions for wiring and configuring on NI data acquisition device for strain gage measurements. Before starting utilizing NI data acquisition hardware, must install the application development environment (ADE) and NI-DAQmx driver programming. Before interfacing any signals, find device pinout. Open NI Measurement and Automation Explorer (MAX) and expand Devices and Interfaces. Right-click on the device name, and select “Device Pinouts.”

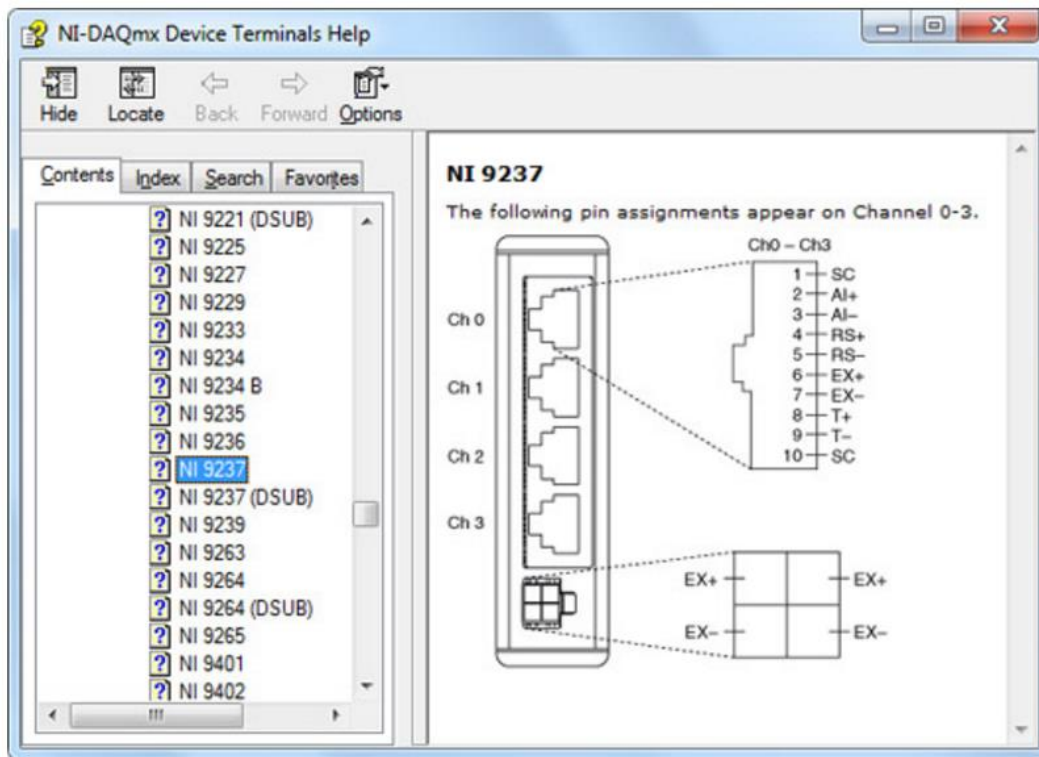


Figure 29. Device Terminals [23]

10.1.2 Configuring a Bridge Measurement

In this, MAX to quickly check the accuracy of measurement system setup. Utilizing a NI-DAQmx global virtual channel, and configure a bridge measurement without any programming. A virtual channel is a concept of the NI-DAQmx driver architecture used to represent a collection of device property settings that can include a name, a physical channel, input terminal connections, the type of measurement and scaling information.

Following these steps to begin:

1. NI MAX open, select Data, Neighbourhood and click Create New.
2. Select NI-DAQmx Global Virtual Channel and click Next.
3. Select Acquire Signals» Analog Input» Force» Force (Bridge).
4. Select ai0. A physical channel is a terminal or pin at which you can measure an analog or digital signal. A single physical channel can include more than one terminal or pin, as in the case of a differential input channel.
5. Click Next and enter a name for the global virtual channel.
6. Click Finish and on the Settings tab, type in the minimum and maximum values expect to read from your sensor.

7. Configure the Bridge Type and configure a scale to map physical values to electrical values. There are options for Two-Point Linear, and Polynomial. The information for these scales can be found in the data sheet for the sensor. The excitation and bridge resistance also need to be verified.



Figure 30. Load Cell data acquisition system

The above connection diagram indicates the loadcell connecting to the NI 9237 module and its chassis to DAQ 9174 device should be wired by the physical channel you choose [23]. For instance, a connection load cell which has a full-bridge type I configure utilizes pins, comparing to EX+, EX-AI+, and AI-, on an NI 9237 C Series module [23].

10.1.3 cDAQ-9174

NI Compact DAQ USB frame gives the plug-and-play simplicity of USB to sensor and electrical measurements on the benchtop, in the field, and on the production line [24]. By combining more than 60 sensors-particular NI C Series I/O modules with licensed NI Signal Streaming technology, the NI Compact DAQ platform delivers high-speed data and ease of use in a flexible, mixed-measurement system [24]. Modules are available for a variety of sensor measurements, including thermocouples, RTDs, strain gages, load and pressure transducers, torque cells, accelerometers, flow meters, and microphones.



Figure 31. DAQ-9174 Compact DAQ 4-Slot USB Chassis [24]

The main advantage of USB over other PC peripheral buses is simplicity of device detection [24]. Connect any NI Compact DAQ USB chassis to a Windows PC with the NI-DAQmx driver installed, and the chassis is automatically detected with no additional configuration needed. In addition, with NI-DAQmx driver software, you can develop a complete test system in LabVIEW, C/C++, Visual Basic.NET, and other programming environments. This ease of setup makes on USB a good decision for compact applications that may move starting with one PC then onto the next [24].

Result

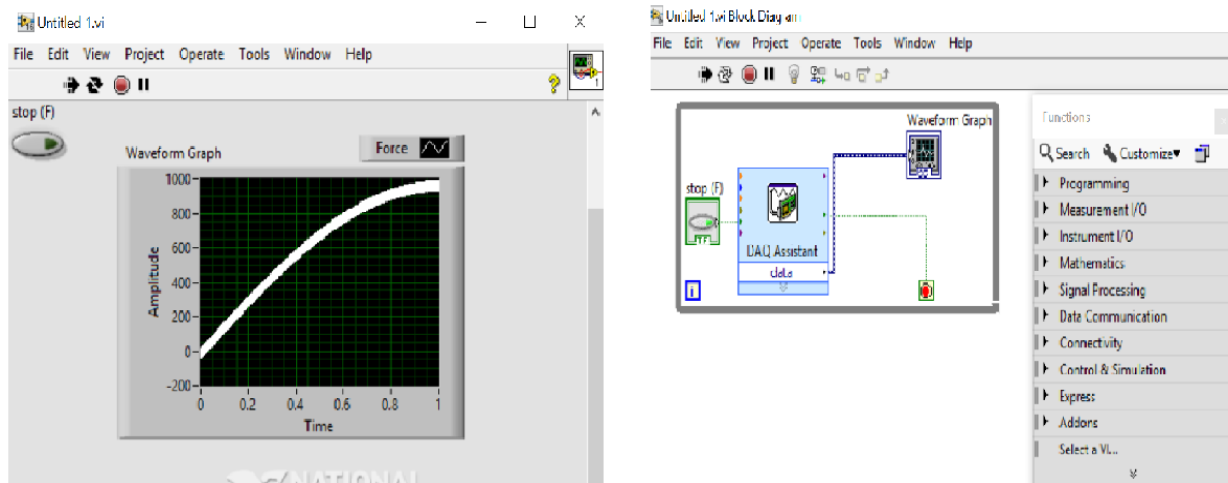


Figure 32. Lab view Output Panels

10.2 Photogate

The Vernier Photogate is utilized for speed and acceleration measurements of objects passing through the gate. The object blocks an infrared beam as it passes. Motion data can be determined in software from the timing of beam blocking. This general-purpose photogate can be utilized for a wide variety of experiments in physics and physical science classes. Examples include

- Measuring freefall acceleration
- Studying the swing of a pendulum
- Measuring the speed of a rolling object
- Timing the period of a rotating object
- Measuring the speed of objects undergoing collisions

Sensor Works

The sensor has an infrared LED emitter on one arm and a phototransistor on the other arm. An object blocks the infrared beam as it passes. Motion data can be determined in software from the timing of beam blocking.

The Vernier Photogate is a general sensor utilized for measuring speeds, accelerations, and periods of moving objects. It can also be used for freefall, projectile motion, and pendulum experiments. The Photogate works by projecting an infrared beam to a sensor. At the point when the beam is blocked, the sensor stops sending a signal, which illuminates an LED on the top of the gate as well as triggering the data collection software to display a blocked message in the data collection area. The sensor has a few unique methods of utilization that are important to understand. The following activity will help you become familiar with the usage of the Vernier Photogate in Pendulum Timing mode. The Pendulum Timing mode utilizes a signal Photogate. The timing will begin when the Photogate is first blocked. The timing will continue until the Photogate is blocked twice more.

A photogate consists of a light source (a photocell) that projects a limited infrared beam (invisible to the eye) towards a photosensitive detector. The detector changes its resistance to electric current by huge amounts as the power of light occurrence on it is changed (as when the beam is interrupted by a flag passing through the photogate.) Such marked changes enable the detector to turn a timer on or off. [25]

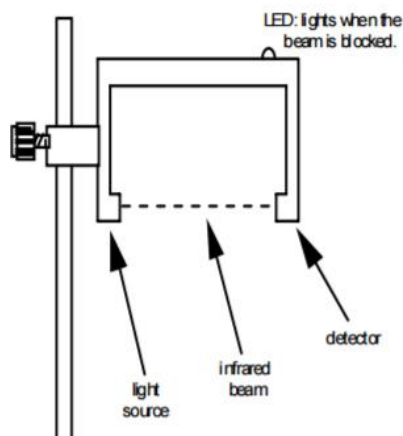


Figure 33. Photogate Sensor [25]

Since the light source and detector of the photogate have a limited width, the true length of a flag passing through the photogate beam may not be the same as its effective length "seen" by the photogate. In the event that the flag passes inside 1 cm of the detector and "cuts" the beam at right angles, then the uncertainty to which the detector senses the length of the flag is ± 1 mm. For the most part, this uncertainty can be safely disregarded, because it is a systematic uncertainty. There is also a 1% uncertainty in the time t measured.

This is a result of the limitations of the electronics in the timer. Always use at least $\pm 1\%$ for time measurements. (Remember, $\delta t \neq 0.01$, but rather $\delta t/t = 0.01$.) [25]

National Instruments' LabVIEW Interfacing System

LabVIEW is a software program made by National Instruments that is utilized with a hardware interfacing as an interfacing system between the computer and the environment. This system can be utilized for either data acquisition or data control. In this course, we will mainly be using LabVIEW for data acquisition.

myDAQ interface

The adapter includes two connectors for Vernier analog sensors and one connector for Vernier digital sensors. A screw terminal and header pins give access to myDAQ lines not utilized by the connectors. This includes the two analog output lines, three digital lines (including the digital lines with the frequency and pulse width modulation outputs), and a +5-volt power terminal. [26]



Vernier myDAQ Adapter connected to NI myDAQ interface [26]

The Vernier myDAQ Adapter board includes an optional external power port. NI myDAQ is a low-cost data acquisition (DAQ) device that gives students the ability to measure and analyze.



Figure 34.NI myDAQ Features [27]

Result

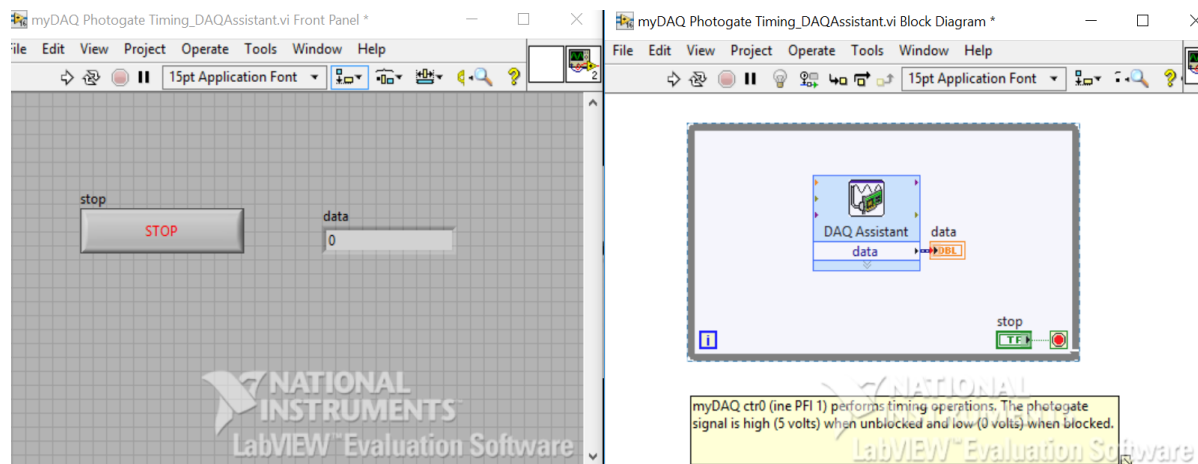


Figure 35.LabVIEW Photogate Front Panel and Block diagram

The programs used for this data acquisition are called Virtual Instruments (VIs) and are written in a high-level programming language supplied by LabVIEW.



Figure 36. myDAQ connects the PC to Photogate sensor

For each of the VIs used, there is sufficient documentation given on the front panel of every VI to enable you to make the proper connections and run the VI. Furthermore, given the uncertainties of the data acquired by each VI in the apparatus section of the lab. In this analysis, we utilized photo gate and its timer to evaluate the time directly.

10.3 Speed Control of Three Phase AC Induction Motor

A three-phase induction motor is fundamentally a constant speed motor so it's to somewhat difficult to control its speed. The speed control of induction motor is done at the cost of decrease in efficiency and low electrical power factor. Before talking about the techniques to control the speed of three phase induction motor one should know the basic formulas of speed and torque of three phase induction motors as the methods of speed control depends upon these formulas.

Synchronous Speed

$$N_s = \frac{120-f}{p} \text{ (RPM)} \quad 10.1$$

Where, f = frequency and P is the number of poles

The speed of induction motor is given by,

$$N = N_s(1-s) \quad 10.2$$

Where, N is the speed of the rotor of an induction motor,

N_s is the synchronous speed,

S is the slip.

Different speed control methods of induction motor are explained below.

- By Changing the Applied Voltage
- By Changing the Applied Frequency
- Constant V/F Control of Induction Motor
- Changing the Number of Stator Poles etc.

In this, procedure we are using V/F control or frequency control method. This is the most well-known method for controlling the speed of an induction motor. As in above method, if the supply frequency is reduced keeping the rated supply voltage, the air gap flux will tend to saturate. In this way, the stator voltage should also be reduced in proportional to the frequency so as to maintain the air-gap flux constant. The magnitude of the stator flux is relative to the proportion of the stator voltage and the frequency. Thus, if the proportion of voltage to frequency is kept constant, the flux remains constant. Additionally, by keeping V/F constant, the developed torque remains approximately constant. This method gives a higher run-time efficiency.

Along these lines, majority of AC speed drives utilizes a consistent V/F method (or variable voltage, variable frequency method) for the speed control. Along with wide range of speed control, this method also 'soft start' capability. [28]

10.3.1 Variable Frequency Drives

The Variable Frequency Drive is a specific kind of adjustable-speed drive that is utilized to control the speed of an AC motor. In order to control the motor's rotational speed, a Variable Frequency Drive controls the frequency of the electrical power provided to it. Adding a Variable Frequency Drive to an application permits the motor speed to be balanced as per the motor's load, ultimately energy. Speed Control Output Frequency Limit Unit: 0.01 Settings 0.00 to 100.00 Hz.

In this process, we are using VFD-007CP43A-21 - Variable Frequency Drives and communicating with the PLC.

PLC – VFD Communication:

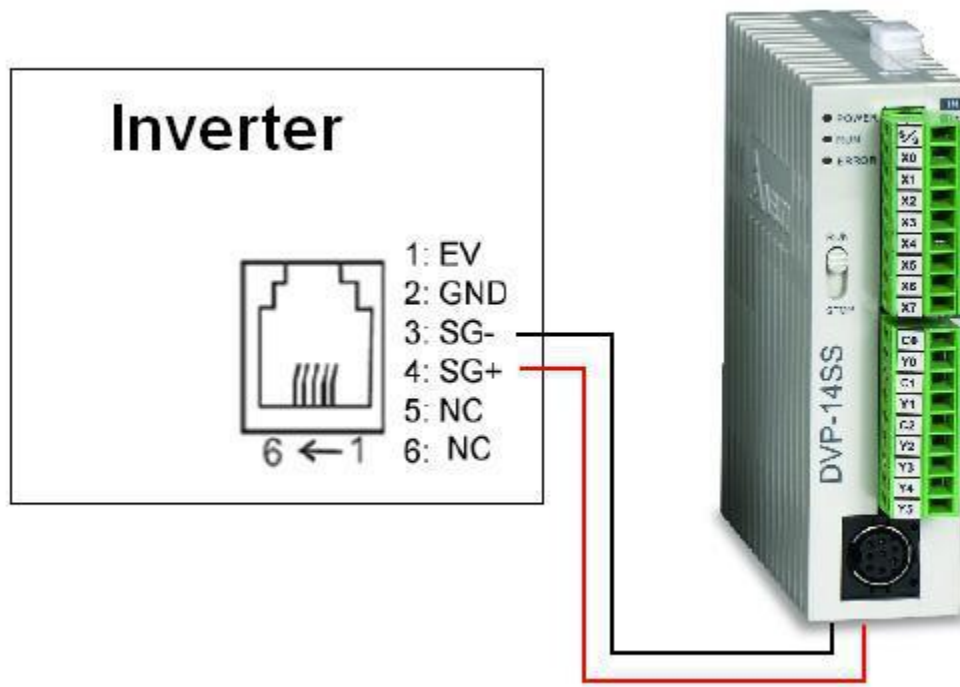


Figure 37 Hardware PLC – VFD Communication [30]

Connection: Connect RJ-45 of AC motor drive to the computer by using RS485. This is the wiring diagram of Modbus PLC. And PLC has part of RS485 and another one inverter port internally in Drive. And, the program of speed control and configuring PLC with communication parameters are shown in Appendix.

10.3.2 Precautions for Using PLC Functions

The built-in PLC function in CP2000 allows following commands: WPL Soft, basic commands and application commands; the operation methods are the same as Delta DVPPLC series.

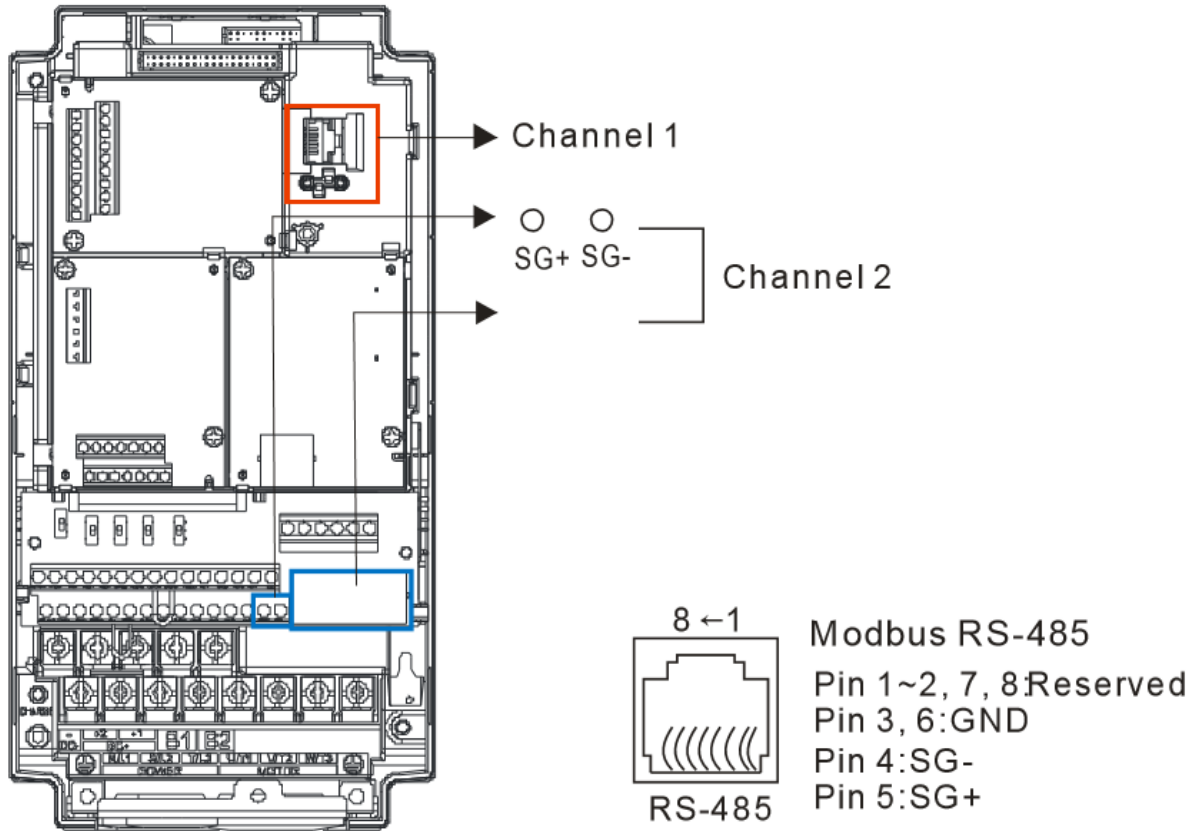


Figure 38 Communication protocols[33]

Host controller can read/write data from/to both the AC motor drive and the inside PLC program by setting the drive and internal PLC program to two different station numbers. For example, if a user wants to set an AC motor drive as station 1 and PLC as station 2, please write following setting of the host controller:

When setting 01 (Station) 03 (Read) 0400 (Address) 0001 (1 data), the host controller can read the Pr.04-00 from the AC motor drive. When setting 02 (Station) 03 (Read) 0400 (Address) 0001 (1 data), host controller will read X0 data from the internal PLC program. The internal PLC program will stop operation when upload/download programs. [33]

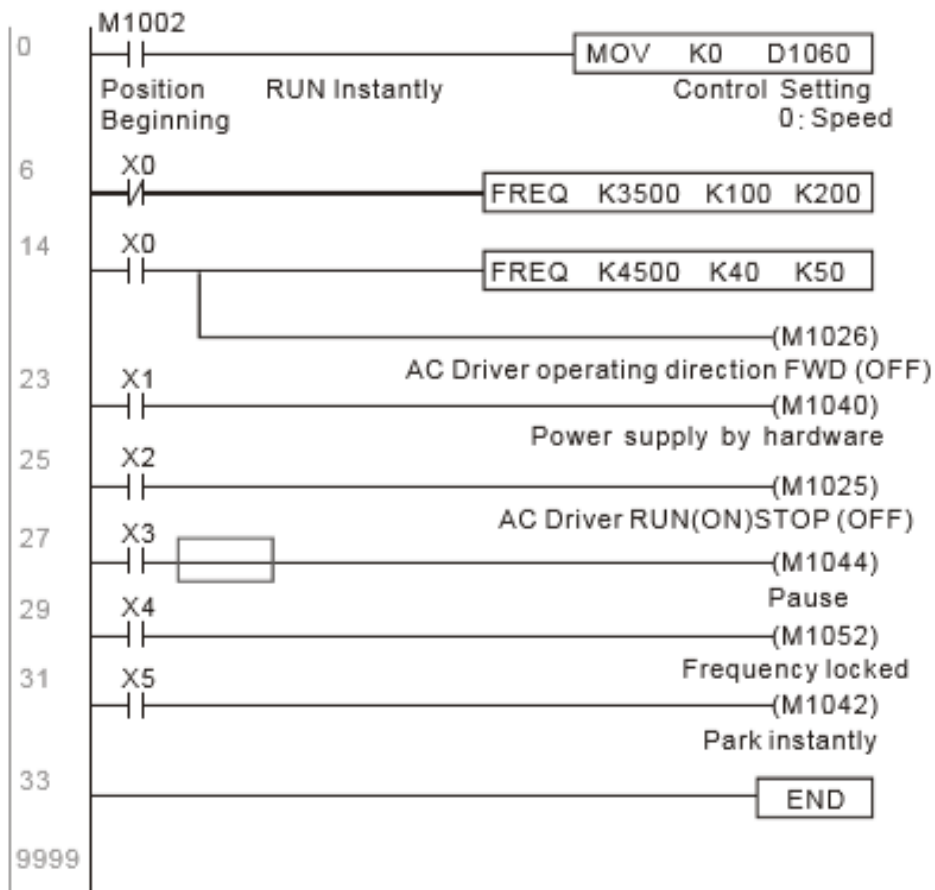
Speed Control Mode:

PLC Program



Figure 39 PLC Program

Example [33]



If the drive is in FOC control mode, please auto-tuning the motor before setting PLC control mode to speed control. [33]

1. When setting D1060 = 0, AC motor drive is in speed mode (default setting).
2. Write FREQ command to the PLC program to control AC motor drive's frequency and Accel. /decel. time.
3. When setting M1040 = 1, AC motor drive power turns ON but the frequency remains 0.
4. When setting M1025 = 1, AC motor drive begins to operate till the FREQ frequency is attained and will accel. /decel. According to the setting of FREQ.
5. Use M1052 to lock present operation frequency.
6. Use M1044 to halt the drive and decelerate by the decleration setting.
7. Use M1042 to quick stopping the drive. The drive will decelerate by its maximum deceleration speed and it is the speed that would not trigger a fault alarm.

However, if loading is too large, a fault alarm may still occur.

8. Priority of the control command is: M1040(Power ON) > M1042(Quick Stop) > M1044(Halt) > M1052(LOCK).

Connect LabVIEW to PLC with Modbus:

NI LabVIEW software can communicate with a programmable logic controller (PLC) in a variety of ways. Modbus is a serial communication protocol to communicate with the PLC, and was then extended to the TCP protocol.

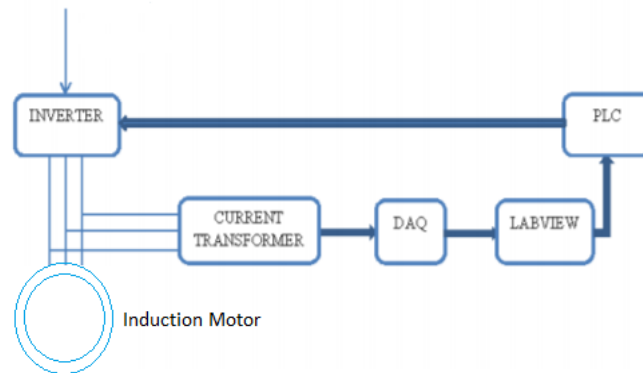


Figure 40 speed control of AC motor [31]

The control of AC motor utilizing LABVIEW. Lab view is one of the helpful software which is used or monitoring and controlling the systems in industries. The induction drive system fed with an inverter which is having different types of controllers, can be utilized to perform different activities like speed control, forward and reverse directions of the motor and along with that motor can be stopped. These things should be possible by utilizing the LABVIEW

programming. It is a human machine interface (HMI) plan programming which is easy to use and we can easily interface hardware.

In this section, you will create a LabVIEW interface to the Modbus addresses called an I/O Server. The I/O Server automatically updates LabVIEW with the current values.

Below shows the Creating a New I/O Server through the LabVIEW Project and Configuring Modbus Master I/O Server

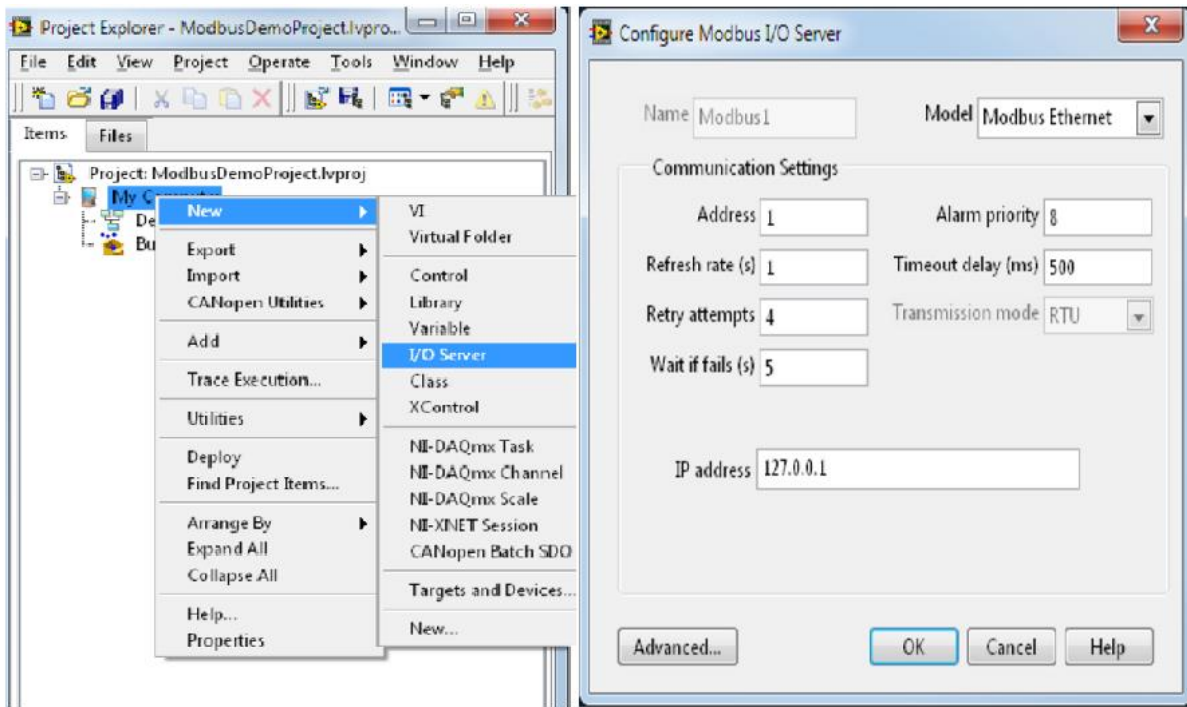


Figure 41 Configuring Modbus Master I/O Server

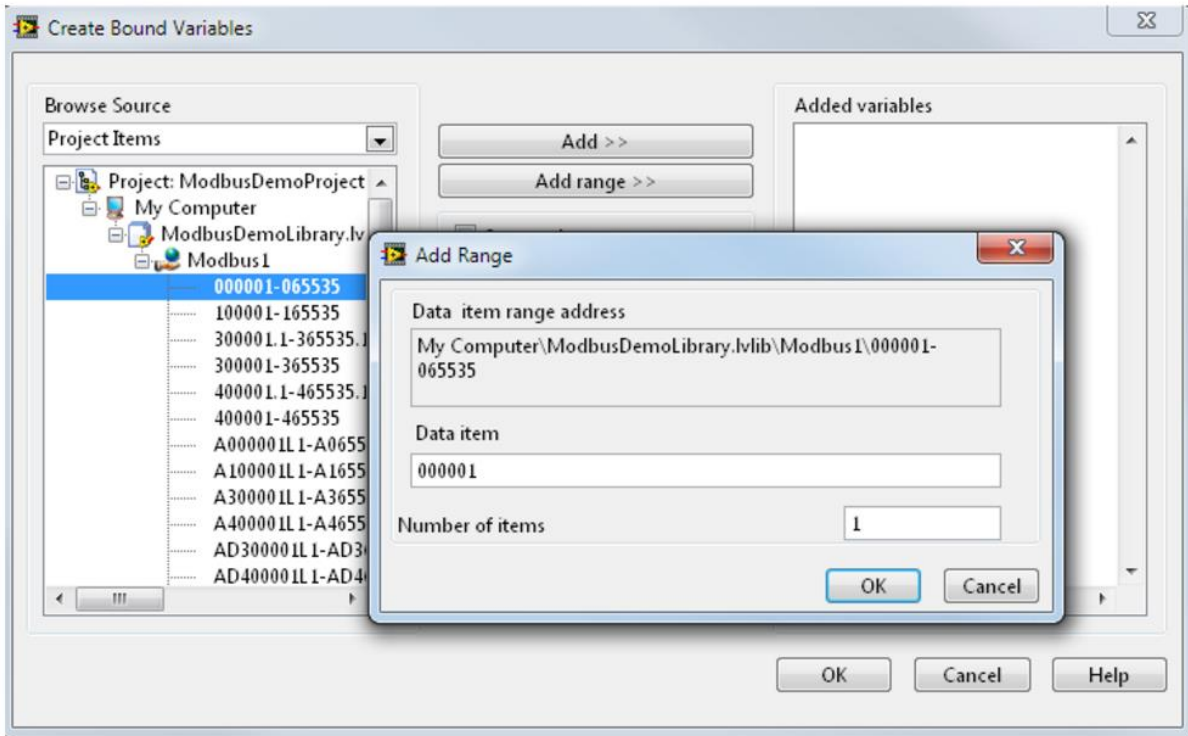


Figure 42 Select Modbus Addresses to Bind to Shared Variables

In this, create shared variables bound to the Modbus addresses, giving you native access in LabVIEW to PLC data. With the shared variable, you can share data across LabVIEW applications on a single computer or across the network.

Connect LabVIEW to PLC Using NI OPC Server

The NI OPC server is having fins they are Delta plc which permits communication between the LABVIEW and PLC. By utilizing the Delta VFD, we can set the server with various tags which are to be made and can be connected to the registers of the PLC. These tags can be called as OPC tags. By utilizing this server, we can monitor the status of the PLC. The Interfacing or communication between the two can be made easy when those OPC tags are created.

The LabVIEW Datalogging and Supervisory Control (DSC) Module is utilized. This module includes TOOLS for logging data to a networked recorded database, real-time and historical trending, managing alarms and events, networking LabVIEW Real-Time targets and OPC devices into one complete system, and adding security to UIs. With these features, LabVIEW becomes a powerful HMI/SCADA package for industrial control applications. [32]

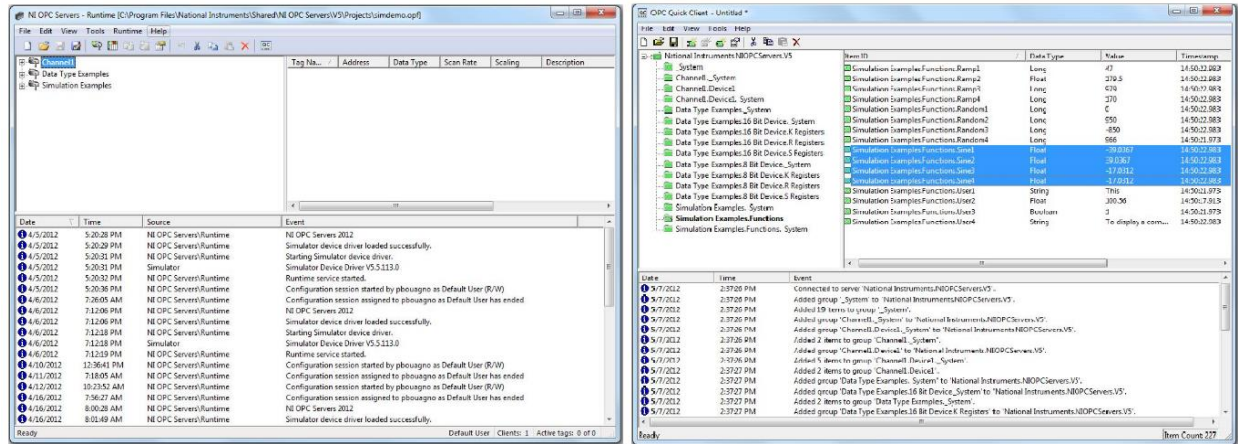


Figure 43 NI OPC Servers 2012 Displaying Simulated PLCs

In this, the steps in this section are written for NI OPC Servers 2012, but similar steps can be used in previous versions of NI OPC Servers. And, NI OPC Quick Client Displaying Simulated Sine OPC Tags are shown above. After that Connect LabVIEW to OPC Tags by Creating an I/O Server.

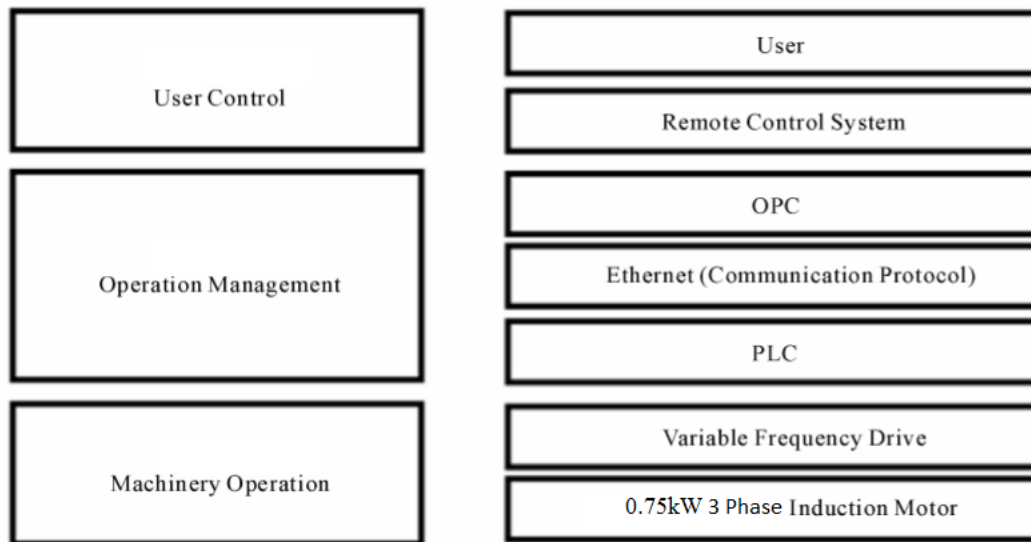


Figure 44 Network architecture

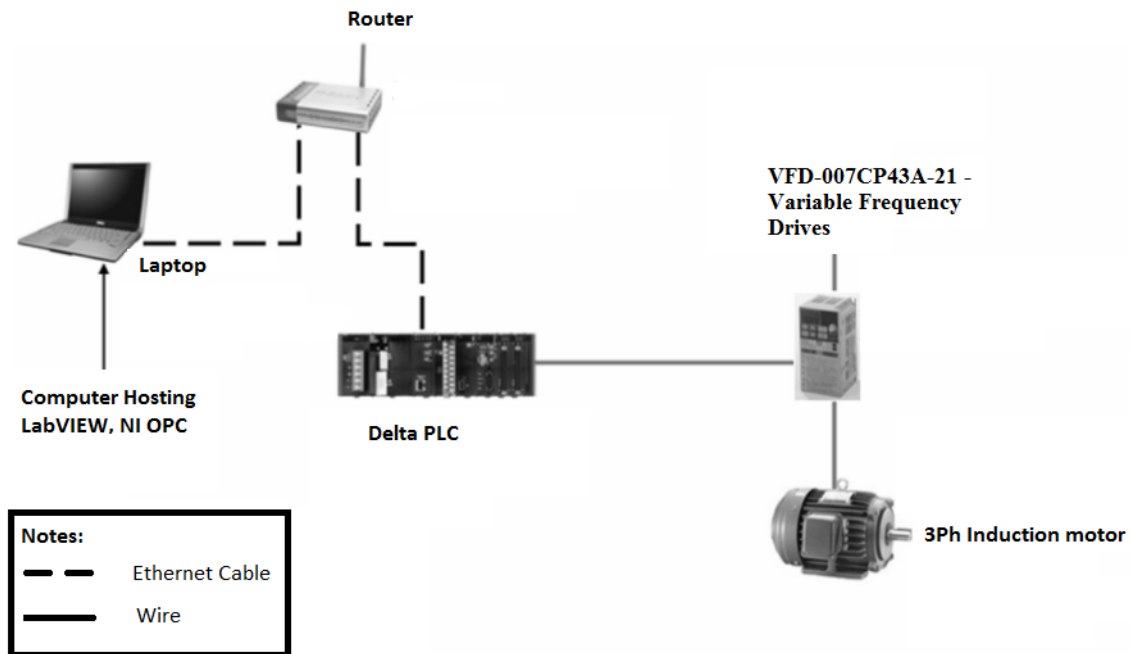


Figure 45 Actual network configuration

If the AC motor drive is controlled by RS-485 serial communication, the communication address for this drive must be set via this parameter. And the communication address for each AC motor drive must be different and unique.

In order to achieve the objectives, the establishment of the communication between PLC and LabVIEW is crucial as LabVIEW is having another software instead of using the software implemented in the PLC itself. Thus, the implementation used LabVIEW to perform the start and stop operation of the motor, either in forward or reverse direction, and varying the speed by changing the frequency of the motor. However, this system is not a supervisory control and data acquisition (SCADA) since there is no practical data measurement acquire from the actual output of the motor.

Result

VI front panel of the project

The RPM signal is sent to a front panel meter and displayed in krpm. The RPM signal also goes to a shift register with ten elements. This provides an averaged RPM signal for the front panel. And, manually control the motor speed with the front panel and for frequency also given one knob labeled Set point. Also, available on the front panel is a graph of the signal as a function of time. Run this VI and take our motor for a spin.

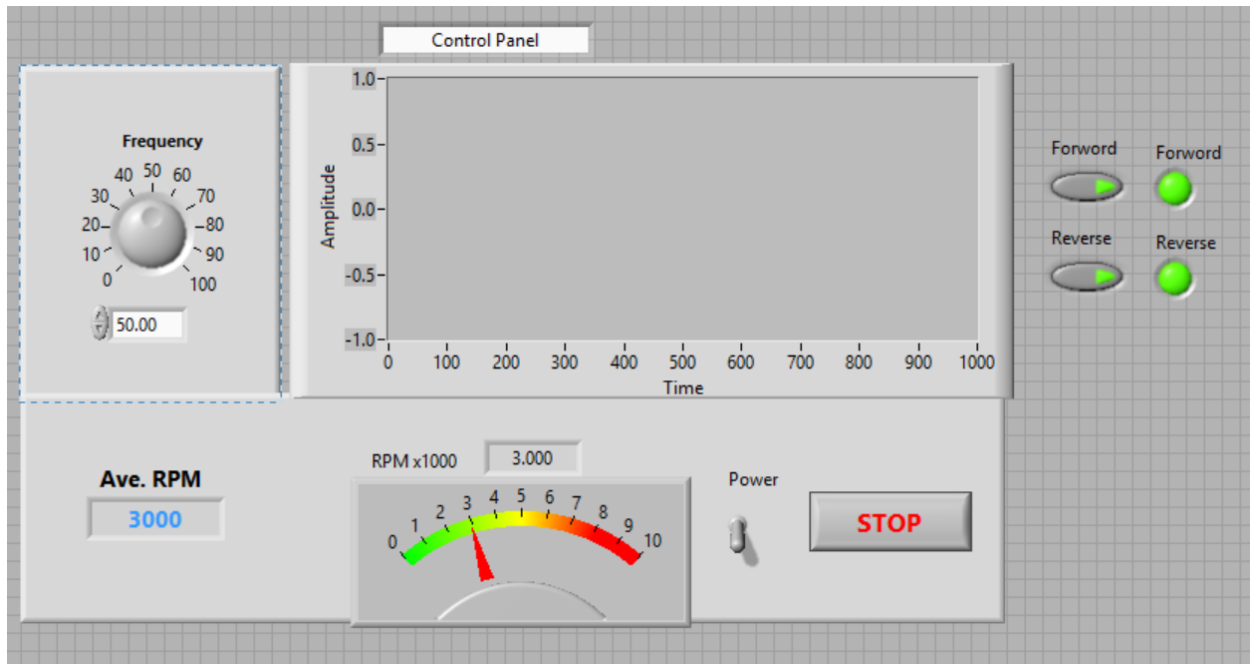


Figure 46 LabVIEW Motor Control Circuit Front Panel

The VI block diagram consists of two parts of the program. First part of the program is to allow user to switch on either Forward or Reverse direction of the squirrel cage induction motor. The second part of the program is to vary the frequency of the motor by changing the knob value.

Comparisons with the previous performances

Compare with existing machine modernize machine lot of changes and performance results are there. Mainly, in DM-28M model they are focus on the loading system and friction moment like by rotating the screw load force P transmitted through the centering balls and a torque bracket on clip with two medium-sized bearings. The load generated by the screw is determined by the magnitude of the elastic deflection. Torque bracket measured dial gauge to the calibration curve. These bearings are clamped to the hub while simultaneously loaded and the reaction force of both end bearings. Occurring in rolling torque is transmitted to the head body which is held against rotation at the bottom mounted weight (pendulum) and deflected by a certain angle depending on the torque. Count torque is carried out on a scale of, is graduated in Nm.

In the modernize machine, loading system and friction moment measuring purpose using sensors and controlling by the PC and mainly speed control. Previous machine they are not controlling the motor and they are not measuring the system. In this, all the devices are controlling by PC and utilizing by LabVIEW software.

In this research, finding the data analysis on loading system and friction moment system. We can recommend from this research design of test rig, measuring systems, research on torque bearing and controlling the test data measurement using a PC.

SUMMARY

The purpose of this thesis was to develop the Modernization of existing ball bearings' friction measuring device and the objectives of the thesis were;

- Design of device transmission and Loading system.
- Design of device friction moment measuring system.
- Redesign of a drive control system.
- Design of an overall concept of device control and test data measurement using a PC.

Firstly, this paper exposes the results of the study of conclusions that reflect the behavior of the torque on the rotational speed, the radial load and the amount of lubricating oil. Furthermore, the device to be designed depends on the existing old friction moment measuring device DM28M. And, Resistance to rotation of the rolling bearing dependent on the size and design of the bearing, the accuracy and quality of manufacturing of working surfaces, load, rotational speed, amount and lubricating properties of the oil lubrication method, the temperature of the bearing assembly. This system reliant on the load torque, speed, and level of the lubricating oil. With increasing load, the friction forces on the contact areas of the rolling elements increase, respectively, and increased torque. The current commercially available examples have been reviewed and their working principles were investigated.

Secondly, finding the calculations part like Bearing Type Coefficient of friction, Measuring friction torque, Radial loads, Inner bearing diameter, Loads, speed and friction angle values etc. And, work was divided subsystems in order to set specifications and make it easier to study. These subsystems were defined as;

Measuring system

Control system includes the machine elements like an AC motor, and VFD as controller. The VFD-007CP43A-21 VFD Variable Frequency Drive joins power and execution into one complete, cost-effective package. This drive controls a 0.7kW (1HP) AC Motor and is equipped with a 3-step V/F curve response which conforms input voltage to achieve maximum efficiency in variable torque applications such as pumps, air blowers and HVAC drives.

Loading system

In this loading system, there was normal force applying into the screw then applying force will be measuring in the load cell. A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured. This load cell connecting to the NI Compact DAQ and NI 9237 Bridge Module and its connecting to the cDAQ-9174. These processes are useful to measuring the loading system and the device is ready to run with the included LabVIEW Signal Express software for simple data-logging applications. In addition, with NI-DAQmx driver software, you can develop a complete test system in LabVIEW, C/C++, Visual Basic.NET, and other programming environments.

Photogate sensor

The Vernier Photogate is a general sensor utilized for measuring speeds, accelerations, and periods of moving objects. It can also be used for freefall, projectile motion, and pendulum experiments. The Photogate works by projecting an infrared beam to a sensor. The sensor has an infrared LED emitter on one arm and a phototransistor on the other arm. An object blocks the infrared beam as it passes. Motion data can be determined in software from the timing of beam blocking. In this analysis, we utilized photo gate and its timer to evaluate the time directly.

Test data measurement using a PC

In this, procedure we are using V/F control or frequency control method. This is the most well-known method for controlling the speed of an induction motor. As in above method, if the supply frequency is reduced keeping the rated supply voltage, the air gap flux will tend to saturate. The Variable Frequency Drive is a specific kind of adjustable-speed drive that is utilized to control the speed of an AC motor. Connect RJ-45 of AC motor drive to the computer by using RS485. This is the wiring diagram of Modbus PLC. And PLC has part of RS485 and another one inverter port internally in Drive. NI LabVIEW software can communicate with a programmable logic controller (PLC) in a variety of ways. Modbus is a serial communication protocol to communicate with the PLC, and was then extended to the TCP protocol. The control of AC motor utilizing LABVIEW. Lab view is one of the helpful software which is used or monitoring and controlling the systems in industries.

Considering the whole process, work has been completed in conceptual level. Components for motion control have been chosen and their connections and motion control method have been established. Mechanical system for loading and friction measurement has been designed. For the future work, these subsystems can be studied in detailed level.

KOKKUVÕTE

Lõputöö väljund on veerelaagri mõõteseadme kaasajastamine, eesmärgid on järgmised:

- Disainida ülekanne ja koormussüsteem
- Disainida seadme hõõrdemomendi mõõtesüsteem
- Ajami juhtsüsteemi muutmine
- Üldise põhimõtte, juhtimissüsteemi ja mõõtmise ümberehitus arvuti baasil

Esmalt uurib lõputöö olemasolevaid lahendusi ja tulemusi, mis mõjutavad väändemomenti ja nurkkiirust, radiaalkoormust ja määrdeaine kogust. Edasises lähenemises võtame arvesse vana hõõrdemomendi seadmelt DM28M, veerelaagri hõõrdetakistust liikumisel võttes arvesse selle suurust, pinnatöötlust, koormust, nurkkiirust, määrdevahendit, töötlustäpsust ja kvaliteeti. Koormuse suurendamisel hõõrdejõud kontaktpindade vahel suurenevad, samuti suureneb väändemoment. Uuritud on hetkel turult vabalt saadaolevad seadmeid ja nende töö põhimõtteid.

Teiseks leiame arvutuslikult laagrite hõõrdetakistuskoeffitsendi mõõtes hõõrdest tulenevat väändemomenti, radiaalset koormust, laagri sisediameetrit, koormuseid, kiiruseid, koormuse nurkväärtuseid jm. Lõputöö on jagatud eraldi etappideks, et eristada erinevaid komponente nende lihtsamaks analüüsimiseks. Need alamsüsteemid on;

Mõõtesüsteem

Juhtimissüsteem sisaldab masina elemente nagu vahelduvvoolu motor, sagedusmuundur mootori juhtimiseks. Delta sagedusmuundur VFD-007CP43A-21 on soodne variant antud rakenduses. Sagedusmuundur juhib 0.7kW vahelduvvoolu mootorit. Mootoril on kolme sammuga pinge/sagedus reageerimine, mis sobib efektiivsusega muutuva väändemomendiga lahendustesse nagu pumbad ja kütte ja ventilatsioonilahendused.

Koormussüsteem

Koormussüsteemis on jõud rakendatud kruvisüsteemile ja seda mõõdab koormuselement. Koormuselement on andur mille signaal teisendatakse elektriliseks signaaliks, et mõõta rakendatavat jõudu, mis on proportsionaalne jõuga rakendatavale objektile. Koormuselement on ühendatud NI Compact DAQ moodulisse, mis on omakorda NI9237 analoogmoodulisse. NI9237 ühendatakse läbi cDAQ-9174 seadme arvutiga. Sellega saame LabVIEW Signal Express tarkvara lisamooduliga logida andmeid. NI-DAQmx draiveriga on võimalik ehitada logimissüsteem LabView, C/C++, VisualBasic.NET või mõned muus programmeerimiskeskkonnas.

Fotoandur

Vernier fotoandur on üldist tüüpi andur mida kasutada antud rakenduses, et mõõta kiiruseid ja kiirendus liikuvatel objektidel. Andur töötab nähtava valguskiire edastamisel vastuvõtjale – vastuvõtja registreerib kiire olemasolu. Anduril on infrapuna saatja ühel pool ja fotoandur teasel pool. Kiirust ja üldist kiiruse andmeid saadakse kui tarkvaraga mõõdetakse aega kuna on anduri signaal peal ja selle maasolekut. Teades mõõtesüsteemi ühe perioodi avade arvu – ehk ühe täispöörde avade arvu, saab arvutada liikumise kiiruse, samuti kiiruse muutust arvutades saab teada kiirenduse.

Testandmed arvuti baasil

Selles protseduuris kasutame pinget ja sageduse karakteristikut, et juhtida vahelduvvoolu mootorit. See on kõige enam levinud meetod vahelduvvoolu mootorite juhtimiseks. Nagu eelpool mainitud, sagedust on vähendatud, et hoida nominaalpinget. Vahelduvmootori inverter võimaldab muuta vahelduvvoolu mootori kiirust. Sagedusmuunduriga juhitakse mootori kiirust. Sagedusmuundur on ühendatud arvutiga RS-485 -ga läbi RJ-45 pistiku. LabVIEW abiga on võimalik monitoorida ja kontrollida tööstuslikke süsteeme. NI LabVIEW tarkvara suudab suhelda PLC-dega mitmel viisil. Samuti on võimalik saata Modbus pakette üle RS485.

Võttes arvesse kogu süsteemi keerukust on antud ülessanne täidetud konseptsiooni tasemel. Välja on valitud komponendid juhtimissüsteemile. Samuti on juhtimissüsteemi meetoodika välja arendatud. Disainitud on koormus ja hõõrdejõudude mõõtmiseks mehaaniline süsteem. Edasise töö eesmärgiks on uuritud detailselt kõigi alamsüsteemide tööd.

REFERENCE

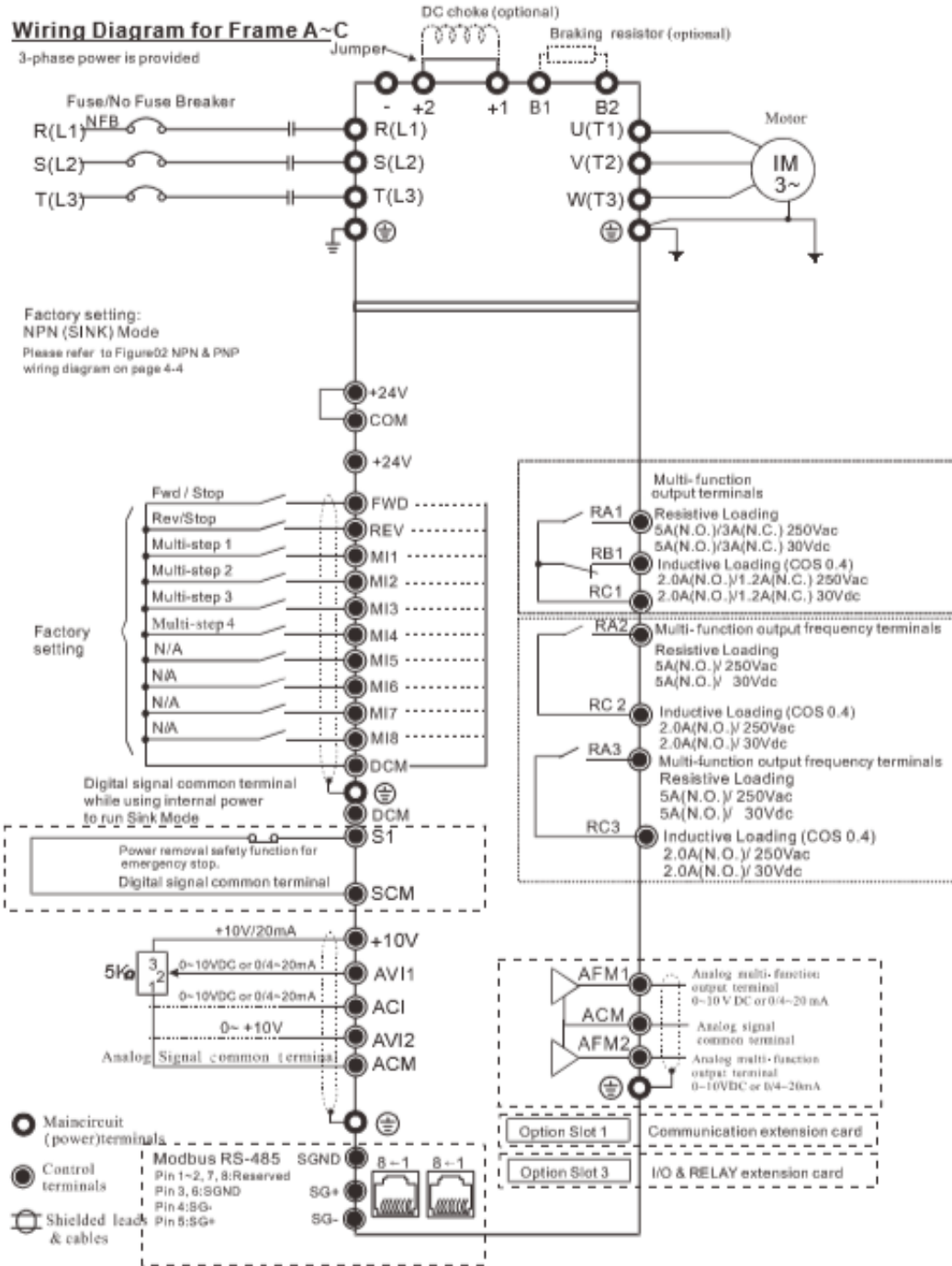
- [1] Хабаровск and И. ХГТУ, “Исследование трения в подшипниках качения,” 2002.
- [2] “Wikipedia.” [Online]. Available: https://en.wikipedia.org/wiki/AC_motor [Accessed: 26- Mar2016]
- [3] “Ball Bearing test rig.” [Online]. Available: <http://swargworld.com/our-product/theory-of-machines-lab/ball-bearing-test-rig-2/> [Accessed: 26-Mar2016]
- [4] “Ball Bearing test rig.” [Online]. Available: http://bspyromatic.com/dynamics_ball_04058.html [Accessed: 26-Apr2016]
- [5] “Friction Test Rig.” [Online]. Available: <http://www.eeepune.org/tribology-laboratory.html> [Accessed: 26-Apr2016]
- [6] А. П. Н. Т. В. П. К. М. указания к лабораторной Работе, “Опд.ф .02.04 детали машин,” pp. 1–13.
- [7] “The coefficients.” [Online]. Available: <http://sprav-constr.ru/html/tom2/pages/chapter2/ckm215.html> [Accessed: 26-Sept2016]
- [8] “DC Motor.” [Online]. Available: https://en.wikipedia.org/wiki/DC_motor [Accessed: 26-Sept2016]
- [9] “Servo Motor.” [Online]. Available: <http://www.kollmorgen.com/en-us/products/motors/servo/servo-motors/> [Accessed: 26-Sept2016]
- [10] “Stepper Motor.” [Online]. Available: <https://learn.adafruit.com/all-about-stepper-motors/what-is-a-stepper-motor> [Accessed: 26-Sept2016]
- [11] “Wikipedia.” [Online]. Available: https://en.wikipedia.org/wiki/AC_motor [Accessed: 26-Oct2016]
- [12] B. A. Q. Series and F. Sizes, “High Efficiency Induction Motors.”
- [13] I. Acs, “ABB machinery drives Catalog.”
- [14] “Drives and controls , motors and mechanical power transmission catalogue.”
- [15] A. Hunt, R. Jenkins, G. Thompson, M. Baker, and M. Hopkins, “Guide to the Measurement of Force Guide to the Measurement of Force,” 2013.
- [16] “Load Cell Application and Test Guideline,” no. 866, 2010.
- [17] V. V Output, “APPLIED MEASUREMENTS LTD . CDFM3 Miniature Button Load Cell Key Features : • Robust Construction Options : Applications : APPLIED MEASUREMENTS LTD . Transducer Specialists ... Specification : Wiring Diagram :,” vol. 44, no. July, pp. 7–9, 2016.
- [18] I. Manual, “INSTRUCTION MANUAL.”

- [19] O. C. Vpg-btd, “Vernier Photogate.”
- [20] M. Elements and M. Design, “Procedure con ’ t,” pp. 1–36, 2003.
- [21] “Wikipedia.” [Online]. <https://en.wikipedia.org/wiki/Coupling> Available: [Accessed: 26-Oct2016]
- [22] “Bearing box oil lubrication.” [Online]. Available: <http://www.reliableplant.com/Read/22602/api-centrifugal-pump-bearings> [Accessed: 26-Oct2016]
- [23] “Wikipedia.” [Online]. Available: <http://www.ni.com/tutorial/7138/en/#toc1> [Accessed: 26-Oct2016]
- [24] C. Tables and M. Analog, “NI CompactDAQ USB Data Acquisition Systems,” no. 866, pp. 1–10, 2015.
- [25] F. C. Results, A. Values, and I. Symbols, “Table of Contents,” pp. 1–104.
- [26] “Wikipedia.” [Online]. Available: <https://www.vernier.com/products/interfaces/bt-mdaq/> [Accessed: 26-Oct2016]
- [27] W. Ni, “Connect students to science and technology.”
- [28] “Different speed control methods of induction motor.” [Online]. Available: <http://www.electricaleasy.com/2014/02/speed-control-methods-of-induction-motor.html> [Accessed: 26-Oct2016]
- [29] “Variable Frequency Drives.” [Online]. Available: <http://www.anaheimautomation.com/products/ac/ac-drivers-controllers-item.php?sID=436&serID=19&pt=i&tID=1105&cID=385> [Accessed: 26-Oct2016]
- [30] “PLC – VFD Communication.” [Online]. Available: <https://www.vernier.com/products/interfaces/bt-mdaq/> [Accessed: 26-Oct2016]
- [31] N. Jyothsna, “Control of AC Motor using Labview,” vol. 3, no. 6, pp. 2016–2019, 2016.
- [32] “LabVIEW to PLC Using OPC.” [Online]. Available: <http://www.ni.com/tutorial/7450/en/> [Accessed: 26-Oct2016]

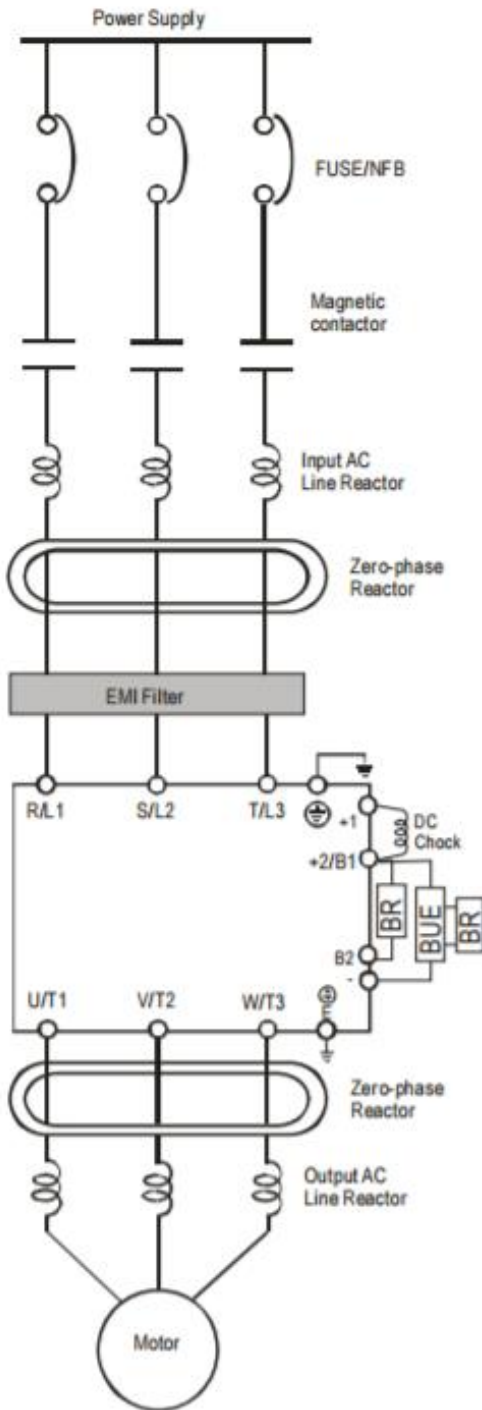
Appendix 1

Installation and Wiring VFD-Series

Wiring



External Wiring



Items	Explanations
Power supply	Please follow the specific power supply requirements shown in Appendix A.
Fuse/NFB (Optional)	There may be an inrush current during power up. Please check the chart of Appendix B and select the correct fuse with rated current. Use of an NFB is optional.
Magnetic contactor (Optional)	Please do not use a Magnetic contactor as the I/O switch of the AC motor drive, as it will reduce the operating life cycle of the AC drive.
Input AC Line Reactor (Optional)	Used to improve the input power factor, to reduce harmonics and provide protection from AC line disturbances (surges, switching spikes, short interruptions, etc.). AC line reactor should be installed when the power supply capacity is 500kVA or more or advanced capacity is activated. The wiring distance should be $\leq 10m$. Refer to appendix B for details.
Zero-phase Reactor (Ferrite Core Common Choke) (Optional)	Zero phase reactors are used to reduce radio noise especially when audio equipment is installed near the inverter. Effective for noise reduction on both the input and output sides. Attenuation quality is good for a wide range from AM band to 10MHz. Appendix B specifies the zero phase reactor. (RF220X00A)
EMI filter (Optional)	To reduce electromagnetic interference, please refer to Appendix B for more details.
Brake Resistor (Optional)	Used to reduce the deceleration time of the motor. Please refer to the chart in Appendix B for specific Brake Resistors.
Output AC Line Reactor (Optional)	Motor surge voltage amplitude depends on motor cable length. For applications with long motor cable ($>20m$), it is necessary to install a

Digital Keypad

KPC-CE01 digital keypad



- A**: LED Display
Display frequency, current, voltage and error etc.
- B**: Status Indicator
F: Frequency Command
H: Output Frequency
U: User Defined Units
ERR: CAN Error Indicator
RUN: CAN Run Indicator
- C**: Function
(Refer to the chart follows for detail description)

Key	Description
ESC	ESC Key When ESC key is pressed, it will return to the previous menu. It is also functioned as a return key in the sub-menu.
MENU	Menu Key It can return to the main menu after pressing MENU key. Menu content: 1. Parameter Detail 2. Copy Parameter 3. Keypad locked 4. PLC Function
ENTER	ENTER Key Press ENTER and go to the next level. If it is the last level then press ENTER to execute the command.
HAND	HAND ON Key 1. This key is executed by the parameter settings of the source of Hand frequency and hand operation. The factory settings of both source of Hand frequency and hand operation are the digital keypad. 2. If pressed at stop status, it will switch to Hand setting of frequency source and operation source. If HAND ON key is pressed during operation, it will stop the AC motor drive first then switch to Hand setting. 3. Hand mode display: H/A LED is ON.
AUTO	Auto Operation Key 1. This key is executed by the parameter settings of the source of AUTO frequency and AUTO operation. The factory setting is the external terminal (source of operation is 4-20mA). 2. If auto is pressed in steady status, it will switch to the auto-setting. However if auto key is pressed during operation, it will stop AC motor drive first then switch to auto-setting. 3. Switch is complete: H/A LED is OFF
FWD/REV	Operation Direction Key 1. This key is only control the operation direction NOT for activate the drive. FWD: forward, REV: reverse. 2. Refer to the LED descriptions for more details.
RUN	Start Key 1. It is only valid when the source of operation command is from the keypad. 2. It can operate the AC motor drive by the function setting and the RUN LED will be ON. 3. It can be pressed again and again during stop. When enabling "HAND" mode, it is only valid when the source of operation command is from the keypad.
STOP	Stop Key. (When Stop key is pressed, all operation will stop in all condition.) This key has the highest priority in all condition. 1. When a STOP command is given, the AC motor drive's operation will stop under any condition. 2. The RESET key can be used to reset the drive when faults occur. If the RESET key is not responding, check MENU → Fault Records search for the most recent fault.

Description of Parameter Settings

00 Drive Parameters

✎ The parameter can be set during operation.

00 - 00 ID Code of the AC Motor Drive

Factory Setting: ##

Settings Read Only

00 - 01 Display AC Motor Drive Rated Current

Factory Setting: ##

Settings Read Only

🔊 Pr. 00-00 displays the identity code of the AC motor drive. Using the following table to check if Pr.00-01 setting is the rated current of the AC motor drive. Pr.00-01 corresponds to the ID code in Pr.00-00.

🔊 The factory setting is the rated current for light duty. Set Pr.00-16 to 1 to display the rated current for normal duty.

230V series											
Frame	A					B			C		
kW	0.75	1.5	2.2	3.7	5.5	7.5	11	15	18.5	22	30
HP	1.0	2.0	3.0	5.0	7.5	10	15	20	25	30	40
ID Code of the AC Motor Drive	4	6	8	10	12	14	16	18	20	22	24
Rated Current of Light Duty (A)	5	7.5	10	15	21	31	46	61	75	90	105
Rated Current of Normal Duty (A)	3	5	8	11	17	25	33	49	65	75	90

Frame	D		E		
kW	37	45	55	75	90
HP	50	60	75	100	125
ID Code of the AC Motor Drive	26	28	30	32	34
Rated Current of Light Duty (A)	146	180	215	276	322
Rated Current of Normal Duty (A)	120	146	180	215	255

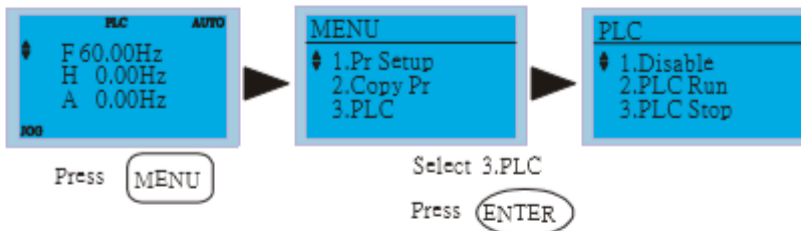
460V series													
Frame	A						B				C		
kW	0.75	1.5	2.2	3.7	4.0	5.5	7.5	11	15	18.5	22	30	37
HP	1	2	3	5	5.5	7.5	10	15	20	25	30	40	50
ID Code of the AC Motor Drive	5	7	9	11	93	13	15	17	19	21	23	25	27
Rated Current of Light Duty (A)	3	3.7	5	7.5	10.5	12	14	22.5	30	36	45	56	72
Rated Current of Normal Duty (A)	1.7	3.0	4.0	6.0	9.0-	10.5	12	18	24	32	38	45	60

Frame	D				E		F		G		H	
kW	45	55	75	90	110	132	160	185	220	280	315	355
HP	60	75	100	125	150	175	215	250	300	375	425	475
ID Code of the AC Motor Drive	29	31	33	35	37	39	41	43	45	47	49	51
Rated Current of Light Duty (A)	91	110	144	180	220	246	310	343	460	530	616	683
Rated Current of Normal Duty (A)	73	91	110	150	180	220	260	310	370	460	550	616

The Steps for PLC Execution

Please operate PLC functions by following the steps indicate below:

1. Press menu key on KPC-CC01 → select **3: PLC** → ENTER.



NOTE

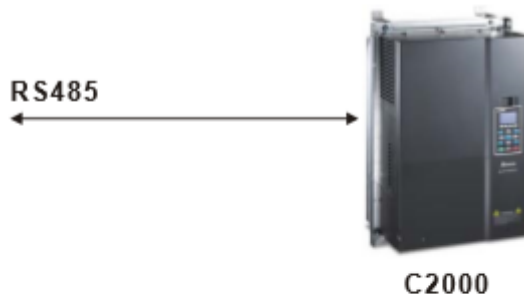
When using KPC-CE01 series digital keypad, switch the mode to PLC2 for program download/upload:

- A. Press MODE key and select 'PLC'.
- B. Press 'UP' key and look for 'PLC2' then press 'ENTER'.
- C. If succeed, display 'END' for one to two seconds and return to 'PLC2' page.

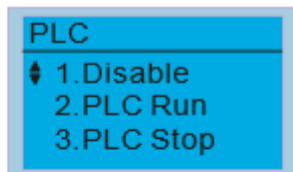
The PLC warning that is displayed before program downloaded to C2000 can be ignored, please continue the operation.



2. Connection: Connect RJ-45 of AC motor drive to the computer by using RS485.



3. Run the program.



- PLC function, select function 2 (PLC Run).

- 1: Disable (PLC0)
- 2: PLC Run (PLC1)
- 3: PLC Stop (PLC2)

Optional accessories: Digital keypad KPC-CE01, display PLC function as shown in the ().

When external input terminals (MI1~MI8) are set to PLC Mode select bit0 (51) or PLC Mode select bit1 (52), it will force to switch to PLC mode regardless the terminal is ON or OFF.

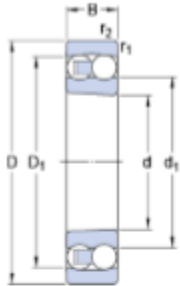
Meanwhile, switching via keypad is disabled. Please refer to the chart below:

Self-aligning ball bearings - 1208 EKTN9

1208 EKTN9

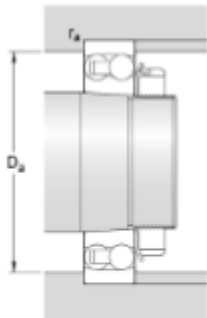
Dimensions

Tapered bore, taper 1:12



d	40	mm
D	80	mm
B	18	mm
d ₁	≈ 53.8	mm
D ₁	≈ 67.5	mm
r _{1,2}	min. 1.1	mm

Abutment dimensions



D _a	max. 73	mm
r _a	max. 1.1	mm

Calculation data

Basic dynamic load rating	C	19.9	kN
Basic static load rating	C ₀	6.9	kN
Fatigue load limit	P _u	0.36	kN
Reference speed		18000	r/min
Limiting speed		11000	r/min
Permissible angular misalignment	α	2.5	°
Calculation factor	k _r	0.04	
Calculation factor	e	0.22	
Calculation factor	Y ₀	2.8	
Calculation factor	Y ₁	2.9	
Calculation factor	Y ₂	4.5	






Mass

Mass bearing	0.42	kg
--------------	------	----

Loadcell specification:

Rated Capacity (RC)	N	100, 250, 500, 1000, 2000, 5000, 10k, 20k
Sensitivity (RO)	mV/V	2 nominal (1.5 nominal on 100N)
Zero Balance/Offset	±%/Rated Output	<1.0
Non-Linearity	±%/Rated Output	<0.5
Hysteresis	%/Rated Output	<0.25
Repeatability	%/Rated Output	<0.2 typical
Temperature Effect on Zero	±%/Rated Output/ °C	<0.030
Temperature Effect on Sensitivity	±%/Applied Load/ °C	<0.005
Input Resistance	Ohms	375 typical
Output Resistance	Ohms	350 typical
Insulation Resistance	Megohms	>5000 @ 50Vdc
Excitation Voltage	Volts AC or DC	10 recommended (2-15 acceptable)
Operating Temperature Range	°C	-20 to +80
Compensated Temperature Range	°C	0 to +70
Storage Temperature Range	°C	-20 to +80
Safe Overload	% of Rated Capacity	125
Ultimate Overload	% of Rated Capacity	150
Deflection @ Rated Capacity		0.02 (20kN) to 0.07 (100N) typical (depending on capacity)
Fundamental Resonant Frequency*	kHz	4 (100N) to 50 (20kN) *
IP Rating (Environmental Protection)		IP65
Weight	grams	50 (excluding cable)
Fatigue Life		10 ⁸ cycles typical (10 ⁹ cycles on fatigue-rated version)
Cable Length (as standard)	metres	2
Cable Type		4-core screened, PVC sheath
Construction Material		Stainless Steel, Nickel-Plated Brass, NBR, PVC
Resolution		1 part in 250,000 (with appropriate instrumentation)
*The resonant frequency is calculated with the body of the load cell attached to a large plate, ensuring that only the sensing element oscillates: This is vital to achieve the highest natural frequency and subsequent frequency response.		

Wiring Diagram:

Wire	Designation
 Red	+ve excitation
 Blue	-ve excitation
 Green	+ve signal
 Yellow	-ve signal
 Screen	To ground - not connected to load cell body

Drive control parameters

After the Modbus communication has been set up, the drive control parameters listed in the table below should be checked and adjusted when necessary.

The **Setting for fieldbus control** column gives the value to use when the Modbus interface is the desired source or destination for that particular signal. The **Function/Information** column gives a description of the parameter.

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 (START/STOP) 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 (START/STOP) when EXT2 is selected as the active control location.		40031 bits 0...1
1003 DIRECTION	FORWARD REVERSE REQUEST	Enables rotation direction control as defined by parameters 1001 and 1002. The direction control is explained in section <i>Reference handling</i> on page 297.		40031 bit 2
1102 EXT1/EXT2 SEL	COMM	Enables EXT1/EXT2 selection through 0301 FB CMD WORD 1 bit 5 (with ABB drives profile 5319 EFB PAR 19 bit 11).	40001 bit 11	40031 bit 5
1103 REF1 SELECT	COMM COMM+A11 COMM*A11	Fieldbus reference REF1 is used when EXT1 is selected as the active control location. See section <i>Fieldbus references</i> on page 294 for information on the alternative settings.	40002 for REF1	
1106 REF2 SELECT	COMM COMM+A11 COMM*A11	Fieldbus reference REF2 is used when EXT2 is selected as the active control location. See section <i>Fieldbus references</i> on page 294 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 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 (with ABB drives profile 5319 EFB PAR 19 bit 3).	40001 bit 3	40031 bit 6

Parameter	Setting for fieldbus control	Function/Information	Modbus register address	
1604 <i>FAULT RESET SEL</i>	<i>COMM</i>	Enables fault reset through fieldbus <i>0301 FB CMD WORD 1</i> bit 4 (with ABB drives profile <i>5319 EFB PAR 19</i> bit 7).	40001 bit 7	40031 bit 4
1606 <i>LOCAL LOCK</i>	<i>COMM</i>	Local control mode lock signal through <i>0301 FB CMD WORD 1</i> bit 14	-	40031 bit 14
1607 <i>PARAM SAVE</i>	<i>DONE SAVE...</i>	Saves parameter value changes (including those made through fieldbus control) to permanent memory.	41607	
1608 <i>START ENABLE 1</i>	<i>COMM</i>	Inverted Start enable 1 (Start disable) through <i>0302 FB CMD WORD 2</i> bit 18	-	40032 bit 18
1609 <i>START ENABLE 2</i>	<i>COMM</i>	Inverted Start enable 2 (Start disable) through <i>0302 FB CMD WORD 2</i> bit 19	-	40032 bit 19
LIMITS			ABB DRV	DCU
2201 <i>ACC/DEC 1/2 SEL</i>	<i>COMM</i>	Acceleration/deceleration ramp pair selection through <i>0301 FB CMD WORD 1</i> bit 10	-	40031 bit 10
2209 <i>RAMP INPUT 0</i>	<i>COMM</i>	Ramp input to zero through <i>0301 FB CMD WORD 1</i> bit 13 (with ABB drives profile <i>5319 EFB PAR 19</i> bit 6)	40001 bit 6	40031 bit 13
COMMUNICATION FAULT FUNCTIONS			ABB DRV	DCU
3018 <i>COMM FAULT FUNC</i>	<i>NOT SEL FAULT CONST SP 7 LAST SPEED</i>	Determines drive action in case fieldbus communication is lost.	43018	
3019 <i>COMM FAULT TIME</i>	0.1...60.0 s	Defines the time between communication loss detection and the action selected with parameter <i>3018 COMM FAULT FUNC</i> .	43019	
PID CONTROLLER REFERENCE SIGNAL SOURCE SELECTION			ABB DRV	DCU
4010/ <i>SET POINT</i> 4110/ <i>SEL</i> 4210	<i>COMM COMM+A11 COMM*A11</i>	PID control reference (REF2)	40003 for REF2	