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College of Engineering

Department of Mechanical Engineering

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Senior Design Project Report

DYNAMOMETER

Design of Dynamometer for Engine Testing

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

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Abstract

Strict emission regulations for vehicles and advances in automotive technology, dictate the thorough testing of engines, fuels and emissions. In past work at PMU, a port fuel injection engine was assembled and tested on biofuel blends. However, the engine was operating on free load. To simulate the effect of load torque on the engine, in this project, we design a break dynamometer. The dynamometer consists of a flange to mount on the PMU engine, a break array, a strain gage, and protective covers. The students will have to perform extensive stresses calculations and FEA analysis prior to manufacturing.

Acknowledgments

We are group of five mechanical engineering students, we have divided the work based on strength and weaknesses of each member. One member is in charge of Solid Design program, while others were in charge of Ordering parts, taking measurements, calculations, and organization of the project report. In addition, the support of our project advisor can't be denied. The printed table of the portfolio will show the tasks each member.

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Chapter 1: Introduction

1.1 Project Definition

This project is intended to design and manufacture a simple rotor test rig, where rotor faults can be inserted and tested. The test rig is to be fitted with vibration sensors to enable collecting data and use it to monitor the health of machines. The project is very important to industry as through understanding the characteristics of failure, time and money will be saved. This is also very important from the safety prospective as this will lead to a safe operating environment for rotary machines.

This project is intended design a break dynamometer. The dynamometer consists of a flange to mount on the PMU engine, a break array, a strain gage, and protective covers. The students will have to perform extensive stresses calculations and FEA analysis prior to manufacturing.

1.2 Project Objectives

1. Design and build a dynamometer (shaft, breaks, safety cover, bearings and housing)
2. Develop the instrumentation of the dynamometer (force gage, rotational speed meter and optical temperature)
3. Test the dynamometer
4. Measure break engine power output

1.3 Project Specifications

The dynamometer can be used on any type of engine with only adjustments required for the type of engine it's going to be used on. The parts for dynamometer can be seen in table 1.1 below.

Parts
Shaft
Brakes
Bearings
Tachometer
Optical thermometer
Force gauge
Disk
Shaft
Bearings
trolley
Safety cover
Caliper holder

Table 0.1 Parts

The above mentioned parts can be seen in the figure 1.1 below.



Figure 1.1(parts getting assembled)

To measure brake power, the angular speed and torque has to be measured. Therefore, the rotor is driven by the engine under test by Hydraulic, mechanical or electromagnetic means.

1.4 Applications

The dynamometer can be used for many different applications. It can fit many criteria to help people in certain areas. The following are the applications for dynamometer:

- Test the IC engine
- Measuring torque of any rotary member, just by coupling with the shaft of dynamometer
- Can be used as a speed controller or load controller

Chapter 2: Literature Review

2.1 Project background

Rolling element bearings are core components of our revolutionary life and developments. They exist in almost all rotary machines, supporting their dynamic forces and facilitating their rotation. The failure of a rolling element bearing may have a catastrophic consequence on the machine if it went undetected and without follow-up. We attempt to monitor these vital components through observing their temperature, noise, vibrations, oil wear debris etc. Among all these monitored parameters, vibration signals have proven to be of great assistance for maintenance personnel, not only in detecting the presence of a fault but also in locating its source. Most recently, information from vibration signals has been used to provide analysts with an idea about the size of the fault and consequently enable prediction of the useful remaining life of the bearing (prognostics). However, vibrations picked up by accelerometers have to go through a number of rigorous processing steps to enable extraction of the fault symptoms and identification and quantification of fault size.

Mechanical force gauge

Mechanical force gauge is an instrument that used to measure both compression and tension force for both ways pulling or pushing. Depends of the vendor product, its considered as a highly accurate tool to measure the mentioned forces above also it measure Peak force by using the peak indicator needle and depends on the weight of the attached item.

1- Spring gauge :

It's a type of weighing scale which is a device to measure mass and this spring made of a fixe spring at on side with hook to attach an object at the other, this spring works by Hooke's Law ($F= KX$) where K represent constant factor characteristic of the spring and X represent the distance. On the other hand, spring force gauge can only measure weight and can't measure mass. Moreover, A spring gauge can only scan properly in a very frame of reference wherever the acceleration within the spring axis is constant, for example on

earth, wherever the acceleration is as a result of gravity).Also, spring gauge have different sizes, in general small size that measure newton will have a less fixed grip on the spring than the larger size that can be measure thousands and tens of newton's or even more than that and that depends on the scale that you use. In fact, the largest spring gauges measurement can be ranged from 5000 to 8000 newton.

2- Deformation gauge:

Knows also as strain gauge , it convert force weight , tension and pressure into in to electrical resistance that can be measure. When you applied external forces to a fixed object strain and stress are the result. A typical gauge arranges an extended, skinny conductive strip during a zigzag pattern of parallel lines. This doesn't increase the sensitivity, since the percentage modification in resistance for a given strain for the complete zigzag is that the same as for any single trace. However, one linear trace would need to be very thin and therefore at risk of over warming (which would each modification its resistance and cause it to expand), or would got to be operated at a far lower voltage, creating it tougher to measure resistance changes accurately.

Prony Brake Dynamometer:

Prony Brake , Figure 2.1,is one of the simplest dynamometers for measuring power output (brake power). It is to attempt to stop the engine using a brake on the flywheel and measure the weight which an arm attached to the brake will support, as it tries to rotate with the flywheel.

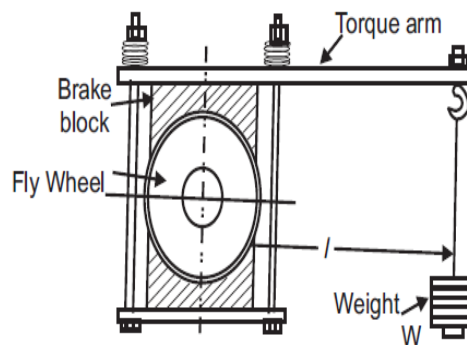


Figure 2.1 Prony Brake

The Prony brake shown in the above consists of a wooden block, frame, rope, brake shoes and flywheel. It works on the principle of converting power into heat by dry friction. Spring-loaded bolts are provided to increase the friction by tightening the wooden block. The whole of the power absorbed is converted into heat and hence this type of dynamometer must be cooled.

Rope Brake Dynamometer:

Rope brake dynamometer is used to measuring the power of the engine shaft. And it contains a shaft that will measure the power from rotating the shaft. Also, it has ropes which are one rope connecting to a spring balance and the other rope attached with the weight. So, this kind of dynamometer it basically works on principle of absorption of power. It has rope tights on brake drum and then the rope will stop the brake drum, when brake drum has stopped then the spring balance will show the reading. A rope break dynamometer can be seen in the figure 2.2 below.

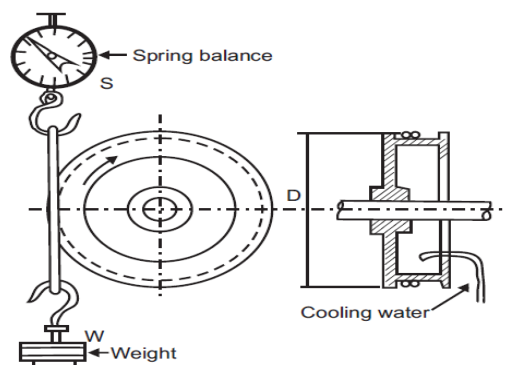


Figure 2.2 Rope Brake Dynamometer

The brake power is given by the formula

$$\text{Brake Power (bp)} = \pi DN (W - S)$$

Where D is the brake drum diameter, W is the weight of the load and S is the spring balance reading.

Eddy Current Dynamometer:

The working principle of **eddy current dynamometer** is shown in the figure 2.3 below. It consists of a stator on which are fitted some electromagnets and a rotor disc made of copper or steel and coupled to the output shaft of the engine. When the rotor rotates, eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets. These eddy currents are dissipated in producing heat so that this type of dynamometer requires some cooling arrangement. The torque is measured exactly as in other types of absorption dynamometers, i.e., with the help of a moment arm. The load in internal combustion engine testing is controlled by regulating the current in the electromagnets.

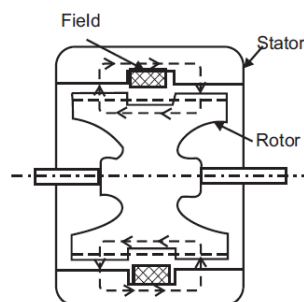


Figure 2.3 Eddy Current Dynamometer

The following are the main advantages of eddy current dynamometers:

- High brake power per unit weight of dynamometer.
- They offer the highest ratio of constant power speed range (up to 5 : 1).
- Level of field excitation is below 1% of total power being handled by the dynamometer. Thus, they are easy to control and operate.
- Development of eddy current is smooth hence the torque is also smooth and continuous under all conditions.
- Relatively higher torque under low-speed conditions.
- It has no intricate rotating parts except shaft bearing.
- No natural limit to size, either small or large.

Hydraulic Dynamometer:

Hydraulic dynamometer is the devices that used to measure power output. It specified to use with oil and water. A hydraulic dynamometer working about rotating disk that rotates during the operation and the rotating disk connecting with a shaft. Which is also the engine shaft will rotating and we want to measure the output power of the engine shaft. At that time the oil go inside the chamber to rotate casing. So, then we can measure the amount of torque.

A **hydraulic dynamometer** as shown in the figure 2.4 below works on the principle of dissipating the power in fluid friction rather than in dry friction.

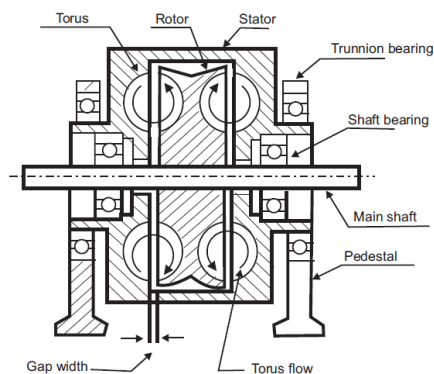


Figure 2.4 Hydraulic Dynamometer

- In principle, hydraulic dynamometer construction is similar to that of a fluid flywheel.
- Hydraulic dynamometer consists of an impeller or inner rotating member coupled to the output shaft of the engine.
- The impeller in this dynamometer rotates in a casing filled with a fluid.
- Due to the centrifugal force developed in the outer casing, tends to revolve with the impeller, but is resisted by a torque arm supporting the balance weight.
- The frictional forces generated between the impeller and the fluid are measured by the spring balance fitted on the casing.
- The heat developed due to the dissipation of power in Hydraulic dynamometer is carried away by a continuous supply of the working fluid.

- The output power can be controlled by regulating the sluice gates which can be moved in and out to partially or wholly obstruct the flow of water between the casing and the impeller.

Absorption Dynamometers:

Transmission dynamometers are also called torque meters. They mostly consist of a set of strain-gauges fixed on the rotating shaft and the torque is measured by the angular deformation of the shaft which is indicated as the strain the of the strain gauge. A four arm bridge is used to reduce the effect of temperature, and the gauges are arranged in pairs such that the effect of axial or transverse load on the strain gauges is avoided.

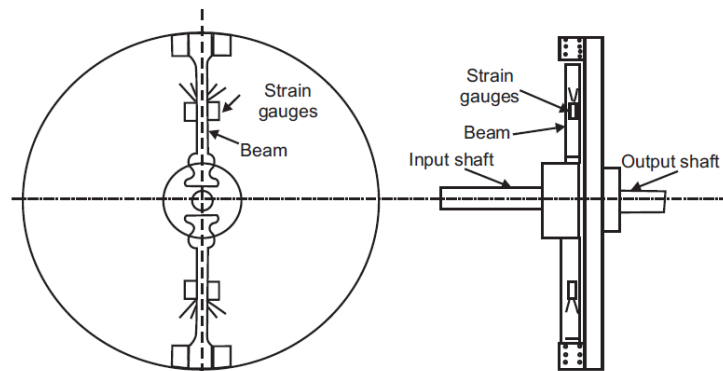


Figure 2.5 Transmission Dynamometer

Above figure shows the transmission dynamometer which employs beams and strain gauges for a sensing torque. Transmission dynamometers measure brake power very accurately and are used where continuous transmission of the load is necessary. These are mainly used in automatic units.

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

- **Geometrical Constraints**

Calculations has been done to design our project are bearing life, volume and mass of the shaft, radial load, and key dimensions.

- **Sustainability**

Based on design and material property standards, we expect a sustainable system.

- **Social and Environmental**

Dynamometers are important technology that effect social communication through the automobile industry, and environmentally by reducing the consumption of fuel in these types of systems.

- **Manufacturability**

Dimension and solidwork design will be given to the workshop to execute and manufacture the parts.

- **Safety**

Our system will be covered by heavy plastic to avoid injuries while running tests.

3.2 Engineering Design standards

Engine testing (Engine power code: J2723-_201509)

Shaft standard (Steel AISI1020)

Bearing

Caliber

Caliber stand

Table

3.3 Theory and Theoretical Calculations

Where:

L_{10} : Bearing life

LR: Desired life, hours

C_{10} : Catalog rating life

N: revolution per minute

F_e : equivalent steady radial load

Volume of shaft:

$$v = \pi r^2 L \quad (\text{Eq. 1.1})$$

$$v = \pi(0.025\text{m})^2(1\text{m}) = 1.9625 \times 10^{-3}\text{m}^3$$

Mass of Shaft:

$$m = \rho \times v \quad (\text{Eq. 1.2})$$

$$m = 7872 \frac{\text{kg}}{\text{m}^3} \times 1.9625 \times 10^{-3}\text{m}^3 = 15.45\text{kg}$$

Radial load

$$F_r = \frac{T}{r} \quad (\text{Eq. 1.4})$$

$$F_r = \frac{143 \text{ N.m}}{0.025 \text{ m}} = 5720 \text{ N}$$

Steady equivalent radial load F_e

$$F_e = X_2 V F_r + Y_2 F_a \quad (\text{Eq. 1.3})$$

$$\frac{F_a}{C_0} = \frac{5720 \text{ N}}{19.6 \times 10^3 \text{ N}} = 0.29 \quad \text{which } e \text{ is between } 0.28 \text{ and } 0.42$$

Interpolating for e

$$\frac{0.42-0.28}{0.42-0.29} = \frac{0.42-0.38}{0.42-x} = e = 0.384$$

$$\frac{F_a}{V \cdot F_r} = \frac{5720}{1 \cdot 15.45 \times 10^3} = 0.37 \text{ so } Y_2 = 1$$

$$F_e = X_2 \cdot V \cdot F_r + Y_2 \cdot F_a = 0.56(1) (15.45 \times 10^3) + 1(5720) = 14823.9 \text{ KN}$$

Bearing life

$$L_{10} = \frac{LR}{60(N)} \left(\frac{C_{10}}{F_e} \right)^3 \quad (\text{Eq. 1.4})$$

Final calculation for bearing life:

$$C_{10} = 35.1 \text{ KN}$$

$$C_0 = 19.6 \text{ KN}$$

N: Revolution per minute RPM= 7000

$$F_e = 14824.9 \text{ KN}$$

a = 3 because it is ball bearing

$$L_{10} = \frac{10^6}{60(7000)} * \left(\frac{35100}{14823.9} \right)^3 = 316.07 \text{ h}$$

Key Calculation

The UNS steel shaft is G10350, heat-treated to minimum yield strength has a radius of 25mm. the shaft rotates at 7000RPM and transmits 143Nm through a gear. So select an appropriate key for the gear. The key can be seen in the figure 3.1 below.

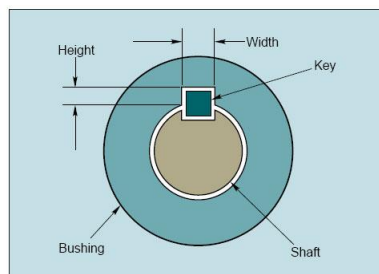


Figure 3 — Key fits snugly between bushing and shaft to lock them together radially.

Figure 3.1: 2.024 mm square key

A 2.024-mm square key is selected, UNS G10200 cold-drawn steel being used. The design will be based on yield strength of 455MPa. A factor of 2.80 will be employed in the absence of exact information about the nature of the load. The torque is obtained from the horsepower equation.

$$\text{Angle of speed } \omega = 7000 * 2 / 60 = 733.04 \text{ rad/s}$$

$$T=143/733.04=0.195\text{Nm}$$

Force at surface of the shaft is

$$F=T/r=0.195/0.025=7.8\text{N}$$

By the distortion-Energy theory, S_{sy} will be

$$S_{sy}=0.577*S_y$$

$$S_{sy}=0.577*455=262,535$$

Failure by shear a cross and will create a stress of $t=F/L$ substituting the strength divided by the factor of safety for t gives

$$S_{sy}/n = F/t$$

$$\text{which it is } 262.535*10^6/2.80=7.8/0.01 \text{ L}$$

$$\text{so } L=8.31*10^{-6}\text{mm}$$

To resist crushing, the area of one-half the face of the key is used :

$$S_y/n= F/t$$

$$\text{which it is } 455*10^6/2.8=7.8/0.01*L/2$$

$$L=9.6*10^{-6}\text{mm}$$

The shaft was carefully manufactured after the calculations and hence it can be seen in the figure 3.2 below:



Figure 3.2: Shaft used for our dynamometer

3.4 Product Subsystems and selection of Components

The shaft and the bearing can be seen in the figures 3.3 and 3.4 below:

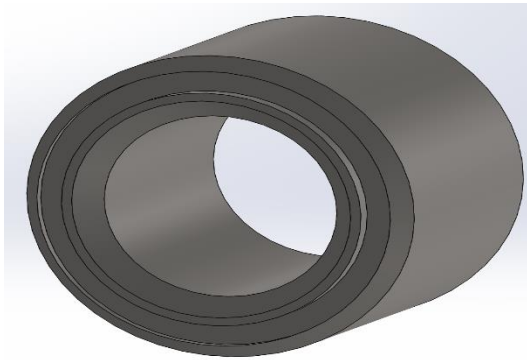


Figure 3.3 bearing in solid works

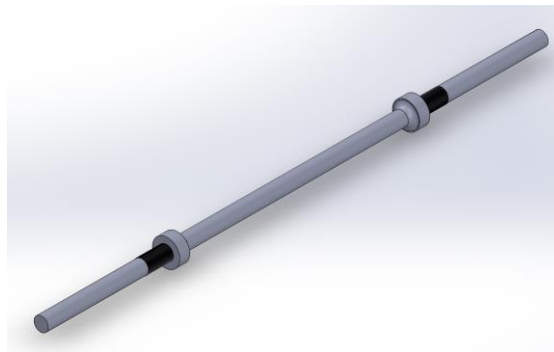


Figure 3.4 Shaft design in solid works

3.5 Manufacturing and assembly (Implementation)

The figures 3.5 and 3.6 shows all the parts required to implement our dynamometer project. First, the figure 3.5 shows the caliber stand and the shaft has to be connected to the table which is our base, then discs has to be installed in the shaft where the calibers have to be connected to the stand which is parallel to the shaft. Therefore, figure 3.6 shows the assembled caliber stand and other parts.

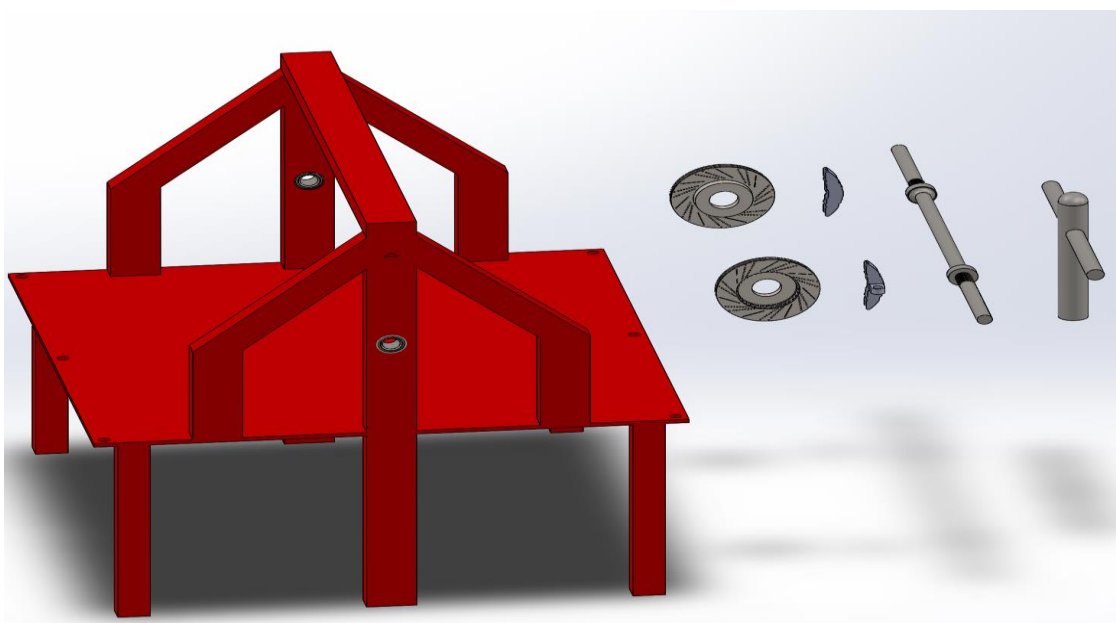


Figure 3.5 Caliber stand with shafts, caliber and other parts

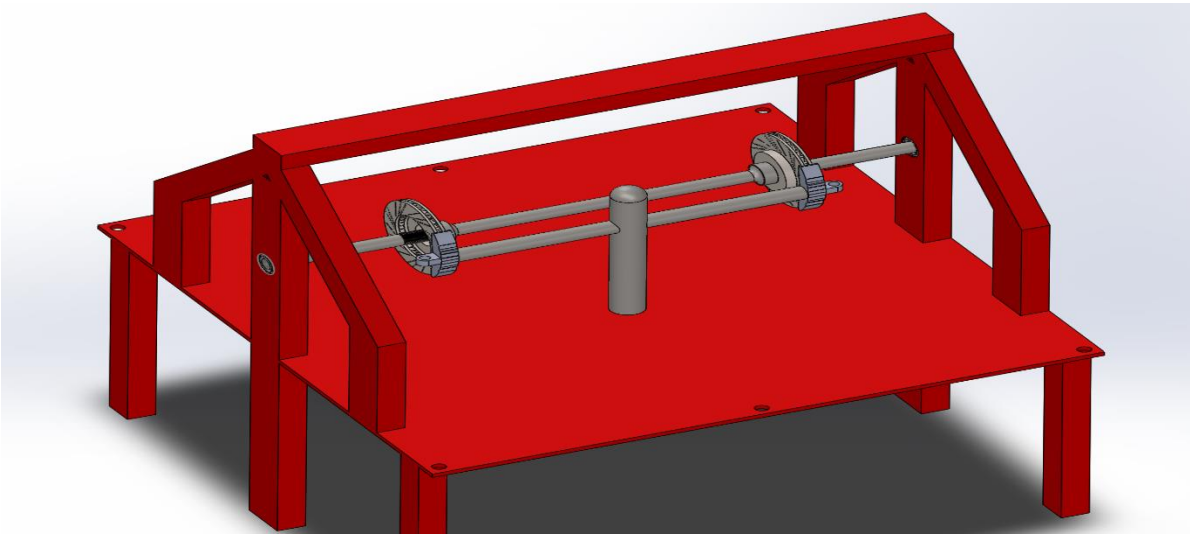


Figure 3.6 (Assembled) Caliber stand with shafts, caliber and other parts

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and data acquisition system

The setup of the dynamometer can be seen in figure 4.1 below:

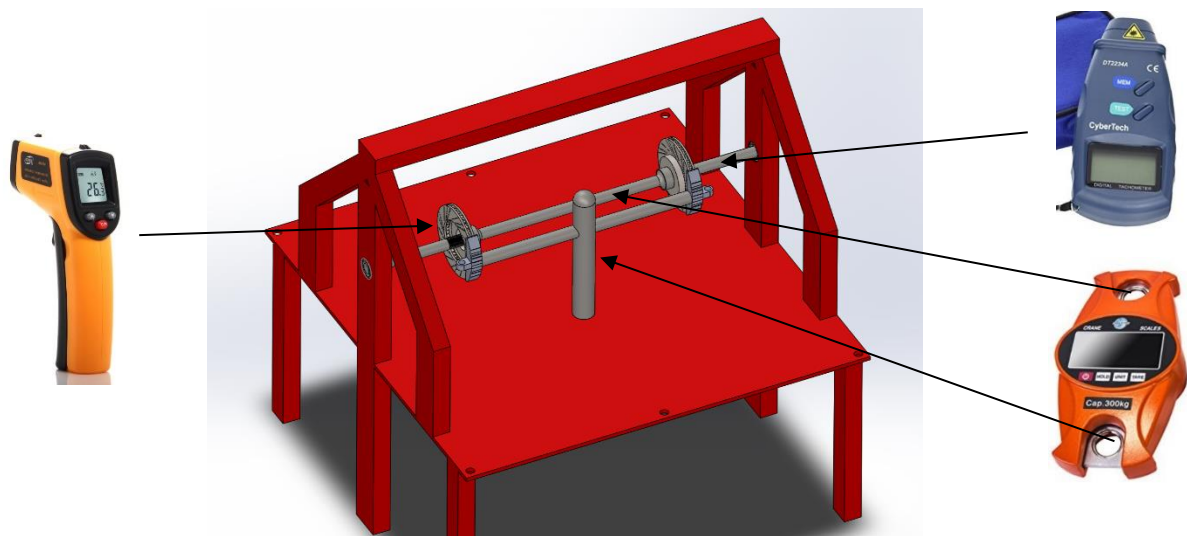


Figure 4.1: Setup & Location of Sensors

List the specification of the sensor and explain why you chose them.

Force gage specification:

- Digital professional hanging scale up to 300kg

- Accurate reloading spring sensor
- Large 2" backlight display
- Sturdy built aluminum body
- Stainless steel rotary hook, shackle
- Mode function (lb/kg/n)
- Weight data hold, tare function
- Low battery indication, auto-off
- 2 AAA batteries included
- Net weight 22oz/620g
- Assembled in P.R.C.
- Designed by Modern step in California, www.mscales.com

Tachometer specifications

- Measures the rotational speed with visible red light beam from a powerful LED
- High intensity class II laser measures from 2.5 - 99,999 RPM
- Extra-large 5-digit LCD display, high accuracy of +/- 0.05%
- Auto zero adjustment, stores last, minimum, and maximum readings
- Can be used for HVAC applications in measuring fan speed
- Powered by 4 x AA battery
- Size: 180 x 72 x 37mm (7.0 x 2.8 x 1.5 inch)

Thermometer specification

- Measurement range: -50 to 650°C (-58 to 1202°F)
- Accuracy: $\pm 2^\circ\text{C}$
- Emissivity: fixed, 0.95
- Field of View: D/S=Approx. 12:1 ratio (D: Distance; S=Spot or Target)
- Response time: Less than 1s
- Diode laser: output < 1mw at 630-670nm class 11 laser produce
- Display: LCD Backlight
- Auto Power Shut Off: YES, 7s
- Low Battery Indication: YES

Reasons of chosen Sensor Devices:

- Force Gage: it's required for us to measure pulling force through this device
- Tachometer: it's required to measure speed of rotating the shaft RPM
- Thermometer: it's required to measure the changing temperature of disks
- The limited performance of the devices fits our need
- Due to our limited budget we chose smartly to get best quality with low price

Testing parameters and approach:

Temperature – Rotation Speed – Pulling Force – Efficiency of the System

Our approach is about observing all changes in parameters from the running time of the system until the braking is applied by the caliper on the disks, which will also lead us to observe the stability of the system and establish high-efficiency production.

4.2 Results, Analysis and Discussion

- **Goals:-**

In this experiment, we are aiming to design, manufacture of Break System Dynamometer. In addition, data will be collected after installing all the parts together, which required from any mechanical engineer in the field to check the stability and the efficiency of any system.

- **Execute experiment procedure and collect data**

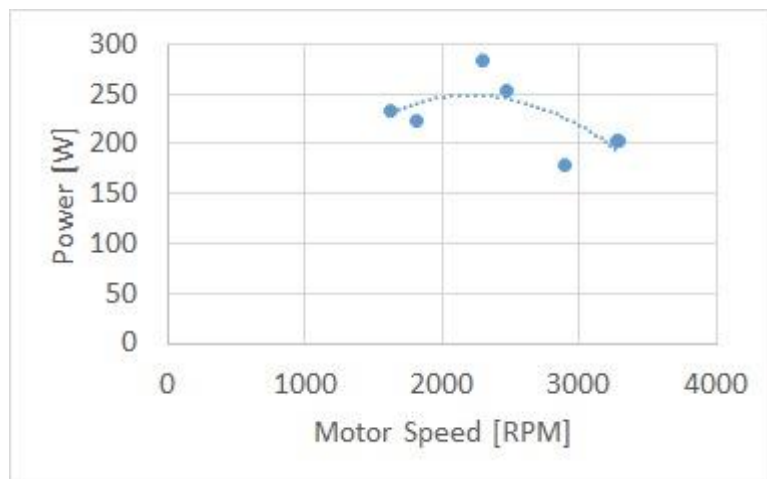
As shown above (figure 3.4), after putting all the main parts together we will place the three sensors in the right position to get an accurate reading. Starting with force gage that is held by the caliper shaft from one side, and hooked to the rotating shaft from the other side. Secondly, lazier Thermometer device that is directed to the one of the disks after running the engine to observe change in temperature. Thirdly, the tachometer that measures the rotating shaft speed (RPM).

- **Data Analysis**

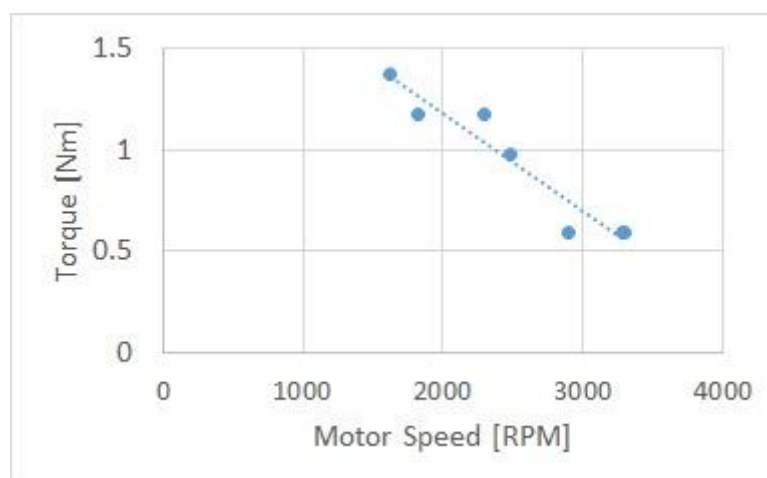
Data has been taken as shown in the table, each table is a separate test, and the duration of each test is 30 seconds. The tables are ordered based on the value of the speed motor, from low to high. Different motor speeds and their results can be seen below:

	max	min	fin	F(kg)		F(N)	T=F*R(Nm)	P=T*RPM*2pi/60
4.4	1624	92.5	1386	0.7		6.867	1.3734	233.4487008
5.8	2296	235.2	1342	0.6		5.886	1.1772	282.8984256
6.4	1817	774.6	932	0.6		5.886	1.1772	223.8791112
7.2	2477	402.8	2392	0.5		4.905	0.981	254.333406
8.7	2487	124.2	1465	0.3		2.943		
9.6	3294	480.3	2768	0.3		2.943	0.5886	202.9327992
10.2	2891	1664	1792	0.3		2.943	0.5886	178.1052588
11.7	3281	199.7	2163	0.3		2.943	0.5886	202.1319108

Motor Speed & Power



Motor Speed & Torque



Chapter 5: Project Management

Project Plan

We worked as a group for this project and we only have few months to build and test it. Here you can see table 5.1 which provides detailed presentation of the duration of the different tasks during the life of project.

Table 0.1 Duration of the tasks

No.	Tasks		Start Date	Finish Date	Duration
1	Introduction		March 5, 18	March 7, 18	3 Days
2	Literature Review	Force gages	February 8, 18	February 11, 18	4 Days
		Tachometer			
		Optical Thermometer			
		Types of dynamometer			
3	Calculations	Shaft Diameter	February 18, 18	February 28, 18	10 Days
		Key			
		Bearing			
4	Preliminary tests	-			
		-			
5	Manufacturing	Shaft	March 26, 18	April 18, 18	23 Days
		Trolley			
		Safety cover			
		Caliper holder			
6	Test the	-	April 24, 18	April 30, 18	7 Days

	system	-			
		-			
7	Writing, corrections and presentation		-	-	-

Contribution of Team

Each task in this project assigned to one member and some tasks assigned to more than one member. The group leader and advisor are responsible to assign each task to the group members. Table 5.2 shows who assigned to each task and what the contribution for each member.

Table 0.2 Tasks distribution

No.	Tasks		Assigned	Contribution
1	Introduction		Mohammed	100%
2	Literature Review	Force Gauges	All	100%
		Tachometer		
		Types of dynamometer		
		Optical thermometer		
3	Calculations	Shaft diameter	Saleh Hasan Ibrahim Mohammed	100%
		Key		
		Bearing life		
4	Preliminary tests			-
				-
				-
5	Manufacturing	Solidworks model	Hasan	100%
		Safety cover	Rayan & Saleh	100%

		Shaft	& Hasan	
		Caliper holder		
		Trolley		
6	Test the system	-	-	-
		-		
7	Writing, corrections and presentation		Rayan & Mohammed	-

Project Execution Monitoring

We had many activities during our project period. Some of the activities are continuous and some of them are taking place only one time. Table 5.3 shows the time for each activity.

Table 0.3 Table of activities

Time	Activities
Two times a week	Assessment class
Weekly meeting	With group members
weekly meeting	With advisor
Thu, March 29	Midterm presentation
	Preliminary test
	Test the system
	Final presentation

Challenging and Decision Making

During working on our project we have faced some difficulties such as: Throughout our senior project period we faced many difficulties and challenges such as:

1. Material and equipment resourcing (purchasing).
2. Design problems.
3. Report writing and document.

5.1.1 Material and equipment resourcing (purchasing)

- 1- Thermometer
- 2- Disk

Our project needs many things to purchase either from local stores or international stores. We faced a variety of difficulties when we start purchasing the parts that we need. Some difficulties were:

- International stores.
one of the measurement devices is that the thermometer we fine it in international stores and we chose the good device that fit with our project but when we order it they said it cannot be shipped to Saudi Arabia then we tried to find another one until we found a device from china but it will take more time than the other devices but we don't have a choice, so we ordered it from china and It arrived before the test time

5.1.2 Design problems

One of the main challenges that we faced is that finding good disk that have a diameter above the minimum number so we were about buying truck's disks until we found a car disk that has required diameter. On the other hand, we designed a shaft with required diameter but the disks have grove so we needed to redesign the shaft with making grove on the shaft to fit with disks.

5.1.3 Report writing and document

When we start writing the report every member writes a part and everyone has different ability than others. We found some mistakes that might affect the value of report, so we make a plan to fix them by some process such as:

- 1- Read each other part's and fix the mistakes.
- 2- Our advisor take a place to find some mistakes and help us to fix it.
- 3- Give the co-advisor some parts to take a look on it if need to fix.

By doing these process we get benefited of advisor and co-advisor experience to decrease the mistakes.

Project Bill of Materials and Budget

Table 5.4 provides the costs of all the material and equipment that we have purchased and manufactured.

Table 0.4 List of material and their cost

Materials	Cost (SR)
Tachometer	71
Optical thermometer	71
Force gauge	180
Disk	600
Shaft	850
Bearings	100
trolley	600
Safety cover	-
Caliper holder	-
Total	-

Chapter 6: Project Analysis

6.1 Life Long Learning

In this project we have learned and increase the level of knowledge, skills and experiences. Working in a group have taught us how to work in limited time with many tasks, and using communication skills. We gained different things of skills, experience, and knowledge. What we have learned during our project will be divided into some section to me explained more.

6.1.1 Improve our Skills in Some Software Tools

Every university student knows how to use software tools. In our projects we need to use some software such as: solid work, Microsoft word, Microsoft PowerPoint, and excel. All of us knows how to use them but for our project we used it in professional ways and we get improved our skills on them.

6.1.2 Time Management Skill

We always hear about time management and how it is important for projects life. In this project we apply what we have learned about time management to achieve the project objective on time. There are many tasks and they have specific time to be submitted. When we start working for the project we gave each member a task to do it and finish it before the time. These challenges gave us a great skill to manage the time. We had something called GANTTS chart which include each task with its time so it make them easier to be achieved during project's life. It was very useful by showing us the start and end time.

6.1.3 Problem Solving

Every one or group will face some problems while doing projects. While we worked on the project we faced some problem that need to be solved. By solving these problems we gained some new knowledge, skills, and experience of how we solved them. We faced some

problems while working on our project such as: purchasing right tools, finding workshop, and designing good parts.

6.2 Impact of Engineering Solutions

Our project achieved great impact on the society, environment, and economy. We will explain the impact of each of them in details.

6.2.1 Society

While doing projects people have to think about what is the benefit of the project to society. One of the targets that we want to provide is a good impact on society. One of the uses of our project is to test engines so when people want to buy a used engine they can test it before buy it and make sure that it works well. We know that pollution is one of the most important problems that we want to solve so by using our project to test engines we can find that it works well and doesn't produce smoke that might affect society. The project can be used for many kinds of engines so it will reduce problems for many people.

6.2.2 Environment

There are many ways that can polluted the environment and car engines are one of the ways when it doesn't work well and have some problem. With our project we can test the engine before we connect it to the car so we can know earlier if we can use it or not, so that will prevent it to make some pollution.

6.2.3 Economy

When it comes to the impacts that our project achieved on the economy, our project is a simple example of an efficient economic Dynamometer. Our project doesn't have a software, but instead of it we will use some cheap tools to measure temperature, force and output power. Also, our project will test the engine itself so no need to put it in the car to test it by wheels.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusions

Project experience

Working on this senior project was a very rich experience for our future, yet we were faced by many challenges. These challenges included, but not limited to, working under pressure and working effectively as a one team. We had a very limited time to finish the project tasks which some of them requires much time and effort. We were rushed to buy the tools and parts and do the assembling and testing to the machine. At the same moment, we were required to know and understand each other in the team and work effectively to solve the challenges we having.

In fact, we overcome these challenges by managing each process of the project alone. The project work was broken down into smaller tasks and these tasks were assigned to individual members of the team or to groups with a certain deadline to finish. This reduces the conflicts and improved the communication among the team.

However, management of team and work was not the only challenge, we had more technical and design problems. We used what we learned during our courses to analyze the problems and provide the best solution by using critical thinking and best design practices. For example, we used FEA analysis to perform structural and analysis and we used Solidworks software to provide the best design solution. We had to be familiar with these advanced tools and techniques in the context of dealing with a real design situations.

Project experience

During the project time we learnt and improved so many skills and we gained huge amount of knowledge. We learned how to work under pressure and perform complex tasks quickly in short time. We, also, applied what we learned in course to actual work and used the design principles to produce and test a new working machine. These lessons included:

- 1. Improve our skills in using design and analysis software.**

To finish the project work we had to utilize many of the available software tools. These tools included but not limited to Solidworks, Microsoft Word, and Microsoft

PowerPoint. These software tools are not new for us, but we had used them in a more professional way. We learned many things in these software tools that we had not learned them before. It was a wonderful opportunity that we had the chance to apply these tools to a real problem.

2. Time management

Time is always a valuable resource in any work or project that need to be completed. In this project we were supposed to finish within small window of time so that we had to effectively utilize our time to be able to finish successfully. The project work was complicated with many tasks to complete and many of these tasks were depended on each other. Some tasks when delayed will has significant effect on the whole project. Accordingly, we identified the critical tasks that may affect the deadline of the project and we put more focus on completing them.

During the work on the project many tasks were assigned at specific time. This challenge gave us a great skill and experience to manage our time. To do so we used GANTTS chart that includes all the tasks and the subtasks that we have to achieve them through the project's life. GANTTS chart a useful tool that help to know when we should start and when we should end each task.

3. Problem solving

During the project time we faced many problems at various levels that we eventually solved. Some of these problems were related to technical or management issues. For technical issues we used engineering concepts and fundamental principles of design to find the best solutions. For such problems, we tried to use what we learned effectively to be able to judge the results. On the other hand, for management problems we tried to utilize the best practices to effectively manage our time and finish the work within the time limit. Solving these problems provided us with many useful skills that will benefit us greatly.

7.2 Future work

Our future recommendation can be summarized briefly in several points:

- 1- Regular checkup and maintenance of the brakes.
- 2- Adding bearing and support in the middle of the shaft is recommended for future work.
- 3- Replacing the motor-shaft coupler to an elastic coupler.
- 4- To get better readings in the future, it is recommended to weld the force gage on the frame of the table.
- 5- Getting a high efficiency tachometer, will advance future studies.

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Appendix A: Drawings

