Design and Construction of a Frictional Brake Absorption Dynamometer using Electrical Strain Gauges

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Abstract- *The objective is to design and construct a Frictional-Brake Absorption type Dynamometer using electrical strain gauges in order to calculate the power out put of low speed prime movers like Wind Turbine, Micro Hydro Turbines, etc. An electrical motor or a cross flow turbine can be incorporated for measuring the required parameters in the Instrumentation Laboratory of Mechanical Engineering Department, NWFP UET Peshawar.*

This research-oriented project aims to design and develop an indigenous and innovative mechanism which is simple and precise in calculation and can produce accurate results for different varying loads. The technique is implemented for the first time on the undergraduate level in the field of Engineering Instrumentation at NWFP UET Peshawar.

Keywords: *Engineering Instrumentation, Mechanical Engineering Design, Mechatronics*

1. INTRODUCTION

A dynamometer is a device used for measuring Power, Torque or Force of an engine, motor, or any rotating prime mover.

There are two major types of Dynamometers:

- Passive or Absorption Dynamometer
- Active or Universal Dynamometer

A dynamometer that is designed to be driven is called an Absorption or Passive Dynamometer. A dynamometer that can either drive or absorb is called a Universal or Active Dynamometer.

Other specific types of dynamometers are:

- Eddy current or electromagnetic brake (absorption only)
- Magnetic Powder brake (absorption only)
- Hysteresis Brake (absorption only)
- Electric motor/generator (absorb or drive)
- Fan brake (absorption only)
- Hydraulic brake (absorption only)
- Mechanical friction brake or Prony brake (absorption only)
- Water brake (absorption only)

Figure 1 demonstrates a generalized components break-up of a dynamometer.

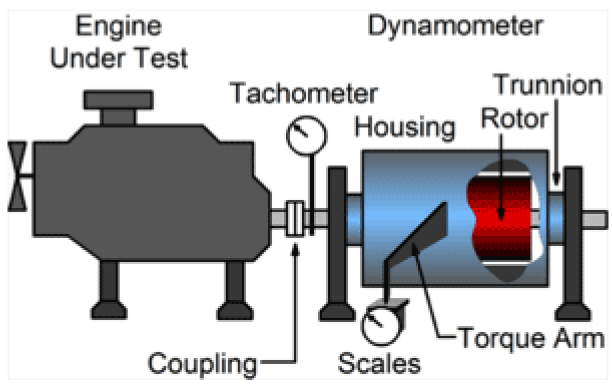

Figure 1: A generalized components break-up of a dynamometer.

2. BRAINSTORMING THE IDEAS

The most important constituent of a research-oriented technical initiative is to brainstorm and gather up all the creative ideas and elaborate the working and advantages of different proposals. The best idea is then pursued for the fulfillment of the objective.

Different types of dynamometers are required and suit different conditions. For instance, an Eddy Current Dynamometer is the most common type deployed for the modern chassis dynamometers. Similarly, Water Brake Dynamometers come in compact packages and are used for applications which have a slow operation and can still be accurately measured using a less steady water brake.

The Frictional Brake Absorption type Dynamometer is one of the most simple, standard, and easy to prototype dynamometer. It has many advantages over other orthodox dynamometers like economical viability, ease of maintenance, compactness, and suitability for higher power absorption.

Table 1 depicts a merit comparison between different major types of dynamometers and suggests FBA (Frictional Brake Absorption) Dynamometer to be the ideal one for our use:

Table 1: Figure of Merit (FOM)

Type	Simplicity of Design	Power Range	Cost Efficient	
Eddy Current	*1*	*4*	*1*	*6*
Frictional Brake	***5***	***4***	***4***	***13***
Water Brake	*2*	*3*	*4*	*9*
Engine Dyno	*3*	*5*	*2*	*10*
Magnetic Powder Brake	*1*	*3*	*1*	*5*
Fan Brake	*5*	*3*	*4*	*12*
Hydraulic Brake	*4*	*3*	*3*	*10*

1 = Worse/Low, 5 = Best/High, 3 = Moderate

Therefore, after summing up all the major factors of the different standard types of dynamometers in practice, we came up with the conclusion of opting for a Frictional Brake Absorption Dynamometer (FBAD) due to its mechanical design simplicity, good power absorption, and cost efficiency.

3. CONCEPTUAL DESIGN

The conceptual design for the development of a FBA Dynamometer started with a few raw ideas on a paper. Continuous analyses and technical considerations on mechanical and manufacturing grounds along with special consideration to the data acquisition and processing of signal output from the strain gauges, refined the idea and hence the raw idea transformed into a practical project.

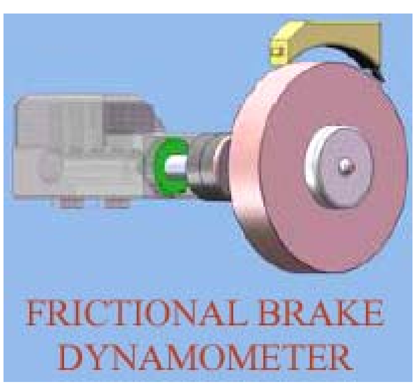

Figure 2: FBA Dynamometer

As the dynamometer is an absorption frictional-brake type; its shaft will be coupled to the rotating shaft of a turbine / motor. Electrical strain gauges are to be mounted on the dynamometer shaft. On the application of brakes; the dynamometer will tend to stop the engine; which will in turn create a twist in the shaft as a result of which the gauges will become elongated and their strain will be recorded through a "Data Acquisition System".

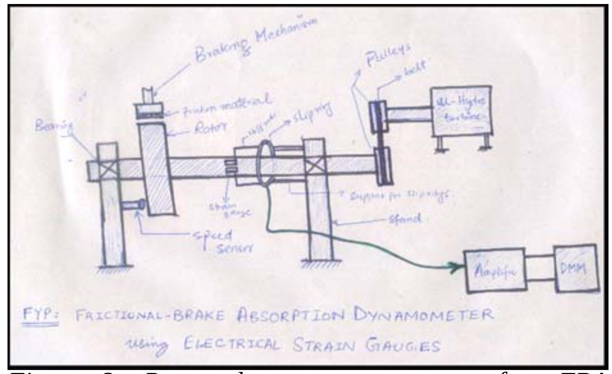

Figure 3: Paper drawn raw concept of a FBA Dynamometer

The Data Acquisition System is designed using a pure microcontroller-based approach with its initiation from the Wheatstone bridge of the four Strain Gauges mounted on the shaft. On application of load, the bridge will become unbalanced so a Voltage O/P (in Milli Volts) will be generated from the bridge. This O/P Voltage is amplified using a constant gain and is then fed to the AT89c2051 microcontroller via an Analog-to-Digital Converter. The output of the Microcontroller is fed to an Infra Red (IR) Sensor mounted on the shaft. This IR Sensor transmits this signal to the IR Receiver present in the range of the dynamometer, wirelessly. On receiving the signal, an AT89c51 microcontroller manipulates it and displays the corresponding value of voltage generated from the Wheatstone bridge in terms of the mechanical strain created due to the load twist. Speed sensor will be installed on the apparatus which will measure the rpm "N" of the dynamometer shaft.

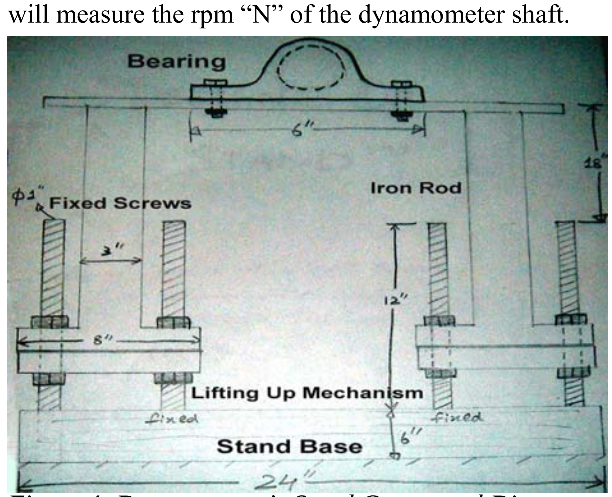

Figure 4: Dynamometer's Stand Conceptual Diagram

4. GOVERNING EQUATIONS

The following formulae govern the measurement proceedings:

$$\tau = \gamma \times G$$
$$\tau = T \times r / J$$

Where:

τ (Tau) = Shear Stress
γ = Shear Strain
T = Torque
J = Polar Moment of Inertia
G = Shear Modulus

On obtaining T power can be calculated as follows:

$$P = T \times \omega$$

Where ω = angular velocity; and can be calculated as:

$$\omega = 2 \times \pi \times N \text{ (RPM)}$$

5. DETAILED DESIGN

5.1. Power & Torque Design Calculations

- Maximum Power = 10,000 Watt = 10 KW
- Maximum RPM = 2631.5
  (By considering Power Graphs of *Pelton Wheel* with a head of 30 meters (full nozzle opening))
- Maximum Torque = 160 Newton-Meter

5.2. Dimensions & overall Sizing

- Total dynamometer LENGTH = 32 inches
- Total Dynamometer HEIGHT = 30 inches
- Total Dynamometer WIDTH = 24 inches

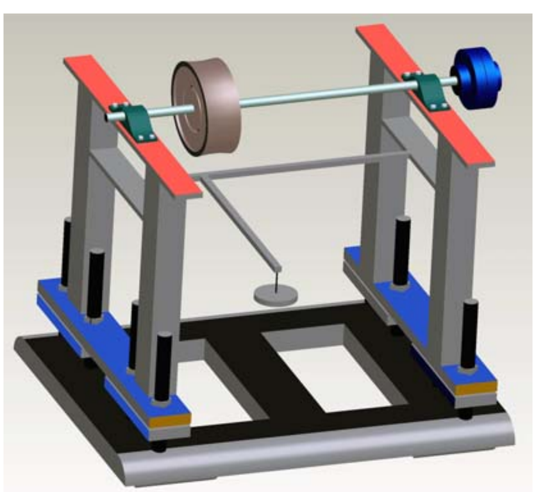

Figure 5: A 3D Model of the FBAD in Pro|Engineer

5.3. Mechanical Components

A. Shaft:

- Shaft Diameter (d) calculated as 0.75 inches

$$d = \frac{[16 \sqrt{3} \times n \times T]^{1/3}}{[Pi \times Sy]^{1/3}}$$

- Material: AISI-1020 Steel, Factor of Safety = 1.45
- Yield Strength, Sy = 294.8 MPa
- Loading: Torsion

Figure 6: A CAD Model of the dynamometer's Shaft

B. Bearings:

- Single Row – Ball Bearings
- High Radial and good Axial Loadings
- Less wear and high efficiency

Figure 7: Ball Bearings

C. Jaw Coupling:

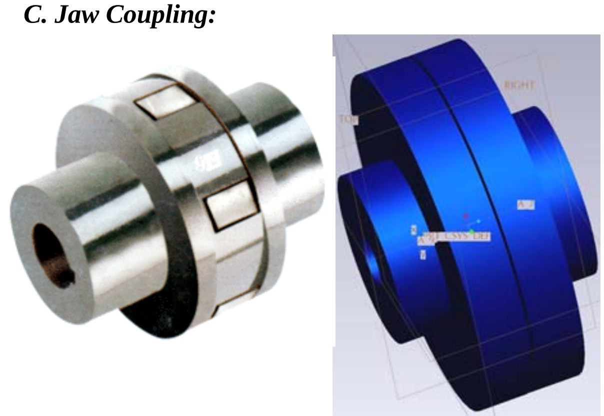

Figure 8: The Jaw coupling's 3D Models

D. Dynamometer Brake:

- Band Brake – the most suitable and easy to fabricate
- Simple, Economical, and Flexible

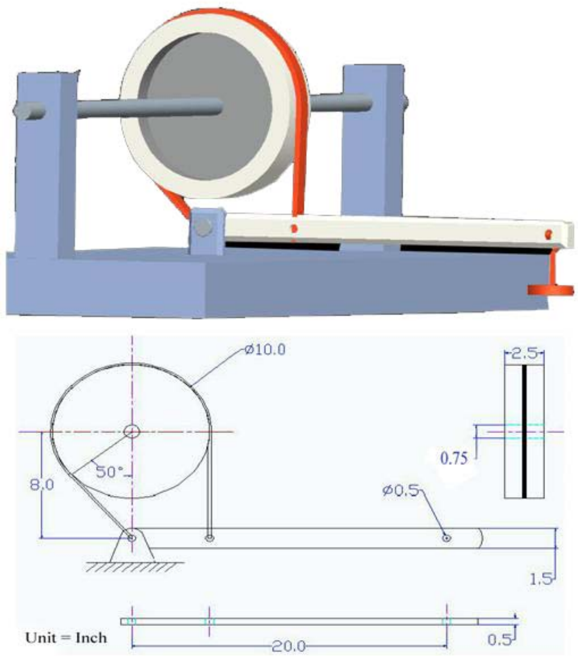

Figure 9: The Band Brake of the FBAD

E. Dynamometer Stand:

- Rigid & Simple
- Vertically Adjustable
- Economical & easy to fabricate

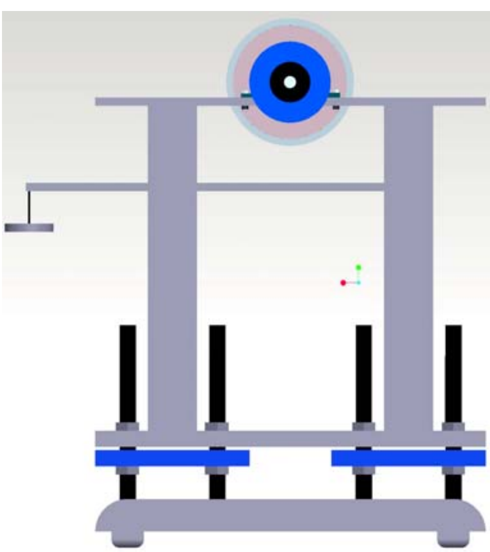

Figure 10: Side View of the FBAD's Stand

6. THE DATA ACQUISITION SYSTEM

The Data Acquisition System is one of the most critical components of our dynamometer as our entire calculations are based entirely on its accuracy and preciseness.

Figure 11 shows a block diagram of the Data Acquisition System of our project.

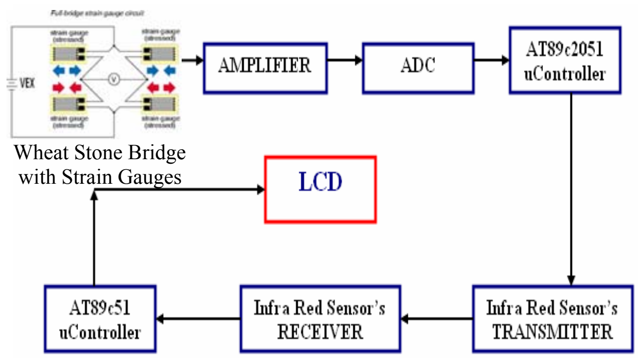

Figure 11: The Data Acquisition System

7. PROTEUS CIRCUIT SIMULATION & PROGRAMMING

The entire circuitry of the Data Acquisition System is to be simulated in the software called Proteus. Simulation is very beneficial as it helps figuring out any problems or short comings in the electronics domain. Moreover, it provides a pre-picture of the practical circuitry to be made, before hand.

Keil Compiler is used to compile and debug the program which is to be burnt in the microcontrollers of the Data Acquisition System. Figure 12 shows a glimpse of the environments of both Proteus and Keil.

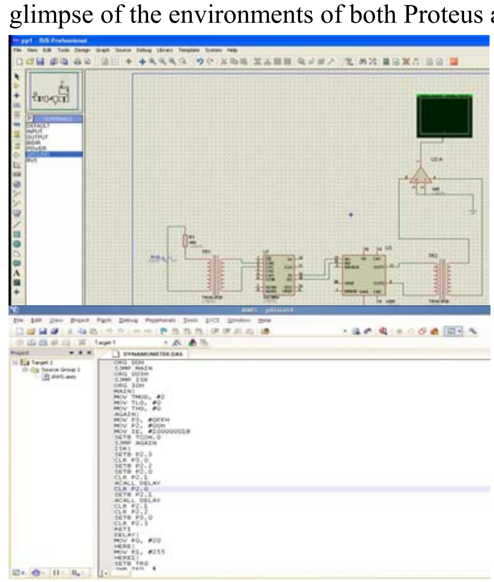

Figure 12: Keil & Proteus Environments

8. MAXIMUM STRESS & STRAIN CALCULATIONS

As the Shear Strain is given as:

γ = (T x r) / (J x G)

&

τ = (T x r) / J

Where:
τ = Shear stress
γ = Shear strain
T = Torque
J = Polar moment of Inertia
G = Shear Modulus

The values are:

T = 160 Nm (Max. Torque)
r = 0.375in= 9.525019X10^-3 m
d = 0.75 in = 0.019050038m
J = pi * d^4/32 = 1.292954612x 10^-8 m^4
G = 11.4 x 10^6 psi = 78600229.8 x 10^3 N/m^2

So, finally:

$$\boxed{\tau = 117869801.9\ N/m^2}$$

$$\boxed{\gamma = 1.499611416 \times 10^{-3}}$$

9. STRAIN GAUGES SELECTION

Electrical Strain Gauges are to be deployed for the purpose of recording the strain in our apparatus. Due to the torsion induced in the shaft, the shear strain will tend to unbalance the Wheat Stone Bridge (having the 4 starin gauges instead of 4 resistances). Due to the unbalancing of the bridge, a voltage output in millivolts will be generated which is then further manipulated by the Data Acquisition System.

Following are few of the Starin Gauge basic parameters:

- Student Strain Gauges
- The serial number is: EA.06.120LZ.120/E
- Gauge Factor = 2
- Voltage O/P Range: 15 to 30 mm
- Resistance of each gauge = 120 ohm

10. CONCLUSION

The end practice is to record the different values of Power and Torque of the Frictional Brake Absorption Dynamometer at different varying loads. Power and Torque Curves should be developed for different loads and then the optimization analysis is done.

Cross Flow Turbine is mostly used in the northern areas of Pakistan for power generation. However, the performance of these turbines is not up to the mark and the same is also confirmed after testing the local manufactured Cross Flow Turbine.

Hence, a broader picture of a FBA Dynamometer is that it helps evaluate the existing models of different low speed primers like Wind Turbines, Cross Flow Turbines, etc. The local manufacturers of these low speed primers should be guided technically on how to improve and enhance the current design in terms of efficiency and durability.

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