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DESIGN AND FABRICATION OF ELECTROMAGNETIC DYNAMOMETER FOR MICRO-POWER MEASUREMENT

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ABSTRACT

The torque measurement has been a challenge especially for low torques. The amplification of the torque with either pulleys or gears is one way out, but it introduces its own losses and affects the accuracy of the measurand. The magnetic force applied to the flywheel is one of the nascent option which is explored in this present work. The prime mover is low power impulse steam turbine, but a 50 W generic universal electrical motor is opted for prime mover. The speed being very high, it is reduced at 4 times with corresponding amplification in torque. A properly bearing supported shaft with flywheel is coupled to this motor through V-belt pulleys. The electromagnets are applied at the circumference with predefined gap. The arrangement to vary this gap is provided on the setup. The three DC voltages are applied to electromagnets for so as to produce three different magnitudes. This calibrated force in turn torque applied to steam turbine, where the torque generated is still lower. Hence, thus calibrated force i.e. torque shall enable to estimate the power developed, which is essentially useful for efficiency calculations. The results obtained through this present work are encouraging.

KEYWORDS: Operational Features of Dynamometer,Constant Gap and Variable Voltage.

INTRODUCTION

The measurement of torque has always been a challenge especially for the low torques. The torque has to be absorbed or transmitted while measurement. Out of these two alternatives, for low torque measurement, always absorption type is default option. In the present study, a low power universal electric motor is selected to be prime mover for source of low torque and the electromagnetic breaking is the opted way to measure the torque.

The electromagnetic dynamometer would have been the best choice. This is limited by the size of the proposed dynamometer. Therefore electromagnets are applied at the circumference of the rotor, and the distance between the magnet and the rotating disc is manipulated to obtain the torque range. The non contact type dynamometers are studied by various authors:

I.Giouroudi [1] describes the practical application of development of highly sensitive torque measurement system. While designing the micro-motors the major parameters to be measured are torque and rotational speed. For this purpose the cable brake principle is implemented.. The measurements of speed were performed using a commercially available laser tachometer.

Brin [2] explained the design of an eddy current brake dynamometer to determine the efficiency of wheel hub motor. Magnetic field produced is increased and the braking force is also increased when the current supply to the coils of the electromagnets is increases. The power ratting of the electric motor is known and the angular velocity is measured with tachometer then the torque that could be produced at minimum speed can be calculated.

Heinrich Ruser [3] describes principle of contactless torque measurement using the magneto-elastic effect of ferromagnetic materials. The shaft undergoes cyclic complete magnetization and re-magnetization to effectively erase its magnetic and thermal history. The assessment of the complete hysteresis curve by complete re-magnetization of the shaft material allows determining the torque-dependent parameters of the hysteresis. This enables the measurement of torque with High linearity and reproducibility for a large variety of materials

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The generated eddy currents, the total eddy current power input to a rotating conductor is calculated.
Then by using the correlation between the power and the torque, the braking torque is obtained by dividing the power by the angular velocity. Scheiber[4] studied the effects of a magnetic field on a moving conductor with low magnetic Reynolds number. Using the magnetic potential of Smythe [5] describes the model of eddy currents generated on a rotating disk by using Maxwell-Ampere law in order to relate the current flow on the surface of the conductor to the applied magnetic field. The induced magnetic field generated due to the eddy currents in terms of the external field is obtained by using Faraday's law and Gauss' law. An important conclusion is that the eddy currents cause demagnetizing fields on electromagnets that oppose the applied field and this result in a variation in the eddy current distribution.

DESIGNING THE DYNAMOMETER ASSEMBLY

In the following, the principle procedure of designing the dynamometer is outlined. The complete assembly is as shown in figure 2. The production drawings contained the parts features and dimensions to be used during the production and assembly process. This design produces a much stronger magnetic field. A power supply is used such that the current in these winding of the magnets could be increased and thus decreasing the number of magnets. Rectangular electromagnets were implemented in this design, because a closer air gap could be used and controlled much more easily. This design holds the magnets such that the flywheel can rotate though the air gap between the magnets and keep the required air gap. This dynamometer design is much more stable and reliable. In this design the universal motor is coupled to the dynamometer with a open belt drive system.

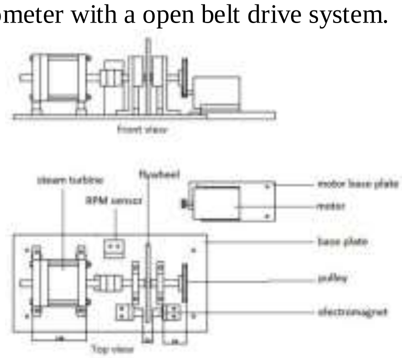

Figure 2: Sketch & 3D Model of Dynamometer Assembly

EXPERIMENTATION OF ELECTRO-MAGNETIC DYNAMOMETER

The electromagnetic dynamometer is designed for a table top set up of steam power plant. The miniaturization of the power plant dictates the size of the turbine and mass flow rate of steam along with pressure and temperature. This compels the power of the steam turbine. Since turbine operates with less than 50 Watts, a specially designed dynamometer is required to estimate the power developed by the steam turbine and performance characteristics of the same.

The turbine was designed to be operated at 24000 rpm at 50 W, thus producing a negligible torque. This actually limits the used of absorption type dynamometer as it blocks the shaft. Therefore a non contact type magnetic brake type dynamometer is being designed and implemented for the turbine.

The Constructional Details

The figure 3 shows the constructional details of dynamometer based on electromagnetic principal. The prime aim is to estimate the power of turbine. This is achieved by measuring the speed of the rotor, while loading for known torque. Since the designing of electromagnetic dynamometer and design and manufacturing of steam turbine are simultaneously activities, it was resolved to design the dynamometer suitable for the low power motor. The motor is selected to be universal motor of 50 W. The motor runs at 9500 rpm at 0.05 Nm torque.
The universal motors are used where low torque at high speed is desired. The output of the universal motor is coupled to the flywheel shaft through the initial reduction of 1:4. This is implied by V-belt pulley arrangement. The dimensions of the driving and driven pulleys are 25 mm and 100 mm respectively. The thicknesses of both the pulleys are 10 mm. The driven pulley has a central hole of diameter 17mm and a 6mm by 6mm groove on the periphery and is mounted on the shaft of flywheel. The centre distance between motor shaft and flywheel shaft is 140mm. The v-belt of length 350mm is used for connecting two shafts.

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The electromagnets are used to reduce the speed of the flywheel. The flywheel rotates between the gap of magnets. A coupling is used for connecting the flywheel shaft to the turbine shaft. The gaussmeter is used to measure the magnetic field density. The Magnetic Pulse tachometer is used to measure the angular speed of the flywheel. The setup is mounted on base plate having dimension of 500mm by 250mm.The base plate is placed on stand having dimension of 675mm by 750mm by 700mm.

Figure 3 Experimental Set up

Operational Features of Dynamometer

The electromagnetic dynamometer works on the principle of the electromagnetic braking system. The motor is operated at variable speed by varying the input voltage of the motor using dimmer-stat. The output of this motor is given to the flywheel shaft which rotates between the air gap of electromagnets. The varying torque is applied by changing the power supply of the magnets. The distance between two electromagnets is changed after getting a strong magnetic field. The speed of the flywheel is measured in presence of magnetic field.

The magnetic field intensity increases with reduction in distance and there is reduction in speed of flywheel. The speed of the flywheel is measured with the help of magnetic pulse tachometer. The same torque is applied when the flywheel is connected with the help of universal coupling to the output shaft of turbine whose power is to be measured. As the value of applied torque and speed of flywheel are known the output power of turbine can be directly calculated.

Analysis of electromagnets

The magnetic field B and force are nonlinear functions of the current, depending on the nonlinear relation between B and H for the particular core material used. The B field increases quickly with increasing current up to certain value, but above that value the field levels off and becomes almost constant, regardless of how much current is sent through the windings. As long as the length of the gap is smaller than the cross section dimensions of the core, the field in the gap will be approximately the same as in the core.

The magnetic field of electromagnets in the general case is given by Ampere's Law:

$$NI = \oint H.dl$$

Another equation used, that gives the magnetic field due to each small segment of current is the Biot–Savart law. The force exerted by an electromagnet on a section of core material is:

$$F = \frac{B^2 A}{2\mu_0} \qquad \text{....1}$$

For given core geometry, the B field for a required force can be calculated from (1)

The core area considered is rectangular shape of 11mm by 9mm and length of the winding is 58mm which is selected by calculating amount of current expected to pass through the coil to produce desired magnetic field. Consider maximum mass of the object to be lifted is as 20Kg i.e. the gravitational force is of 196.2N.Therefore the lifting force has to be greater than 196.2N from which B is calculated as,

$$B = 2.23 wb/m^2 = 2.23 \text{ Tesla.}$$

This is the flux density in the core as well as for a very small air-gap. Where, $\mu o=4\pi x10^{-7}$ is the absolute permeability of air.

The magnetizing force (H) is given by,

$$H = B/\mu_0\mu_r \qquad \text{......2}$$

By putting the value of B & μo

$$H=887.2885 AT/m.$$

Where, μ_r=2000 for mild steel.

This magneto-motive force is the product of the current that will go round the magnet and the number of turns of the wire that make up the magnet. If one of the variable is chosen the other variable can be calculated, thus if the number of turns is chosen to be 1100, then the current in the electromagnet is calculated by relation

$$H = NI/l \qquad \text{.....3}$$

Therefore the current is computed to be 0.05A. The maximum operating voltage is determined to produce the desired magnetic field.

Table 1:Magnetic field at core

Sr. No.	Force(N)	B(Tesla)	I(A)
1	9.81	0.499	0.010

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2	19.62	0.705	0.014
3	39.24	0.998	0.020
4	58.86	1.222	0.025
5	78.48	1.411	0.029

ESTIMATION OF MAGNETIC FIELD DUE TO CHANGE IN AIR GAP

The magnetic field created by an electromagnet is proportional to both the number of turns in the winding, *N*, and the current in the wire, *I*, hence this product, *NI*, in ampere-turns, is given the name magnetomotive force. For an electromagnet with the air gap the voltage supply is also need to be increases. For the electromagnet which is having length of core as L_{core} and length L_{gap} is in air gaps, Ampere's law modified as,

$$NI = H_{core}L_{core} + H_{gap}L_{gap}$$

$$NI = B\left(\frac{L_{core}}{\mu} + \frac{L_{gap}}{\mu_0}\right) \quad ....4$$

Where, $\mu = \frac{B}{H}$

$$\mu_0 = 4\pi(10^{-7})$$

This is a nonlinear equation, because the permeability of the core μ, varies with the magnetic field B. For an exact solution, the value of μ at the B value used must be obtained from the core material hysteresis curve. For most core materials, μ_r=μ/μ_0 ≈2000-6000 in equation (4) above, the second term dominates. Therefore, in magnetic circuits with an air gap the strength of the magnetic field B depends strongly on the length of the air gap.

Table 2 :Magnetic field at air gap

Sr. No.	Force(N)	B(Tesla)	Lgap(m)	I(A)
1	10	0.499034	0.001	0.36
2	20	0.705741	0.002	1.02
3	28	0.864353	0.003	1.21

RESULTS AND DISCUSSIONS

The electromagnetic dynamometer so designed and manufactured is now ready for trials. The experimentation is aimed to identify various parameters which influence the torque implied on the flywheel. It is illustrated earlier that the magnetic force is function of the air gap between magnet and the flywheel and the voltage applied to the electromagnet. Similarly the force implied on the flywheel times the radial distance of the magnets from the center amounts to the torque applied on the shaft.

Thus the electromagnetic dynamometer is tested for three conditions i.e. changing the air gap, changing the voltage applied to the electromagnets and changing the applied voltage to the motor. These three trials are documented as result table and the findings are consolidated as important deductions of the chapter.

Constant Gap and Variable Voltage

This is the first trial, and the readings are consolidated below. The air gap between the flywheel and the electromagnet is maintained as 2 mm and 3 mm while applied voltage to the electromagnets is 15 V DC and 20 VDC. The power applied to the electrical motor is measured to be 44 W. The speed is recorded using digital tachometer. The readings are as follows.

Table 3 : Effect of varying voltage at fixed air gap

Sr.	Voltage at Electro-Magnet	Magnetic field B	Force implied on flywheel	T (Nm)	Speed at Flywheel
Gap=0.002m					
1	18	0.617	15	1.125	373
2	20	0.694	19	1.425	294
3	22	0.764	23	1.725	243
4	24	0.827	27	2.025	207
Gap=0.003m					
5	18	0.422	7	0.525	800
6	20	0.451	8	0.600	700
7	22	0.504	10	0.750	560
8	24	0.552	12	0.900	466

Constant Voltage and Variable Motor Power

In this trial the voltage applied to the electromagnet is kept constant i.e. 12 V DC. The air gap between the flywheel and the electromagnet is maintained as 1 mm and 2 mm while voltage applied to the motor is 90V AC to 110V AC. The speed is recorded using digital tachometer. The readings are as follows.

Table 4: Effect of varying motor power at fixed air gap

Sr. no.	Voltage	Current	Power	Torque	Speed
Gap=0.001m					
1	110	0.5	44	2.032	206
2	105	0.495	41.38	2.032	195
3	100	0.49	39.2	2.032	184
Gap = 0.002 m					
4	110	0.5	44	0.508	827
5	105	0.5	41.38	0.508	781

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6	100	0.5	39.2	0.508	736

The table 4 shows that, varying the motor power at constant voltage supply to the electromagnets in the variable air gap between flywheel and the electromagnet, the speed of flywheel is decreases.

Constant Voltage and Variable Gap

In this trial, the applied voltage to the electromagnets is constant i.e. 16 V DC and the air gap between the flywheel and the electromagnet is varied from 1 mm to 3 mm. The power applied to the electrical motor is measured to be 44 W. The change in the speed of flywheel is recorded using digital tachometer. The readings are as follows.

Table 5 : Effect of varying air gap at constant voltage

Sr. no.	Lgap	B	Force	Torque	Speed
1	0.001	1.10	48	3.61	116
2	0.002	0.55	12	0.90	465
3	0.003	0.37	5	0.40	1046

The table 5 shows that, by keeping the power of motor and voltage supply to electromagnet constant and varying the gap between flywheel and electromagnet, the speed of flywheel is increases.

CONCLUSION

The concept of applying the electromagnetic force at the flywheel is attempted in this dissertation and electromagnetic dynamometer is fabricated. As discussed in the resume of the dissertation work, this dynamometer is used to measure the power of the

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steam turbine in mini steam power plant. For this turbine the torque developed is very low in gm.cm. The careful trials are conducted to reach to precise conclusion.

- The two different gaps gives of two different forces at given DC supply to electromagnets.
- The magnetic force developed for different DC voltages is not seen varying much.
- The angular velocity of the electrical motor is seen to be reduced by 25 to 80 rpm for different magnitudes of magnetic force applied as discussed in the previous chapter. But this is precisely compatible for the torque range for the proposed steam turbine.

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