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# DESIGN AND DEVELOPMENT OF POWER RECIRCULATING GEAR TEST RIG

GONSALVIS[1*] J., SACHIDANANDA[2] H.K., PRAKASH[3] H. R. and RAJESH[4] A.R.

## ABSTRACT

Gears are used for transmission of motion or power from one shaft to another. The type of gear, and design features, determine not only the operating characteristics of a gear pair but also whether it may fail prematurely. Testing of gears is essential to know their reliability in their field performance. Laboratory methods, though cannot fully create a replica of the environment to which these gears are subjected to while working in the fields, but these methods certainly help in building confidence in their level of performance expected. In order to measure the performance of the gear it has to be designed, fabricated and tested. Various types of gear testing machines are available which use the principle of “four square” in which two gear sets are joined back to back and locked together after applying a twisting couple to one of the connecting shafts. The novelty of this gear testing machine is that in order to apply tooth loads back to back, a torque meter is employed, which helps apply metered torque, which eliminates twisting of a long shaft. The power required to drive this test rig is only the frictional power loss occurring between gear tooth contacts. This paper discusses about design and development of a power re-circulating test rig for testing gear samples.

## KEY WORDS

Gears, four square, FZG, power recirculation, accelerated and fatigue

[1] Principal, St. Joseph Engineering College, Mangalore.
Email- drjgonsalves@rediffmail.com Mob: +919448705595

[2] Assistant Professor Dept. of Mechanical Engineering Sahyadri Institute of Technology, Mangalore. Email- sachi_dananda@yahoo.com Mob: +919844251061

[3] Lecturer, Dept. of Mechanical Engineering, BMS College of Engineering, Bangalore. Email- prakash_hr73@yahoo.co.in Mob: +919964073802

[4] Senior Lecturer, Dept. of Mechanical Engineering DACG Polytechnic, Chickmagalur. Email- rajesh_ranganath@rediffmail.com Mob: +919448787292

* Author for correspondence

## INTRODUCTION

Spur gears are widely used for transmission of power and motion between two parallel shafts. They successfully serve to transmit from a fraction of a watt to dozens of mega watts of power. Performance of the gears designed is best demonstrated by a test in which the gear train is operated under the same conditions as are encountered in actual applications. Therefore an attempt has been made to develop a power-recirculation type test rig to test standard as well as profile corrected gears. Gears are designed to satisfy special power transmission characteristics which are based on power capacity, speed of operation, noise, vibration, efficiency or surface strength. It is very much essential to test the gears to ascertain the characteristics built in when they are being designed and manufactured. Gears can be tested under real conditions but takes a longer time and consumes much power. Nevertheless, alternate gear testing solutions have been evolved over the time which not only take very short period of time to assert their design features and also help in predicting accurately the modes of failure. In addition to this methods are also suggested which consume a small power to test gears while a large amount of power being locked between them. Several important torque applying techniques are being suggested based on “four square” test setup in which gear sets are joined back to back and locked together after applying the required amount of twisting couple to one of the connecting shafts. Many gear-load testing machines used today belong to the static loading type. The Niemann’s [1] testing machine belonging to this type has been used mainly for obtaining data concerning load-carrying capacities of tooth surface [2]. Dawson [3] suggests various types of testing machines for testing gears under different modes of loading, rotating and non-rotating, vibrations, fatigue, impact accelerated testing. Shipley [4-5] has listed twelve ways to load test the gears. Majority of these are based on power recirculation type or FZG (back to back gearing) principle.

There are about 2 ways in which torque can be applied to a gear system. These are based on four-square test setup, in which gears sets are joined back to back and locked

1. Methods in which torque can be applied to gears when they are stationary.
2. Methods in which torque can be applied while gears are running.

In the first case the method is simple but requires the gears to start up under full load. In the second case loads can be remote controlled and varied under realistic field conditions. They can be programmed; there is also an advantage of less machine wear because loads can be applied when lubricating conditions are most suitable.

## MACHINE DESCRIPTION

The gear testing machine designed is shown in Fig.1. The test rig consists of following components

1- Gear Housing
2- Vernier Coupling
3- Loading Torque Meter
4- Input Torque Meter

## The Gear Housing

Gear Housing consists of a box, which accommodates identical pair of gears in it. There are two such housings one contains the test gear pair and in the other the driving gear set or constant mesh gear set. They are connected to form a closed power circuit capable of free continues rotation by means of four piece shafting. As seen in the Fig. 1 above, the power input shaft, the first shaft, receives power from the driving motor through an input torque meter. To this shaft is fastened one of the constant mesh gears (driving gears). The other end of this shaft is supported inside the drum which houses the spiral torsion springs, on an antifriction bearing. This arrangement facilitates free rotation of the input shaft in relation to the drum. The length of the input shaft inside the drum is slit diametrically along the length to accommodate the inner ends of the spiral springs. The drum (of the loading torque meter) is mounted on the second piece of shafting, which is supported on bearings housed in the test gear set box. A slot is cut on the drum to hook the free end of the spiral springs. The other end of the second piece of shaft carries the test gear fastened by means of a key. The free end of this shaft is threaded such that the test gear is held in position and also this arrangement facilitates easy removal of the test gear for inspection and replacement of test gear samples. The first and the second shaft rotate on the same axis. The third piece of shaft is mounted on bearings housed in the test gear box. To one end of this shaft one half of the Vernier coupling is fastened by means of a key and to the other end, which is free is mounted with the mating test gear. The end of this shaft is also threaded such that the gear samples can be replaced easily. The fourth shaft, to one end of which the other half of the Vernier coupling is fastened and to the other end of this shaft is fastened the mating gear of the constant mesh gear pair. The third and the fourth shafts rotate on the same axis. Thus the centre distance between the axis of first and second shaft and the axis of third and fourth shat is defined as 100mm for this test rig.

## Vernier Coupling

The Vernier coupling consists of two circular plates fastened to the shaft ends using keys. One among these plates has twenty holes and the other has nineteen holes. The holes are of 8mm diameter and are drilled on a pitch circle diameter of 80mm. This arrangement permits achieving a definite angular increment for every successive hole as it coincides with the reference hole on the Vernier plate. The following relationship gives the incremental value of angular rotation when one plate is rotated in relation to the other.

$$\theta_n - \theta_{n-1} = 360^0 / \{(1/19)-(1/20)\} = 0.9473^0$$

where, $\theta_n$ and $\theta_{n-1}$ are the final and initial value of angle of rotation respectively with reference to the coinciding hole on the Vernier plate. As there are 19 holes on one plate and 20 holes on the other plate, with every successive hole coinciding with the reference hole on the plate having twenty holes, the angle of rotation is given by

$$\theta_n^{th} = 18.9473^0 \times n^{th} \text{ coinciding hole}$$

This feature enables achieving accurate control over the amount of torque applied as the application of loading torque is facilitated using a set of spiral (torsion) springs. Such a feature is desirable for this gear test set up. This is a special feature of this test whereas in the conventional gear test rigs the torque is applied by releasing the clamping bolts which separates the coupling halves. The one half of the coupling is held stationary while the other half is acted upon by a lever loaded by dead weights of desired value effecting the torque required to cause angular twist of a long shaft. The coupling halves are then clamped so that the applied torque is locked between the gear pairs. The torque so locked, however, depends solely on the frictional property of the mating surfaces of the coupling halves. Therefore the reliability of the magnitude of torque locked is less due to vibration and slip between the coupling halves. In addition to this torque transmitted by the test gear will not come close to the realistic environment. The Vernier coupling permits locking the torque more accurately as the coupling halves are locked positively after the application of torque.

**Loading Torque Meter**

Loading torque meter employs a set of spiral springs (one or more depending on the value of torque, for this test rig a maximum of four springs can be used) made from strips of high carbon steel. The torque meter employs four spiral springs together they create a maximum of $3.6\times10^{4}$ N mm torque. Thus when the drive shaft is rotating at 150 rad/s the power locked in the system will be equal to 33 kW or the tooth surface gets loaded to the extent of 150N/mm length of the face width. The schematic view of the test machine is shown in Figures 2. As spiral springs are coiled in a plane normal to the axis of the drive shaft (the first shaft), the inner end of the coil is fastened to the drive shaft through a slot machined on the drive shaft. The springs are housed inside a drum, which also facilitates fastening the outer end of the spiral spring through hooks formed at the outer end of the springs. This arrangement facilitates storage of torque between the drive shaft and the drum and also eliminates the need of a long shaft to udergo angular twist on application of torque. The drive shaft is supported on an antifriction bearing, which facilitates free rotation of the shaft in relation to the drum. Fig.3 illustrates the calibration of the loading torque meter, which clearly indicates the linear fit of the torque versus the angular deflection of the spiral spring. This calibration obtained is for three spiral springs which are identical in their behaviour. Thus, at the zero$^{th}$ ($0^{th}$) coinciding hole the torque applied is zero N.mm and for the first coinciding hole the torque applied is 1520 N.mm, for the second coinciding hole.

the torque increases by 1596 N.mm, giving the total torque applied being 3116 N.mm at the second coinciding hole and 4790 N.mm on the third and so on. The torque locked between the gears, however, remains constant being undisturbed by vibration for a given position of coinciding hole. From the calibration chart given above it is clear that a maximum of $6.6 \times 10^{4}$ N.mm torque can be applied using four springs. For larger toque the springs have to be suitably designed.

**Input Torque meter**

The gear test rig can be used for power loss measurements such that the efficiency of the gear transmission can be measured. It is well known that in this test set up the power required to drive the system is just enough only to overcome the various types of power losses such as frictional power loss due to sliding and rolling between gear tooth-contacts, gear windage losses, losses in bearings and oil churning losses. Among these losses the power loss occurring between gear tooth-contacts (frictional power loss) is predominant and also is proportional to the amount of power transmitted while other types of losses remain nearly constant at a given speed. Therefore the total power loss can be determined by measuring the input torque to the system. As we know that the sliding power loss is much larger than the rolling power loss (the coefficient of friction during rolling is much smaller than during sliding) and other losses being nearly the same at all loads the difference of input power to the system at any two different loads gives the measure of power loss due to friction. Thus the power loss measured is predominantly is sliding power loss and is equal to the summation of sliding power loss occurring between the two pairs of gears loaded back to back in the system.

In order to measure the input power to the test rig a torque meter is employed which is similar in construction to the loading torque meter. But this torque meter is of smaller size as the torque measured is only the frictional power, which amounts to not more than 6% of the power locked between the gear pairs (since there are two pair of gears). A spiral spring is used that can sense a maximum torque of 4000 N-mm. The calibration of the spiral spring is shown in Fig.4. Thus when the input shaft is rotating at an angular velocity of 150 rad/s and if the input torque reaches the maximum value, the input power will be equal to 600 Watts. For larger input power measurement spring of larger torque capacity may be employed. The input torque meter shown in figures 5 and 6, is however, has been exclusively designed and fabricated for measuring the dynamic input torque. The angular rotation of the input shaft in relation to the drum on application of torque is measured by a moving contact (carbon brush) mounted on the cover plate, on a rheostat mounted on the drum. A separate D.C. supply at a constant voltage is maintained through the circuit and an ammeter is used to measure the current flowing in the circuit. The flow of current in the circuit is proportional to the angular rotation of the brush contact on the rheostat which in turn depends on the torque transmitted between the motor and the gear test rig.. The circuit diagram is shown in Fig. 7.

## MEASUREMENT OF INPUT POWER USING DC MOTOR

Alternatively a direct current (DC) motor of capacity 373 Watts (0.5 Horse power) is employed which is excited externally, to drive the gear test rig. The amount of power supplied to the armature gives the measure of power loss in the system. Fig. 8 illustrates the circuit diagram of the motor. Using measuring devices with fine resolution the sensitivity of the system can be improved enabling measurement of power loss very accurately.

In this way, the input power to the test rig can be mesured using three different methods which helps in comparing the accuracy of mesurements and also the reliability of measurements.

## CONCLUSIONS

For the purpose of testing gears for their performance a number of gear testing machine have been built. Most of the machines in use are based on power recirculation type because they consume a small amount of power to drive them even when a large power is locked between the gears. This power consists largely of frictional power loss occurring between the gear tooth-contacts. The power and hence the efficiency of the gear set can be measured if accurate measurement of input power is possible. This test set up can also be used for measuring surface durability of gear samples through accelerated gear testing methods. These machines being very large in size cost more, weigh more and become less portable. In view of these problems a simple gear test rig is developed and based on the performance following conclusions are drawn:

- The test set up is very compact and a large value of torque can be created by suitably selecting the springs to apply the loads.
- The power required to drive the test set up is very small
- Torque applied remains constant as the spring load is positively locked.
- Test gears can be easily replaced after testing each sample
- Power loss occurring in a gear pair can be estimated more accurately
- The test set up can be easily dismantled for transportation from one place to another.

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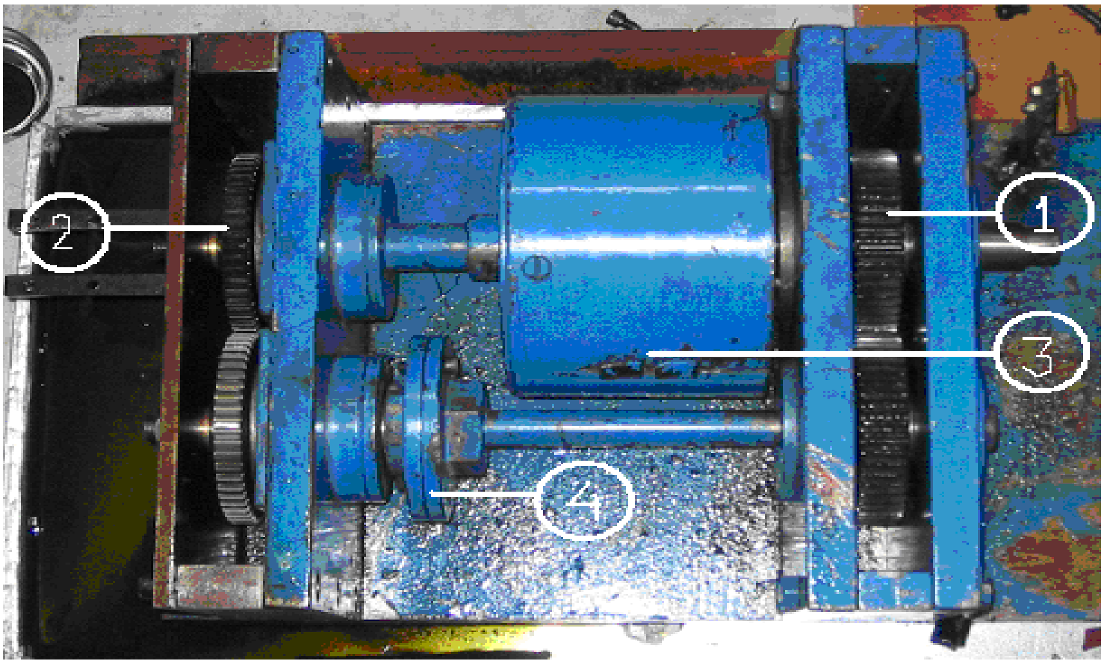


Fig. 1. GEAR TESTING MACHINE
1. Constant mesh gears, 2. Test gear, 3. Loading torque meter and 4. Vernier coupling.

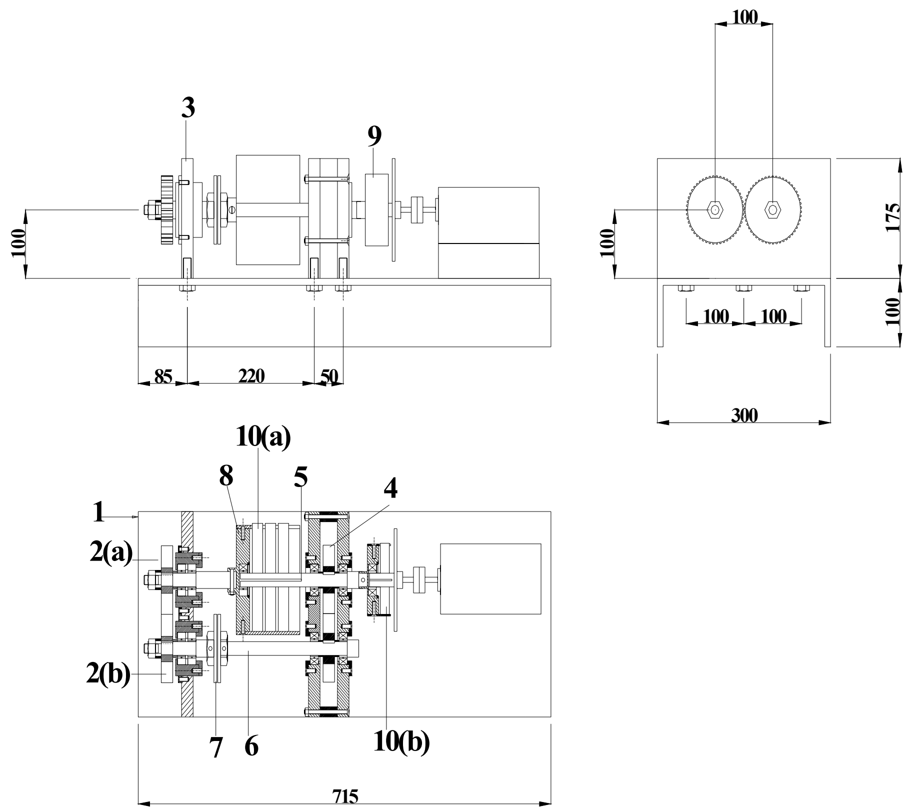


**Fig. 2**. Power Recirculation type Gear Test Rig.

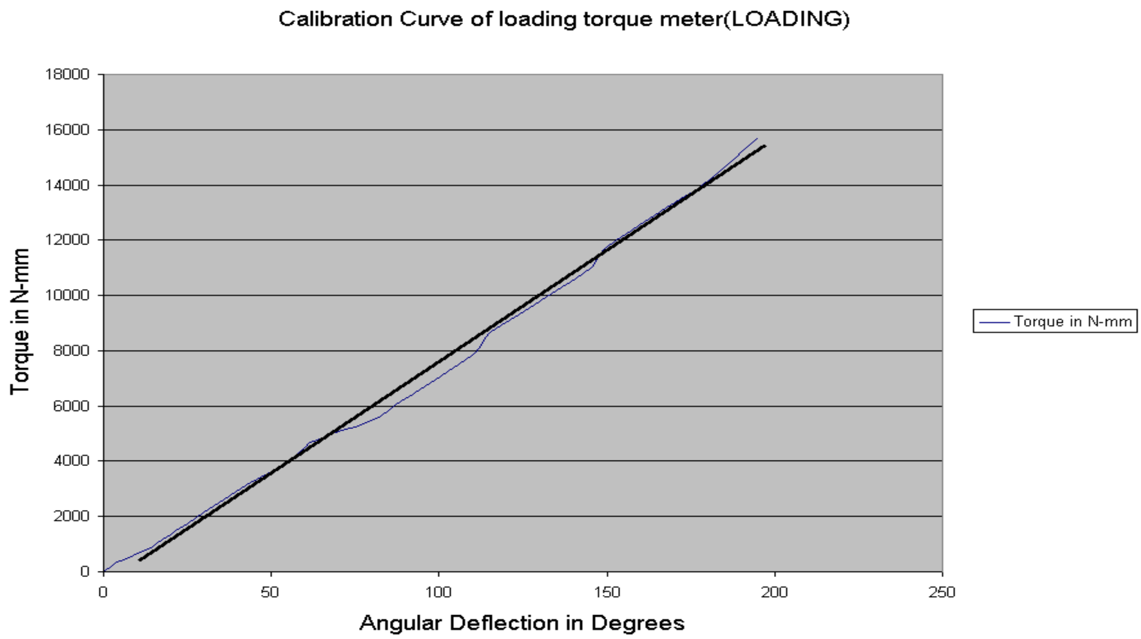


**Fig.3.** Calibration of loading torque meter using three spiral springs.

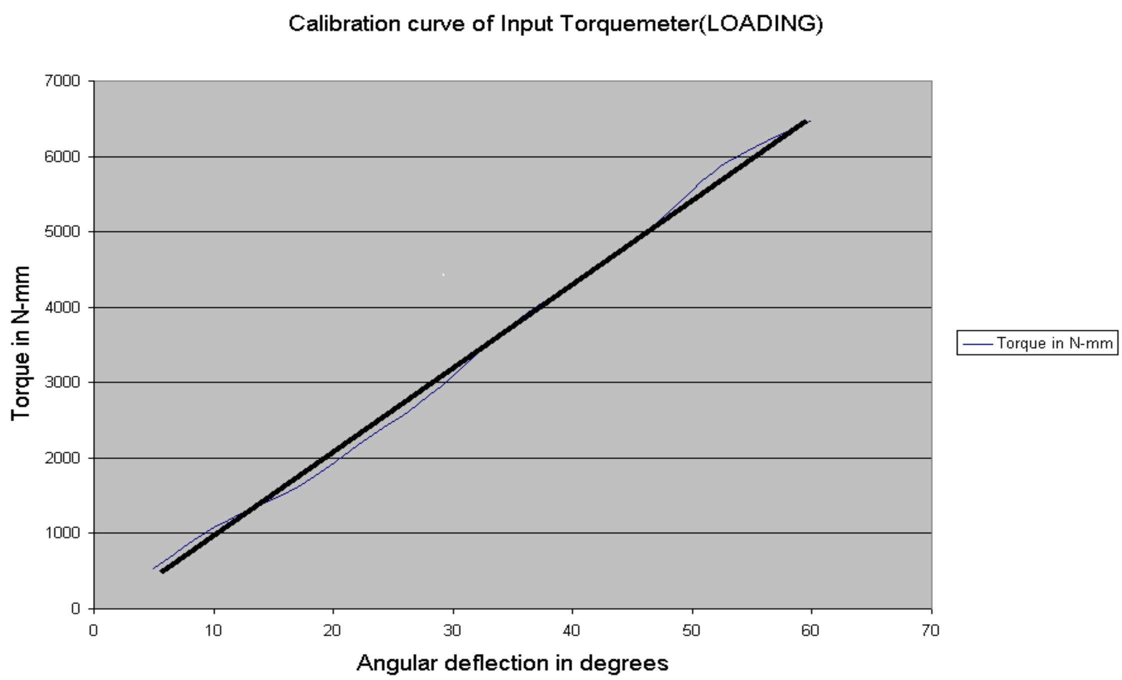


**Fig.4.** Calibration of the spiral spring used in the input torque meter.

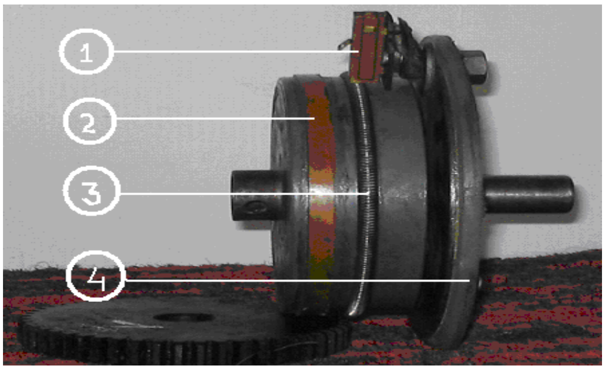


**Fig.5.** INPUT TORQUE METER
(1) Carbon brush holder (2) Copper ring
(3) Resistance wire (nichrome wire)
(4) Cover plate

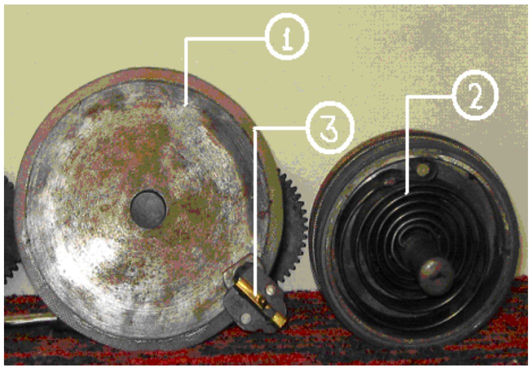


**Fig.6**. INPUT TORQUE METER (Details)
1- Cover plate, 2- Spiral spring
3- Carbon brush holder

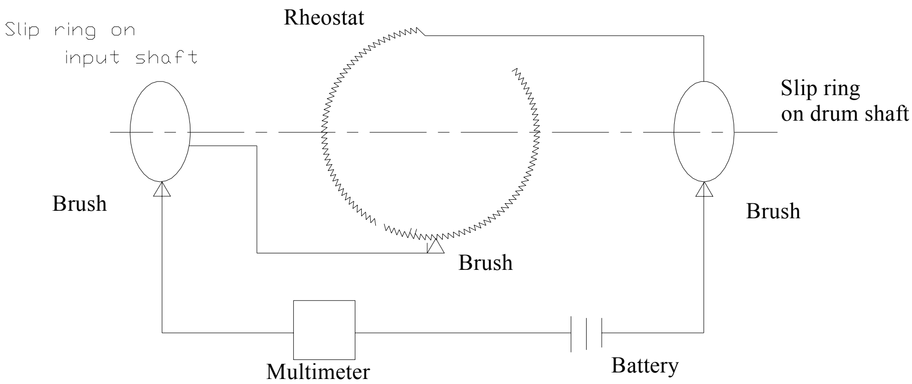


**Fig.7.** Circuit diagram to measure power loss at input Torque meter.

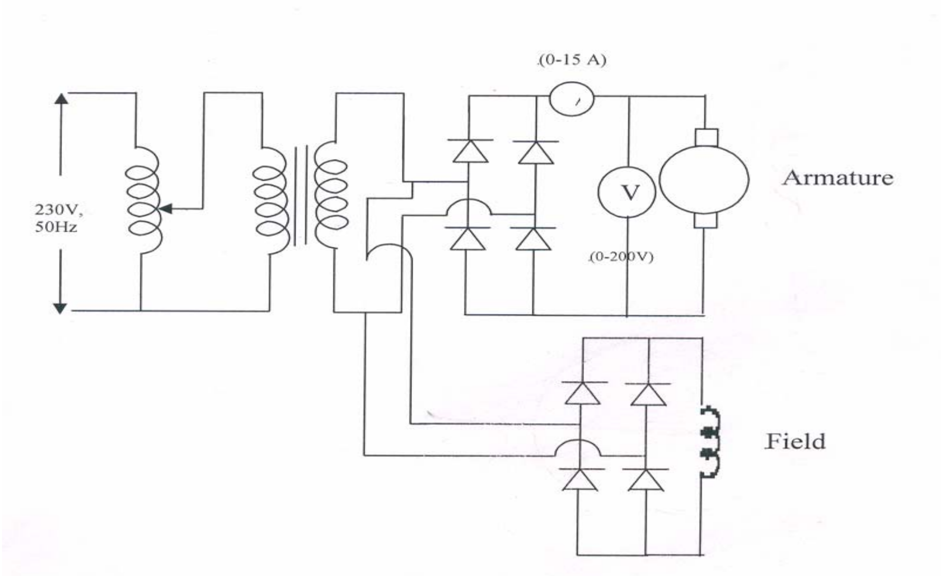


**Fig. 8.** Illustrates the separate excitation of the field and power supply to the armature.

Fig. 9. A Side View of the Test Rig which shows test gear driving gear and the photograph on the right is of the spiral spring used in the torque meter.