Development and Testing of Friction and Wear Test Rig

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ABSTRACT

This research paper presents a friction and wear test rig, developed from locally available materials. Sizing of the various components of the rig was done as specified by Society of Automobile Engineers. The required materials for the test rig were sourced locally, constructed and assembled. The input shaft was sized to fit in the speed range of available lathe machines. The test rig was tested using Soy oil, groundnut oil and SAE 40 oil lubricant. Samples generated from the test rig were analyzed using Atomic Absorption Spectroscopy to obtain wear metal count in the oil samples. Results for three wear elements showed that at 40 rpm, copper in oil samples ranged from 6.2 % - 10.2 % concentration whereas at higher speeds, a distinct reduction in wear metal concentration was obtained. Other wear elements followed similar profile. The test rig is capable of predicting performance of oil lubricants in storage and operating conditions. The test rig is recommended in industries to increase mean time between machine failures of production equipment thereby improving productivity and profitability.

KEYWORDS: Test, Rig, Lubrication, Friction, Wear, Design

1. INTRODUCTION

Friction between two bodies is generally defined as the force at their surface of contact which resists their sliding on one another. The friction force, F is the force required to initiate or maintain motion. If W is the normal reaction of one body on the other, the coefficient of friction, μ is defined as [1]:

$$\mu = \frac{F}{N} \tag{1}$$

Wear is a process of gradual removal of a material from surfaces of solids subject to contact and sliding. Damages of contact surfaces are results of wear [2]. Types of wear include Abrasive wear, fatigue wear, corrosion wear etc. Usually, wear is undesirable, because it makes necessary frequent inspection and replacements of parts and leads to deterioration of accuracy of machine parts. Wear induces vibrations, fatigue and consequently failure of the parts.

Lubrication is the application of a lubricant between contacting surfaces, moving relative to each other with the aim of reducing friction [3]. In most cases, the applied load is carried by pressure generated within the fluid due to the frictional viscous resistance to motion of the lubricating fluid between the surfaces. Lubrication may be classified into Boundary lubrication, Eastohydrodynamic and Full Fluid-film lubrication.

The science and technology of interacting surfaces in relative motion is called Tribology. Tribology is derived from the Greek word *"Tribos"* meaning rubbing. It is the study of the friction, lubrication and wear of engineering surfaces with a view of understanding surface interactions in detail and then prescribing improvements in given applications [4]. Variables in friction and wear testing are load, velocity, contact area, surface finish, sliding distance, environment, material of contact face, type of lubricant, hardness of contact face and temperature [5].

A test rig is an apparatus or equipment used for measuring the performance of any mechanical equipment [6]. Tribo test rigs are devices used for investigating friction and wear. Laboratory friction and wear tests utilize tribometer systems of simple geometry that may include a rotating cylinder or disc against which another solid specimen of different curvature is pressed [7]. When test rigs are used in combination with ferrographic analyzers and metal counters, friction and wear can be measured fairly accurately. These tests assess predominantly the overall ability of a lubricant to permit rubbing surfaces to operate without scuffing, seizure or other manifestation of material destruction.

This study developed and evaluated the performance of a friction and wear test rig to be used for measuring the performance of lubricating oils.

2. COMPONENTS AND MECHANISM OF OPERATION
2.1. Components of the Test Rig

The Test Rig is made of the helical spring, shaft, screw, bevel gears, oil plug, webbed lever, and fasteners.

2.2. Mechanism of Operation

The proposed design was actualized by assembling four bevel gears (two pinions and two wheels) in a gear housing. A shaft machined to fit into the jaw of a centre lathe and welded to one of the pinion gears was employed to transfer torque from the centre lather to the bevel gears. While performing a test, the center lathe is used to turn the bevel gears at selected speeds. Pressure between the meshing gears is achieved by means of a power screw connected to a spring of known stiffness. During tests, the system remains submerged in a lubricant carried by the gear housing. A thermometer is used to take the temperature reading of each oil sample after every running operation. After running a sample at a specific speed, load and time, the oil sample is drained and taken for metal count. The efficiency of a lubricant is determined by the degree to which it reduces the amount of metal worn into the oil.

3. DESIGN CONCEPT

The design of the various components of the test rig was done, making reference to the scholarly works of Khurmi R. S. and Gupta J.K. [8-9].

3.1. Design of the Spring

The spring constant, K can be determined from the relationship below:

$$K = \frac{Gd^4}{8D^3 n_a} \tag{2}$$

Where G = Shear modulus of material, d = Spring wire diameter, D = Mean diameter of spring, and n_a = Number of active coils.

The shear modulus, G is given as:

$$G = \frac{E}{2(1+v)} \tag{3}$$

Where E = Young's modulus and v = Poisson's ratio.
The mean diameter, D is given as:

$$D = D_{outer} - d \tag{4}$$

Where D_{outer} = Outer diameter.

The maximum force the spring can, F_{max} is expressed as:

$$F_{max} = K(L_{free} - L_{solid}) \tag{5}$$

Where L_{free} = Free length of spring, L_{solid} = Solid length of spring.

The maximum shear stress, τ_{max} is given as:

$$\tau_{max} = \frac{8WD}{\pi d^3} F_{max} \tag{6}$$

Where W is the Wahl correction factor, defined as:

$$W = \frac{4C-1}{4C-4} + \frac{0.615}{C} \tag{7}$$

Where C is given as:

$$C = \frac{D}{d} \tag{8}$$

3.2. Design of Shaft for the Pinion

Since the pinion is subjected to torsion only, the diameter of the shaft, d may be obtained as follows:

$$\frac{T}{J} = \frac{\tau}{r} \tag{9}$$

$$r = \frac{d}{2} \tag{10}$$

Where T = Twisting moment or torque transmitted by shaft, τ = Shear stress, r = Distance of neural axis from outermost fibre and J = Polar moment of inertia, defined as:

$$J = \frac{\pi}{32} d^4 \tag{11}$$

The Torque transmitted by the shaft can thus be expressed as:

$$T = \frac{\tau}{16} \tau d^3 \tag{12}$$

Or

$$T = \frac{60P}{2\pi N} \tag{13}$$

Where: P = Power transmitted by shaft and N = Speed of shaft in rpm

3.3. Design of the Screw

In order to design a screw jack for a load W, the following procedure may be adopted:
The core diameter of the screw, d_c considering only the compressive stress, σ_c may be calculated from:

$$\sigma_c = \frac{W}{\frac{\pi}{4} d_c^2} \tag{14}$$

The effort at the handle required to raise the load, P_r is given as:

$$P_r = W tan(\varphi + \alpha) \tag{15}$$

The effort at the handle required to lower the load, P_l is given as:

$$P_l = W tan(\varphi - \alpha) \tag{16}$$

Where φ = Angle of friction and α = Screw helix angle.

The torque required to raise the load, T_r is given as:

$$T_r = \frac{P d_m}{2} \tag{17}$$

The torque required to lower the load, T_l is given as:

$$T_l = \frac{P d_m}{2} \tag{18}$$

Where d_m = Mean diameter of the screw

This means,

$$T_r = W tan(\varphi + \alpha) \frac{d}{2} \tag{19}$$

And

$$T_l = W tan(\varphi - \alpha) \frac{d}{2} \tag{20}$$

3.4. Assembly of Test Rig

The test rig was assembled as shown below (Figure 1-3). The parts include 1. Webbed lever 2. Power screw 3. Compression spring 4. Test rig casing 5. Gear housing 6. Pinion shaft 7. Bearing 8. Oil plug 9. Bolt and nut 10 Bevel gear
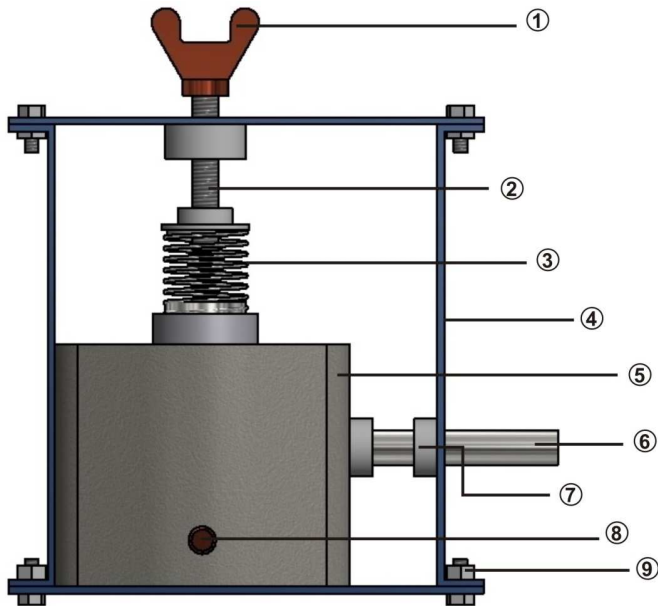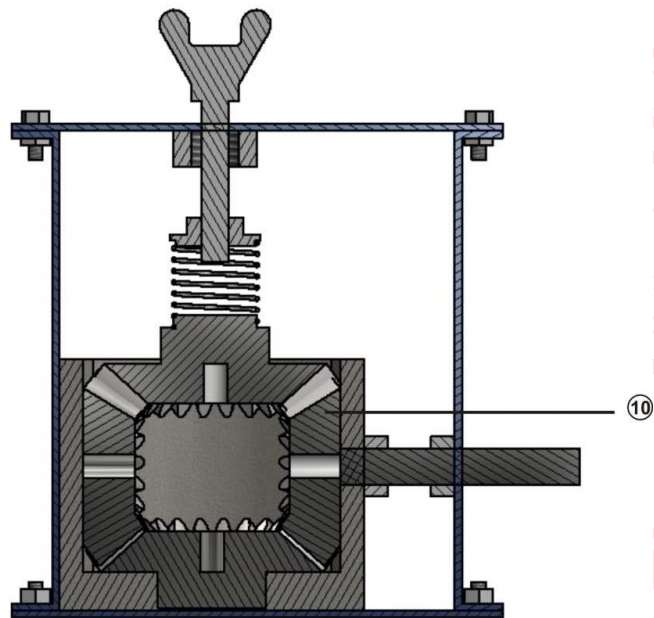
Figure1: Test Rig - Front View
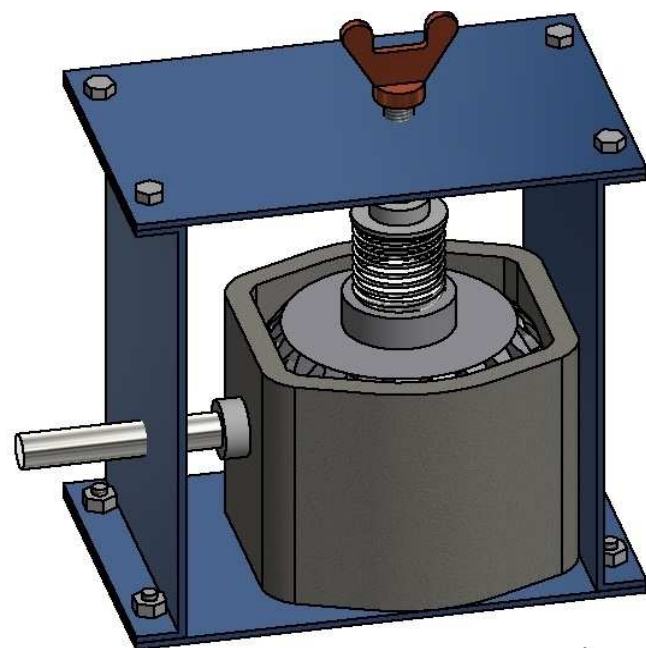

Figure2: Test Rig – Sectional Front View

Figure3: Test Rig – Three Dimensional Model View

4. TESTING OF RIG
4.1. Generation of Oil Samples
The test was conducted using Soy oil, Groundnut oil and SAE 40 lubricating oil. A total of 9 test samples were generated after running the aforementioned oils at 3 different speeds for a constant load at 5 minutes each as shown in the Table 1 below.

Table1: Samples Generated for Metal Count

SN	SAMPLE	SAMPLE DESCRIPTION	SPEED (RPM)
1	S1	Soy Oil	40
2	S2	Soy Oil	90
3	S3	Soy Oil	120
4	S4	G/Nut Oil	40
5	S5	G/Nut Oil	90
6	S6	G/Nut Oil	120
7	S7	SAE 40 Oil	40
8	S8	SAE 40 Oil	90
9	S9	SAE 40 Oil	120

4.2. Metal Count
Oil samples generated above were taken for metal count using Atomic Absorption Spectroscopy. Results for the test are presented in the section that follows.

5. RESULT AND DISCUSSION
5.1. Result
Line graphs obtained from results of metal count are shown in Figure 4 – 6. Figure 4 shows the Change in Percentage Concentration of Metals with Input Shaft Speed for Soy Oil (S1), Figure 5 shows the Change in Percentage Concentration of Metals with Input Shaft Speed for SAE 40 Oil (S3) and Figure 6 shows the Change in Percentage Concentration of Metals with Input Shaft Speed for Groundnut Oil (S2)
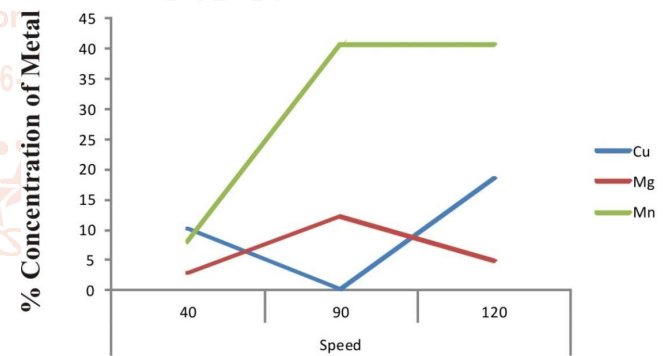

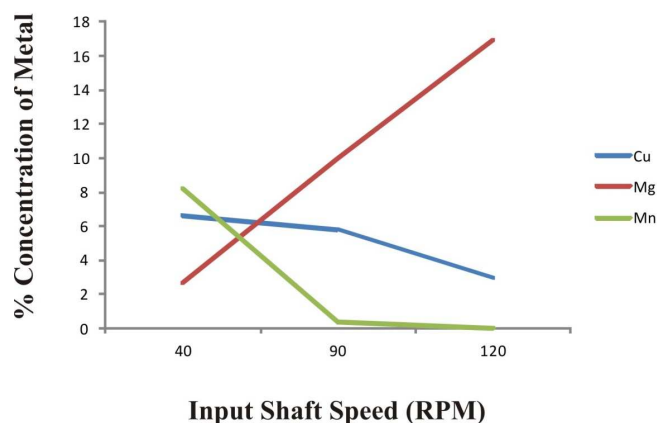**Figure4: Change in Percentage Concentration of Metals with Input Shaft Speed for Soy Oil (S1)**
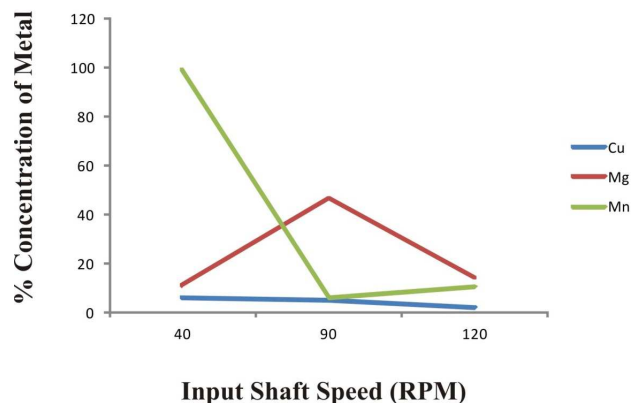

Figure5: Change in Percentage Concentration of Metals with Input Shaft Speed for SAE 40 Oil (S3)

Figure6: Change in Percentage Concentration of Metals with Input Shaft Speed for Groundnut Oil (S2)

5.2. Discussion
Comparing figure 4 – 6, it is observed that at 40rpm, the Soy oil sample (S1) contained 10.2 % Cu, while the Groundnut oil sample (S2), and SAE 40 oil sample (S3) contained 6.2 % Cu and 6.6 % Cu respectively. The source of copper could be traced to the gears and bearings of the friction and wear test rig. The good performance of the groundnut oil sample at low speed of 40 rpm could be attributed to the presence of fatty acids in the oil that formed metallic soaps with the surface of the gears and bearings thereby producing a lubrication film that was able to resist friction and wear. This observation agrees with Nnuka et al. [7] who found that by adding small quantity of natural oil to mineral oil lubricant, there was an improvement in wear and friction performance. For the samples compared above, it is observed that as speed increased, there is a general drop in percentage concentration of copper in the samples. This is in agreement with [10] who observed that at low speeds, lubricants tend to perform under boundary lubrication conditions where composition and properties of lubricants determine lubrication performance. However, as the speed increases, hydrodynamic lubrication condition sets in and the primary property that matter is viscosity.

Also from the figures compared, it is observed that at 40rpm, Manganese stood out but as the speed increased, Magnesium exceeded Manganese while Copper dropped progressively due to transformation from boundary lubrication condition to hydrodynamic condition.

6. CONCLUSION
The friction and wear test rig has been designed and tested. The test rig is used in combination with ferrographic analyzers, metal counters, gas liquid chromatographs, etc. for predicting the ability of oil lubricants to reduce friction and wear. The test rig plays an important role in lubrication because it is pivotal in determining the performance of oil lubricants at different storage and working conditions. The test rig is considerably cheap compared to the conventional testing devices.

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