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Design & Manufacture of Testing Machine To Analyse the Tribological Behaviour of Sliding Contact Materials-A Case Study

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Abstract-

The study of tribology is commonly applied in bearings design but extends into almost all other aspects of modern technology, even to such unlikely areas as hair conditioners and cosmetics such as lipstick, powders and lip gloss.

Any product where one material slides or rubs over another is affected by complex tribological interactions, whether lubricated like hip implants and other artificial prostheses , or unlubricated as in high temperature sliding wear in which conventional lubricants cannot be used but in which the formation of compacted oxide layer glazes have been observed to protect against wear.

Tribology plays an important role in manufacturing. In metal-forming operations, friction increases tool wear and the power required to work a piece. This results in increased costs due to more frequent tool replacement, loss of tolerance as tool dimensions shift, and greater forces required to shape a piece. The use of lubricants which minimize direct surface contact reduces tool wear and power requirements.

The purpose of our testing is to investigate the tribological properties of several low-friction ,sliding contact materials in contact with each other in order to determine their usefulness for different applications. All tests were performed using our testing machine to measure dynamic coefficient of friction. Results will be used to evaluate the potential of materials for the use in various similar applications, where low friction and acceptable wear characteristics are desirable.

Keywords – **Tribology, surface roughness, wear, micro- structure, etc.**

Problem Definition: -

To Design & Manufacture a testing machine to analyse the tribological behaviour of sliding contact materials at well known Pvt Ltd Company in Pune .

- **Introduction to sealing technology**

A mechanical seal is a sealing device which forms a running seal between rotating and stationary parts. They were developed to overcome the disadvantages of compression packing. Leakage can be reduced to a level meeting environmental standards of government regulating agencies and maintenance costs can be lower.

- **Working of Mechanical Seals**

The primary seal is achieved by two very flat, lapped faces which create a difficult leakage path perpendicular to the shaft. Rubbing contact between these two flat mating surfaces minimizes leakage. As in all seals, one face is held stationary in housing and the other face is fixed to, and rotates with, the shaft. One of the faces is usually a non-galling material such as carbon-graphite. The other is usually a relatively hard material like silicon-carbide. Dissimilar materials are usually used for the stationary insert and the rotating seal ring face in order to prevent adhesion of the two faces. The softer face usually has the smaller mating surface and is commonly called the wear nose.

There are four main sealing points within an end face mechanical seal (Fig. 2.1). The primary seal is at the seal face, Point A. The leakage path at Point B is blocked by an O-ring, a V-ring or a wedge. Leakage paths at Points C and D are blocked by gaskets or O-rings.

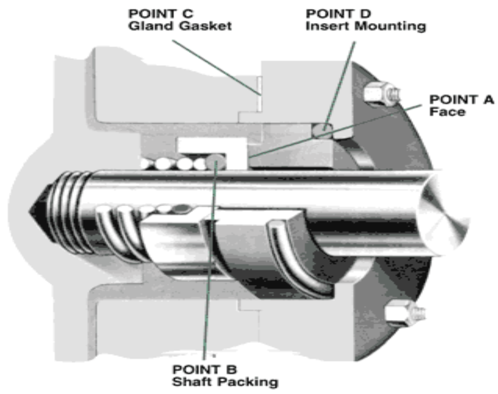


Fig.1 - Sealing Points for Mechanical Seal

The faces in a typical mechanical seal are lubricated with a boundary layer of gas or liquid between the faces. In designing seals for the desired leakage, seal life, and energy consumption, the designer must consider how the faces are to be lubricated and select from a number of modes of seal face lubrication.

To select the best seal design, it's necessary to know as much as possible about the operating conditions and the product to be sealed. Complete information about the product and environment will allow selection of the best seal for the application.

1. PROBLEMS WITH MECHANICAL SEALS

1. 1 Failure of Mechanical Seals-

Mechanical Seals failures because of four broad categories-

- The seal motion was restricted and the faces opened.
- Heat caused the O-rings to deteriorate.
- The seal materials were attacked by the fluid sealed.
- The seal was installed incorrectly.

1.2 Mechanical Seals motion restricted

The spring-loaded (dynamic) seal face constantly moves to maintain full face contact with the stationary seal face. The main reasons for this movement are

1. The stationary face is not perpendicular to the pump shaft..
2. The pump has bearing end play. This means that the shaft moves back and forth a few thousands of an inch at frequent but random intervals.
3. There is some impeller unbalance causing shaft whip.
4. The pump is operated away from its BEP, causing side loads on the shaft.
5. There is thermal shaft growth and Pump vibration that affects the seal.

1.3 Here are the major conditions that can restrict movement of the spring loaded mechanical seals face

1. Solids have collected in the seal or around the dynamic seal ring.
2. The fluid sealed has caused the dynamic O-ring to swell.
3. The temperature limit of the dynamic O-ring has been exceeded and the O-ring has lost its elasticity (compression set) or become hard.
4. Spring compression is inadequate because of incorrect installation.
5. Solids in the stuffing box, gasket protrusion or other foreign material restrict the motion of dynamic seal ring.

1.4 Thermal degradation of Mechanical Seal 0-rings

O-rings are the one part of a mechanical seal that are sensitive to heat because of the way they are manufactured. The ingredients are mixed together, put in a mould and cured at high temperature for a specific time. The compound will then assume the shape of the mould and its hardness will increase. When the O-ring is placed in an O-ring groove in a seal and heated to a temperature beyond its recommended limit, the curing process will continue and the O-ring will take a compression set. This means that the O-ring has lost some of its resilience and squeeze, and fluid may leak past the O-ring. The higher the temperature, the shorter the time before the O-ring takes a compression set. When an O-ring is exposed to high temperature for a long period, it will become hard and brittle, causing mechanical seals failure.

1.5 Since heat is often a problem and seldom helps the mechanical seal application, what can be done about it ?

1. Use a balanced seal to minimize the heat generated by the seal.
2. Use low-friction face materials. Carbon vs silicon carbide is the best choice.
3. Use a clean liquid flush or product recirculation to carry away heat.

1.6 Mechanical Seal materials attacked

When the correct materials are not selected,

1. The 0-rings may swell locking up the mechanical seal,
2. The mechanical seal faces may deteriorate rapidly, and
3. The metal seal components may corrode.

All can cause the mechanical seals to fail.

1.7 Mechanical seals installed incorrectly

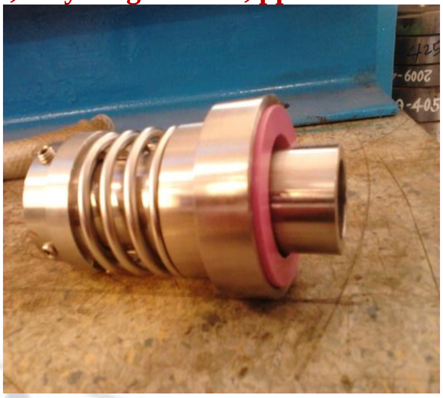
Many mechanical seals fail at initial start-up or prematurely because they were not installed correctly. Cartridge seals eliminate all measurement, protect the seal faces from contamination and are easy to install. With these seals, installation problems are minimized. The Outside seal is preset and requires no installation measurement. Only in-line seals require careful measurement to insure correct installation. By following the mechanical seals installation instructions, step-by-step correct seal installation is easily achieved.

2. MANUFACTURED COMPONENTS OF MACHINE

Housing

Disassembeled Seal Assembly

Seal Face



Assembled Seal Assembly

Gland

Actual Manufactured Testing Machine

Fig. 2 – Various components of machine

3. PROJECT:- TRIBOLOGICAL EVALUATION OF SLIDING FACES

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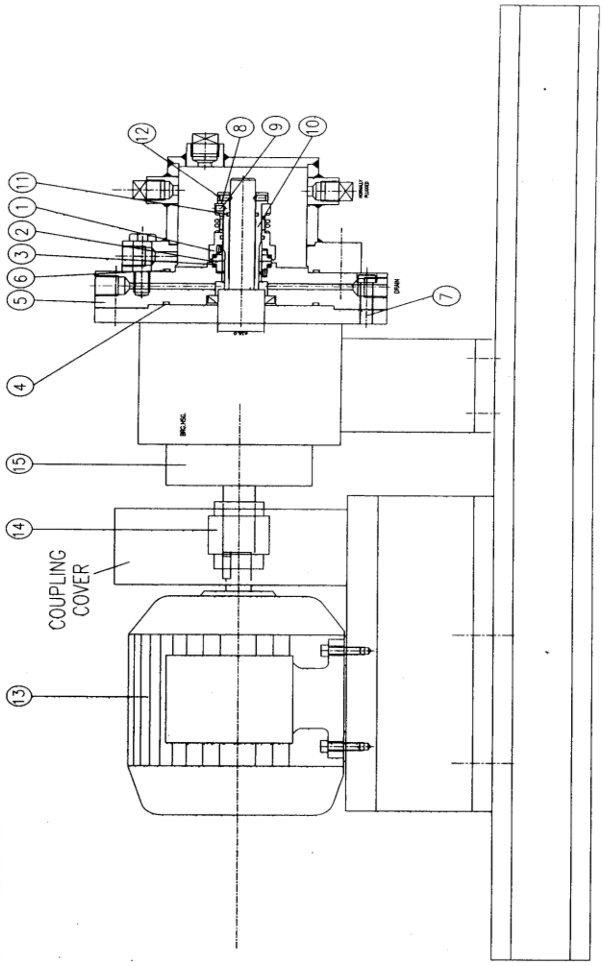

Fig.3 – CAD diagram

NO.	DESCRIPTION	QTY.	MATL.
1	ROTARY SLIDING FACE ASSY.	–	
2	STATIONARY SLIDING FACE	1	–
3	'O' RING	1	VITON
4	'O' RING	1	VITON
5	HOUSING	1	S.S.
6	'O' RING	1	VITON
7	SOC.HD.CAP SCR.	6	HTS.
8	BACKING RING	1	S.S.304

NO.	DESCRIPTION	QTY.	MATL.
9	SOC.SET.SCR.	3	HTS.
10	SLEEVE	1	S.S.304
11	'O' RING	1	VITON
12	SOC.SET.SCR.	3	HTS.
13	MOTOR–1.5 HP	1	STD.
14	LOVEJOY COUPLING	1	CI.
15	BEARING HOUSING WITH BEARING	1	M.S.

4. TESTING AND ANALYSIS

List of Combinations

1. SIC- TC
2. SIC- Carbon
3. SIC- Ceramic
4. SIC- SIC
5. Carbon- SS-316
6. TC- Carbon
7. Ceramic- TC
8. Carbon- Carbon
9. SIC- SS-316
10. Ceramic- Carbon
11. SS-316 – TC
12. Ceramic- SS-316

Due to the limited number of sliding contact materials, we could make only 12 possible combinations for testing.

5. OBSERVATION TABLE

{ $\Delta T = 18°C$ }

Sr. No.	Material-1 (Stationary)	Material-2 (Rotary)	Temp (°C) (Initial= 31)	Current (Amp) (Initial= 0.8)	Time (min)
1	**Ceramic** *(width Before Test)*:- **11.075mm 11.065mm 11.054mm 11.071mm** *(width After Test)*:- **11.067mm 11.071mm 11.064mm 11.061mm**	**Tungsten Carbide** *(width Before Test)*:- **11.245 mm 11.258 mm 11.270 mm 11.261 mm** *(width After Test)*:- **11.251 mm 11.269 mm 11.255 mm 11.245 mm**	36	0.8	10
2			41	0.8	10
3			44	0.7	10
4			47	0.7	10
5			49	0.7	10
6			49	0.7	10

5.1 Note: - (All readings are taken at constant pressure = 10 bar.)
The values of temperature and current are noted down after 10 mins interval and the procedure is repeated for 12 possible combinations mentioned above.)

5.2 Calculations for Coefficient Of Friction
For the case of SIC-TC

As $P = V * I$

Where, P = Power given by motor
V = Rated voltage of motor
I = Average Current consumed by machine
= 415*1.1
= 456.5 VA
P = 0.6119 HP (Since 1HP = 746 W)

As

HP= [2 π nT] /4500

0.6119 = [2 * 3.14 * 1400 * T]/4500

T = 0.3127 Kgf- m

As

T = F * r

0.3127 = F * 0.025

F = 12.508 Kgf

F_1 = 7.32 Kgf (spring load)

F_2 = P * Circumferential area were force is being applied by water

$F_2 = 10 * 3.14 (22^2 – 15^2)$

F_2 = 8132.6 Kgf

As

Coefficient of friction = Force applied/Normal reaction

= $F / (F_1+ F_2)$

= 12.508 / (7.32+8132.6)

= 0.0015

Therefore, Coefficient of friction = 1.5×10^{-3}

Similar coefficient of friction is calculated for all possible combinations.

5.3 Table for coefficient of friction and temperature rise

Test . No	Material 1 (Stationary)	Material 2 (Rotating)	Temp rise in 1 hr in degree Celsius	Coefficient of Friction x $10^{(-3)}$
1	SIC	Carbon	03	0.837
2	ceramic	TC	18	1.041
3	Carbon	Carbon	18	1.113
4	Carbon	SS 316	12	1.12
5	Ceramic	Carbon	14	1.14
6	TC	Carbon	10	1.32
7	SIC	SS 316	10	1.48
8	SIC	TC	5	1.5
9	SIC	SIC	18	1.621
10	SIC	Ceramic	35	1.641
11	SS 316	TC	Leakage	Leakage
12	Ceramic	SS 316	leakage	leakage

5.4 Table for Wear

Test no.		Material 1	Material 2
1	Name	SIC	Carbon
	Wear	0.0005mm	0.0035mm
2	Name	Ceramic	TC
	wear	0.013	0.01775
3	Name	Carbon	Carbon
	Wear	0.0025mm	0.037275mm
4	Name	Carbon	SS 316
	Wear	0.0255mm	0.0015mm
5	Name	Ceramic	Carbon
	Wear	0.0045mm	0.0035mm
6	Name	TC	Carbon
	Wear	0.00425mm	0.001mm
7	Name	SIC	SS 316
	Wear	0.002mm	0.005mm
8	Name	SIC	TC
	Wear	0.0165mm	0.006mm
9	name	SIC	Ceramic
	Wear	0.0995mm	0.01275mm
10	Name	SIC	SIC
	Wear	0.00725mm	0.00025mm

6. PROFILE MICROSRTUCTURE (CERAMIC & TC)

It is to be noted that, the microstructures of 12 possible combinations are observed under the Scanning – Tunnelling microscope before and after the test.

Fig shows the microstructures of Ceramic and Tungsten Carbide combination before and after the test.

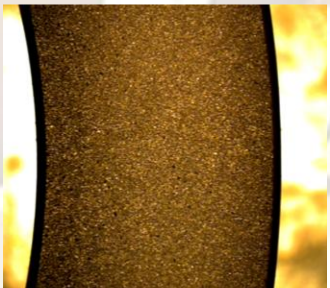

Fig 4 - Ceramic Fig 5 - Tungsten Carbide
(Before Test) (Before Test)

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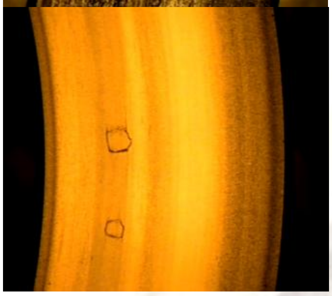
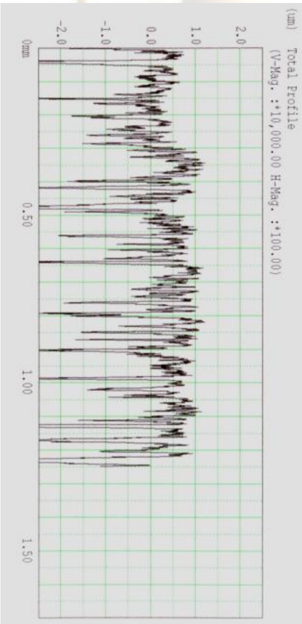


Fig 6 - Ceramic Fig 7 - Tungsten Carbide
(After Test) (After Test)

7. SURFACE ROUGHNESS



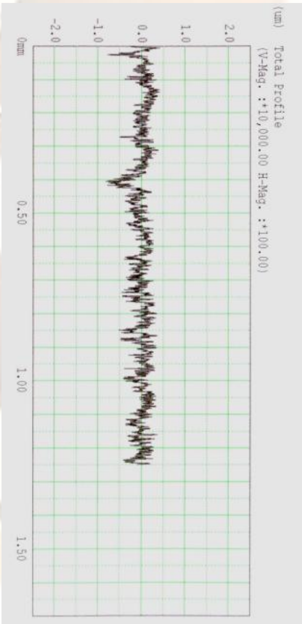
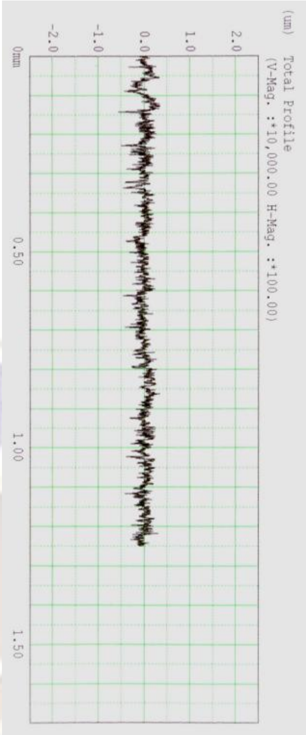


Fig 8 – Ceramic (Before Test) Fig 9 – Ceramic (After Test)
Ra value=0.6635µm Ra value=0.1453µm



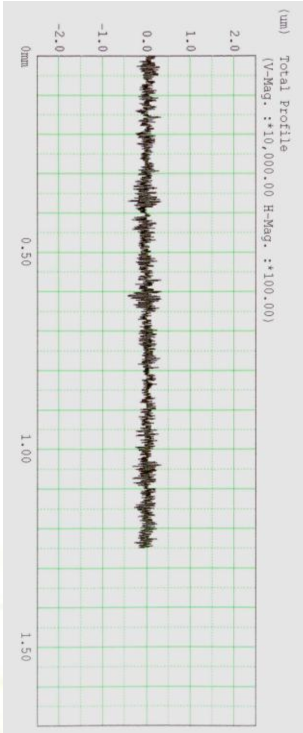


Fig 10 - Tungsten Carbide Fig 11 - Tungsten Carbide
(Before Test) (After Test)
Ra value=0.0958µm Ra value=0.0917µm

7.1 Note: - The graphs of 12 possible combinations are dawn with the help of surface roughness tester, before and after the test.

Fig 8, 9, 10, 11 shows the graphs of Ceramic and Tungsten Carbide combination before and after the test.

FUTURE SCOPE

The following modifications can be done in this machine.

These are as follows: 1) Automation with sensor
2) Different lubricants
3) Mixture of liquids

1. The measured quantities like pressure, temperature, current can be viewed directly on display with the help of sensors.
2. In our testing we used water as lubricant, but other lubricants can be used without much modification.
3. With the help of two tanks different mixtures of liquids can be stored and used i.e. testing with hot and cold liquid is also possible.

9. CONCLUSION

Coefficient of friction is our main parameter of concern so we have selected the three

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pairs which were having the lowest coefficient of friction amongst the twelve pairs. Those are:

(i) SIC-Carbon
(ii) Ceramic-TC
(iii) Carbon-Carbon

Sr. No.	Combinations	Coefficient Of Friction	Surface Roughness Changes In µm	Surface Microstructure Changes	Wear in (mm)
1.	SIC – SS316	Low (0.837* $10^{(-3)}$)	Low (SIC = 0.0311) (Carbon = 1.9554)	High	Medium (SIC = 0.013) (Carbon = 0.01775)
2.	Ceramic - TC	Medium (1.041* $10^{(-3)}$)	High (Ceramic = -0.5182) (TC =-0.0041)	Low	Low (Ceramic = 0.0005) (TC = 0.0035)
3.	Carbon-Carbon	High (1.113* $10^{(-3)}$)	Low (Carbon 1 = -0.0042) (Carbon 2 = 0.0394)	Low	Medium (Carbon 1 = 0.0025) (Carbon 2 = 0.0372)

Comparison amongst the top three combinations

- From the above table we can see that the coefficient of friction is minimum for 1st combination but change in microstructure of SS316 is very horrible also the surface roughness changes for SS316 is very high. Hence, this is not a advisable combination.
- In case of 2nd combination, though the coefficient of friction is not as low as the 1st combination but still its other properties are quite good like the surface microstructure changes of both the material is less and also the surface roughness has not changed much ,in fact the surface roughness has decreased that means both the materials have lapped each other
- As far as the cost factor is concerned these seal faces are used at such places were its cost is just equal to the cost of 0.1% of the whole project. So cost is not a big issue during the use of this seal faces only the importance is of safety of its working and which is ensured by all the properties mentioned in the above table.
- Hence, by our observations and calculations we can conclude that ***CERAMIC-TC*** is the best combination possible from all the available combinations with us.

Due to the following facts

(i) Low Coefficient of Friction
(ii) Less changes in Surface Microstructure
(iii) Less changes in Surface Roughness
(iv) Lowest Wear

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