CHAPTER 5

PIN-ON-DISK TESTS

5.1 The High Temperature Pin-on-disk machine

A high temperature pin-on-disk machine manufactured by the Institute of Terotechnology, Radom, Poland was used to evaluate the anti-wear and anti-friction properties of certain lubricants/ formulations that were eventually used for engine tests. This machine (named T-11) has the capability to test materials such as plastics, ceramics, metals as well as surface coatings under conditions of dry friction or lubrication. This can be carried out in air or gaseous ambiance, at any temperature between room temperature and 300^o C. Moreover, the manufacturer claims that the tribological investigations performed on this tester conform to the ASTM G 99-90 standard: *Standard Test Method for Wear Testing with a Pin-on-disk Apparatus.*

The technical specifications of this machine are included in Appendix C. Important features of this machine are:

- Friction couple loading unit
- Driving unit
- Force transducer unit
- Displacement transducer unit
- Test chamber
- Data Acquisition unit

5.1.1 The Friction Couple Loading Unit

The purpose of the friction couple loading unit (shown in Figure 5.1) is to enable free movement of the pin specimen in both the vertical and horizontal directions. The unit can be leveled and balanced with stationary and movable counterweights, as a whole, prior to loading. A safety stop prevents the pin/ball holder from damage due to excessive wear of the specimen.

5.1.2 The Driving Unit

A squirrel-cage motor is connected to a Speed Controller with which the rotational speed of the squirrel-cage motor can thereby be continuously changed.

5.1.3 The Force transducer Unit

The function of this unit is to mount and position the force transducer that, in turn, measures the friction force [25].

5.1.4 The Displacement Transducer Unit

The displacement transducer continuously measures the amount of wear occurring at the pin-disk interface [25].

5.1.5 The Test Chamber

The test chamber essentially consists of an insulated heating coil that surrounds the pin and disk holding assemblies and is used to keep the bulk temperature constant during a run. A shield and a glass cover seal the gases / vapors from escaping thus, incorporating the facility to conduct high temperature vapor phase tests [25].

Other standard features include a slideable table that supports the friction couple loading unit, pin/ball holding assembly, test chamber, force transducer unit and displacement transducer unit. This sliding faculty of the table essentially induces a critical facility, that of changing the track radius of the disk.

5.1.6 The Data Acquisition Unit

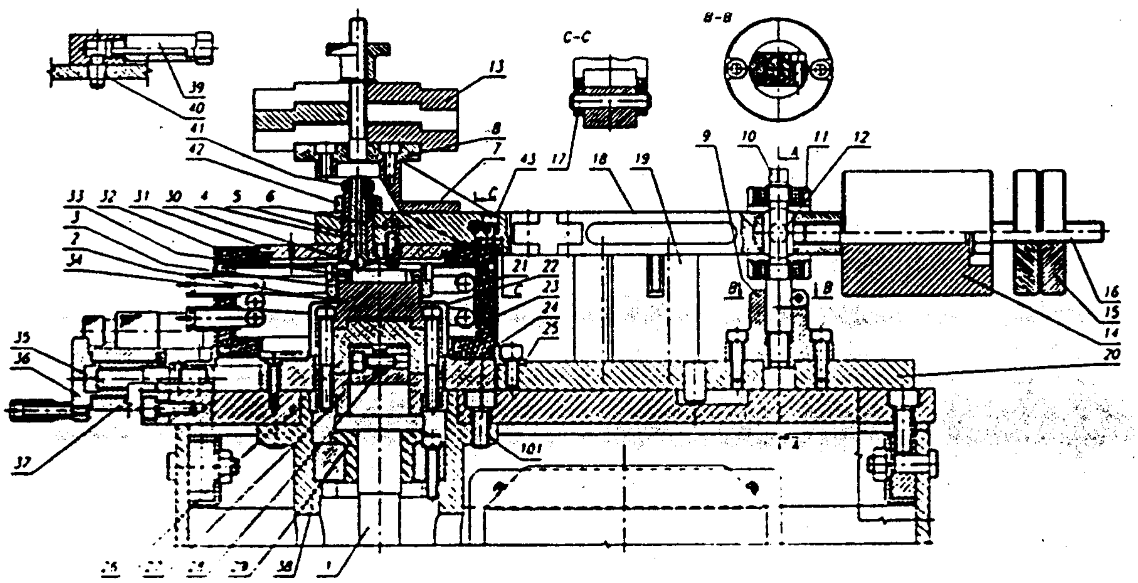
A 'Computer-Aided Set for Control And Measurements' was provided to:

A. Measure friction force, pin/ball holder temperature, test chamber bulk temperature, linear displacement, rotational speed and number of revolutions (duration of a run)

B. Control test chamber bulk temperature, rotational speed of the driving motor

C. Acquire and process data

It consists of a microprocessor-aided controller, a motor speed controller, transducers & sensors that are mounted on the machine and special software loaded on a personal computer. Figure 5.2 is a block diagram of the data acquisition unit. The information thus captured and processed is presented on a graph on a monitor.



Friction couple loading unit, test chamber and specimens holding assemblies

1 – test shaft
2 – keep plate
3 – disk lock nut
4 – pin/ball holder sleeve
5,6 – pin/ball holder
7 - weight bearer
8 - weight pan
9 - lever shaft bearer
10 - lever shaft
11 - lever bearer
12 - lever axle
13 - weight
14 - stationary counterweight
15 - movable counterweight
16 - bolt
17 - weight bearer pin
18 - lever
19 - lever stand
20 - table
21 - internal mantle
22 - shield
23 - insulation lining
24 - insulation ring
25 - external mantle
26 - insulation plate
27 - insulation sleeve
28 - driver
29 - slide bearing
30 - pin/ball
31 - glass cover
32 - chamber ring
33 - spring ring
34 - heater
35 - fine-pitch screw
36 - handwheel
37 - handwheel bearer
38 - test shaft tube
39 - gas inlet fitting
40 - nozzle
41,42- lock nuts

Figure 5.1: The Friction Couple Loading Unit [25]

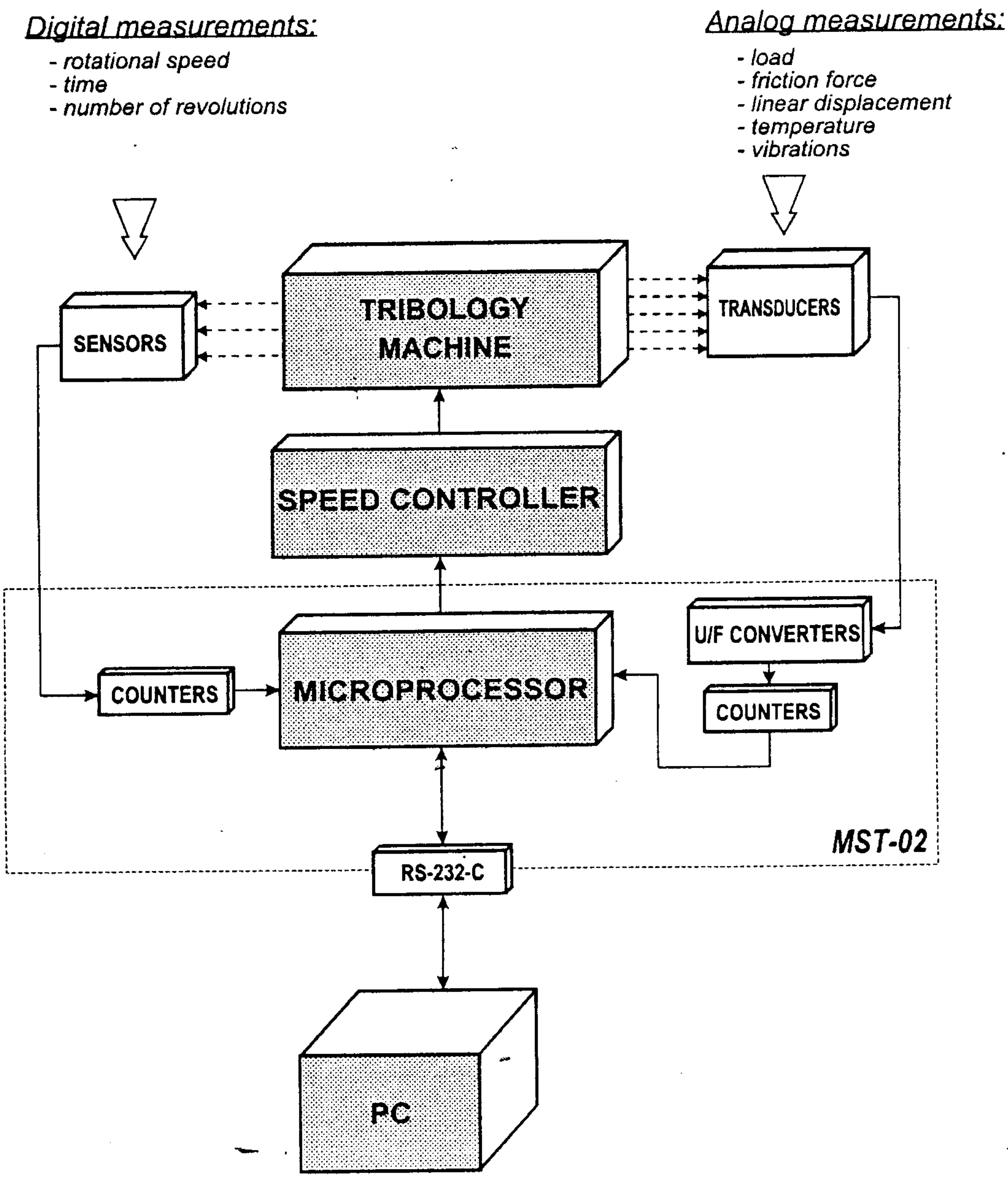


Figure 5.2: Block Diagram of the Data Acquisition Unit [25]

5.2 Overview of Tests Conducted

The tribological properties of certain lubricant compositions were tested on the T-11 pin-on-disk machine to analyze and select lubricants (that exhibit superior properties) for use on the engine tests. Tests were conducted using 2 ml of the lubricant at a constant speed of 250 rpm for a sliding distance of 250 meters, at a sliding velocity of 0.25 m/s.

Prior to each test, the disk, ball (Pin), disk holder and ball holder were cleaned for 20 minutes in an ultrasonic bath to get rid of unwanted material such as metal chips or lubricant adhering to the holders. Specifications of the Pin-on-disk tests are given in Table 5.1

5.2.1 Lubricants composed of different proportions of Monoester and Caprolactam

Tests were conducted both at ambient temperature (approximately 25°C) and at 100°C. Tests at the ambient temperature started immediately while the tests at 100°C involved heating the test chamber and starting the test when this temperature was reached in the lubricant cup. The tested lubricants were monoester and caprolactam in pure form as well as monoester and caprolactam together, in different proportions. In addition, the tribological properties of 100 Neutral Base Oil (obtained from Mobil Oil Co.) were also studied. The test load in this case was 10 N.

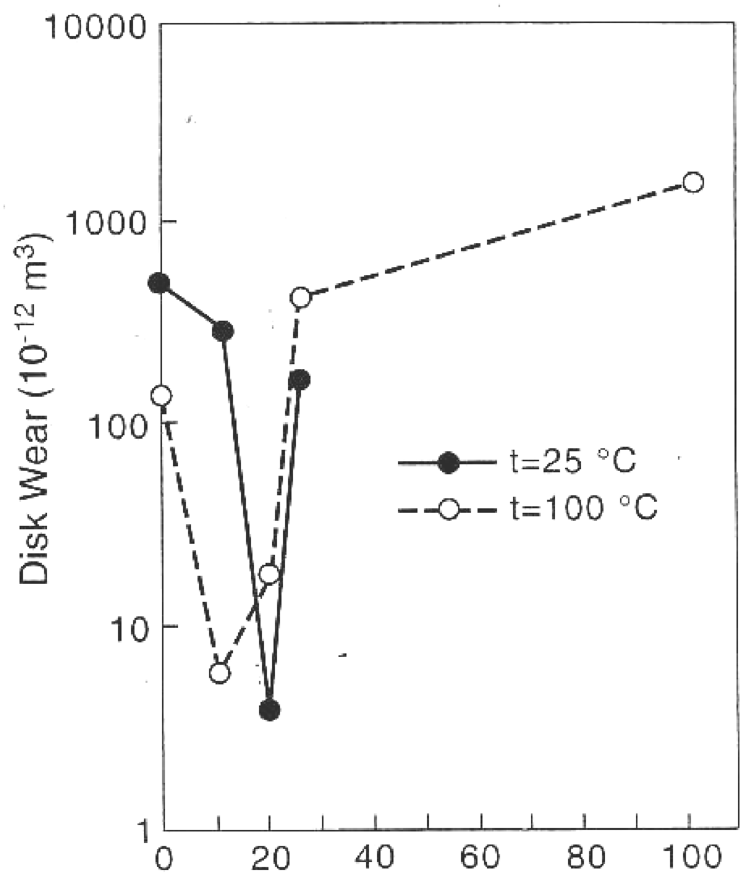
Parameters such as friction coefficient values, vertical displacement of the ball and test chamber temperature were displayed on the monitor and automatically stored in the computer. Ball wear was to be measured using a photomacroscope but was not done as the wear scars on the balls were too minute to be measured by this method. Also, at times, the ball wear scar was smudged by aluminum transferred from the disks. Disk wear was measured at four locations of the wear track, 90 degrees apart, by the "alpha step 500" profilometer. Wear volume was calculated by multiplying the circumference of the track by the average cross-sectional area of the worn track.

Table 5.1: Specification of the Pin-on-disk Tests

Material System	Steel-on-aluminum
Contact Geometry	Fixed ball sliding on rotating disk
Tribological Pair Characteristics Ball: Disk:	 52100 steel diameter – 0.636 mm (1/4") surface roughness Ra –0.0254μm hardness – 63 HRC aluminum diameter – 25.4mm (1") thickness – 6 mm surface roughness Ra –0.45-0.60μm
Lubricants:	1. C_{36} dimer acid/ethylene glycol monoester 2. Caprolactam 3. 90wt%Monoester + 10wt%Caprolactam 4. 80wt%Monoester + 20wt%Caprolactam 5. 70wt%Monoester + 30wt%Caprolactam 6. 100 Neutral Base Oil
Load	10 newtons
Sliding speed	0.25 m/s
Sliding distance	250 m
Test temperature	Ambient and 100°C
Measured Parameters	Friction force – continuous

	Disk Wear; (ball wear –insignificant)

It should be remembered that these tests were conducted after the second phase of engine tests were already completed. The disk wear and friction data for these tests are given in Table 5.2. Figure 5.3 shows the effect of caprolactam/monoester mixture on aluminum wear.



Percent Caprolactam

Figure 5.3: Effect of Caprolactam/Monoester Mixtures on Aluminum Wear [25]

Table 5.2: Disk Wear and Coefficient of Friction [5]

TEMPERA-TURE	LUBRICANT											
	100 N Base Oil		Pure Monoester		90%monoester + 10%Caprolactam		80%monoester + 20%Caprolactam		70%monoester + 30%Caprolactam		Pure Caprolactam	
	Disk Vol. Wear 10^{-12} m^3	μ	Disk Vol. Wear 10^{-12} m^3	μ	Disk Vol. Wear 10^{-12} m^3	μ	Disk Vol. Wear 10^{-12} m^3	μ	Disk Vol. Wear 10^{-12} m^3	μ	Disk Vol. Wear 10^{-12} m^3	μ
Ambient	32.9	0.091	512.7	0.157	262.6	0.095	4.0	0.066	139	0.144	*	*
100°C	76.5	0.155	118.6	0.104	5.8	0.053	17.4	0.102	401.1	0.104	1472.9	0.210

* Test was not conducted, as caprolactam is a powder at ambient temperature.
Wear and friction values at ambient temperature are the average of two tests.

These values show that for the tribological system under consideration the lubricant formulated with 80% Monoester and 20% Caprolactam, by weight, exhibited the best anti-wear and anti-friction properties.

5.2.2 Lubricants composed of reaction products of Monoethanolamine, Diethanolamine and Triethanolamine with Dimer Acid

As an extension of these tests, additional tests were conducted at 100°C using reaction products of dimer acid with monoethanolamine, diethanolamine and triethanolamine, respectively as the lubricants. The results of those tests are presented in table 5.3.

Table 5.3: Test Results using Reaction Products of Monoethanolamine, Diethanolamine and Triethanolamine with Dimer Acid as the Lubricant

LUBRICANT Reaction product of:	**LOAD (N)**	**DISK WEAR** 10^{-12} m^3	**FRICTION COEFFICIENT**
Dimer acid + monoethanolamine	10 20	3.44 22.95	0.056 0.0006
Dimer acid + diethanolamine *	10 20	827.2 48.53	0.079 0.071
Dimer acid + triethanolamine	10 20	2.87 69.53	0.040 0.116

Specifications: Steel-on-Aluminum, 0.25 m/s, 250 m sliding distance, 100°C.
* Lubricant turned into a brown ball after about 14.5 minutes in either test. Tests aborted at that instant.

From these two tables, it is evident that for the reaction products of monoethanolamine and triethanolamine with dimer acid, the wear volume at 10 N and 100°C is less than that obtained using different compositions of monoester and caprolactam as the lubricant. As such, on the next engine test carried out (test # 4S-08), which happened to be the first test on minimum bearing clearance engines (phase 4), the reaction product of monoethanolamine and dimer acid was used as the lubricant at the most crucial interface i.e., the connecting rod – crank bearing.