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WEAR PARTICLES ANALYSIS AND RUNNING-IN OF LUBRICATED HERTZIAN CONTACTS

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ABSTRACT

In running-in period, wear plays an important role in the service-life of machines. Wear is beneficial if it occurs smoothly and gradually.

The object of this work is to assess the effectiveness of wear particles analysis in characterising the running-in period.

A high performance disc machines, with two discs running edge-to-edge, under steady load and different slide-rolling ratios was used. The behaviour of this lubricated Hertzien contact has been followed by three analysing methods:

- Ferrography analysis of the concentration, size and morphology of wear particles.
- Spectrometry oil analysis of iron content in lubricants.
- Micro-geometry analysis of tested surfaces

The results are compared and analysed with respect to running-in phenomena.

Results show that the running-in period has been detected well by two methods , ferregraphy analysis of wear particles and micro-geometry analysis. The spectrometry failed to detect this phenomena due to its insensitivity to large particles.

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INTRODUCTION

The wear particles carry with them the history of their formation, having distinctive characteristics which bear evidence of the condition under they were formed. Thus careful examination and quantitative assessment of particles obtained from worn oil samples can yield specific information about the condition of the contact surfaces. Ferrography is a new technique developed for the isolation and analysis of wear particles [1,2,3]. Since its introduction, it has rapidly found application in the field of machinery health monitoring [4,5,6]. Ferrograph relationship with other machinery health monitoring techniques are given in [7,8,9]. Correlation between ferrogrph oil analysis and other wear assessment techniques such as spectrographic oil analysis procedure (SOAP) have been reported [7,10].

The object of this work is to asse ss the effectiveness of ferrography in characterising the running-in period of two discs in a high-speed disc machine.

EXPERIMENTAL SET-UP

Tests were conducted on a high speed disc machine. The disc machine is shown schematically in Fig.1 and is described in detail elsewhere [11]. The two discs are run edge-to-edge under a steady load. The discs are independently driven and different amounts of sliding can be introduced between them by varying the circumferential speeds.

Two tests were described in this investigation, designated T1 and T2 . In both tests the discs used were made from 16 NCD 13 , a carburising steel of the specification given in Table 1.

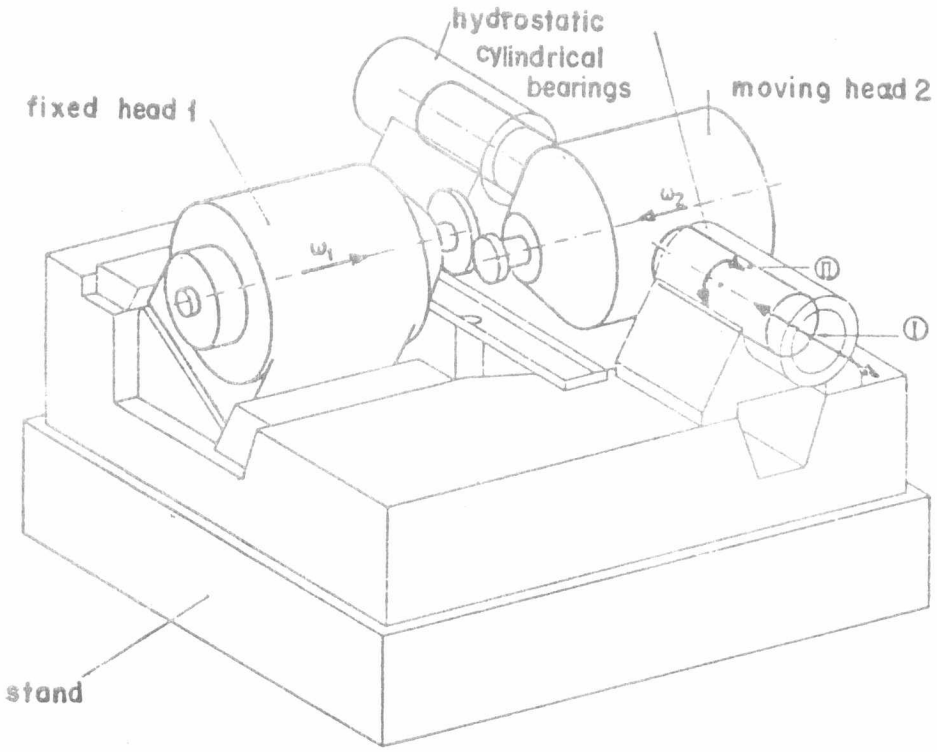


Fig. 1. Disc machine, [11].

The operating conditions are shown in Table 1. The test discs were ground after carburising to keep the surfaces roughness nearer to certain value. The normal load was applied according to the indicated program in Table 1.

The lubricant circuit is shown in Fig.2. Iubrication is achieved by a jet of oil sprayed directly into the contact zone. The lubricant used was a synthetic easter oil (Mobil jet II). The bulk oil temperature was maintained at 80 ^{o}C. A centrifugal pump was used to limit any arising wear particles during pumping. The oil samples were taken by a syringe.

Justification of the sampling technique was performed elsewhere [12]. Complementary tests indicated that the polution of the lubricating oil during circulation in the lubricant circuit was negligible.

During a rhythm between 0.25. 10^6 to 5.10^6 cycles, the following operations were fulfiled.

- Sampling the oil
- recording the discs surface profile
- weighting the tested discs.

All oil samples were diluted with filtered oil to a dilution of 10:1 in order to reduce their particle density. Oil samples were first heated for one hour at a temperature of 65 ^{o}C to reduce the viscosity and allows effective hand mixing of the oil.

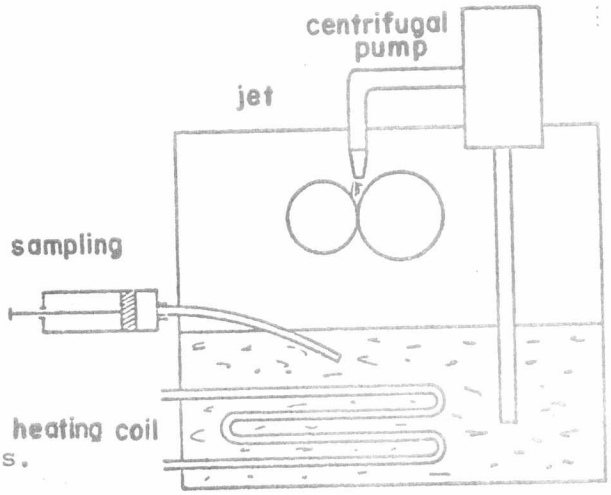


Fig 2 lubricant circuit

ANALYSING METHODS

The following analysing methods were used:

- Spectrometric oil analysis of iron content in lubricants
- Ferrognaphy analysis of the concentration, size, and morphology of wear particles.
- Micro-geometry analysis of tested surfaces.

The results were expressed as a function of operating number of cycles.

Spectrometric Oil Analysis

Spectrometers are most commonly used instruments for trend analysis. It is a standardized technique used by all services. Readouts indicate content of up to 20 elements in p.p.m (part per million). Two types of spectrometric analysis are available and used, emission spectrometry and atomic absorption spectrometry [4].

Emission spectrometry of Aerospatiale-Marignane-France (Type FAS.2) was used

Results were expressed by iron content in p.p.m.

Ferrography

There are two types of ferrograph, the direct-reading ferrograph and the analytical ferrograph, both of them use a powerful magnet to separate the debris from the worn oil. Details of the technique are given in References [1,2,3].

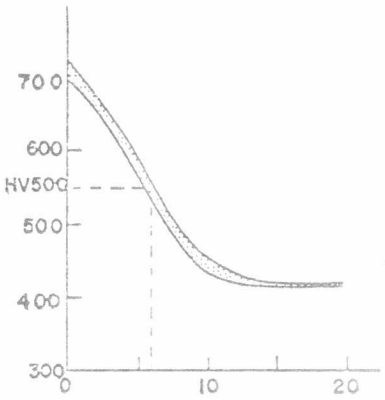
Table 1. The operating Conditions

PHYSICAL PARAMETERS

Material: Carburising steel 16 NCD 13

C: 0,16%
Ni: 3,25%
Cr: 0,95%
Mn: 0,45%
Si: 0,27%
Mo: 0,25%
S : 0, 2%

$E = 2,1 \times 10^{11}$ Pa
V = 0,3



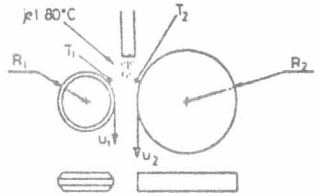
Variation of the microhardness as function of depth

Lubricant:

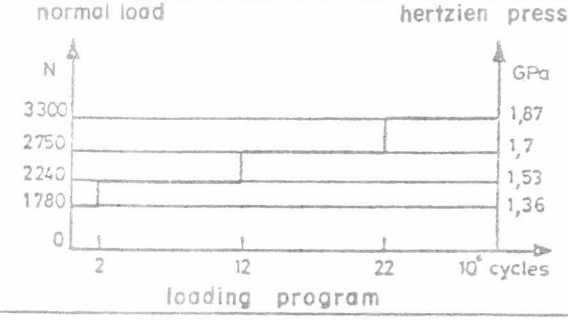
- Synthetic easter Oil
- Viscosity | 7,8 CSt at 80°C
  | 6,2 CSt at 90°C
- Coefficient of piezoviscosity

$\alpha = 1.3 \times 10^{-8}$ Pa-1

MECHANICAL PARAMETERS



Geometry (mm)			1	2
	R		15,70	19,25
	L(mm)		4	10
roughness	Rt(μm)		1,2 ———	4
Kinematics	$\lambda = \frac{U_1 - U_2}{U_1 + U_2}$ λ =0.045	ω(r/min)	4030	3000
		U(m/s)	6,627	6,047
	λ = 0.18	ω(r/min	5290	3000
		U(m/s)	8,181	6,047



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In the present investigation only the analytical ferrograph method was used.

Briefly, the analytical ferrography, Fig. 3, deposits magneticaly the wear particles on a transparent substrate (C. ferrogram) by pumping a sample of oil at a slow steady rate (0.75 cm^3/min.) down the inclined substrate. The substrate is mounted between the poles of a permanent magnet. Because the distance of the slide from the pole face is slightly more at the entry end than at the exit end, the magnetic field gradient increases as the particles pass downwards. The combined effect of the viscous and magnetic forces acting on the particles is to sort them by size, the larger particles being deposited first, whereas the smaller particles and oxides of iron are deposited lower down. For the purpose of reference, positions on the ferrogram are measured in mm from the entry deposit as shown in Fig.4. The resulted ferrograms are then examined by optical or electron microscopy to determine the general nature and the morphology of wear particles [2,13,14]. A great deal of information can be obtained from the analysis of ferrograms by the Quantimet in terms of the particle size distribution, the mean and variance of the distribution and the average aspect ratio of the particles [15,16].

The optical microscope is arranged so that reflection and transmitting modes of illumination are applied simulataneously, with red reflected light and green transmitted light. Objects which are opaque appear red whereas transparent objects pass the green transmitted light and therefore appear green. It is therefore possible to distinguish metallic from oxide particles on the basis of colour of their images within the microscope.

At our analysis, particles were examined by optical microscopy only. Magnifications 200 x, 500 x, and 1000 x were used.

The Quantimet 720 which was used is an image analysing computer which can make geometric and densitometric measurements. This achieved by the measurement of the chord width of each particle in terms of picture point (pp), Fig.5. The particle distribution was determined by counting the number of particles within pre-set size ranges from sub-micron up to the maximum particle size detected.

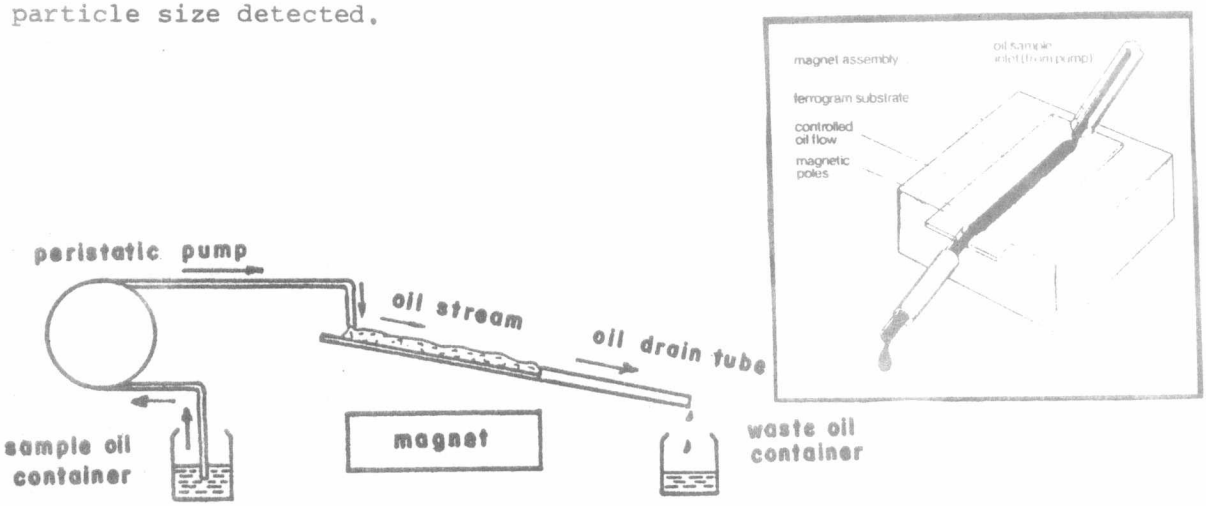

Fig.3. Schematic of analytical ferrograph.

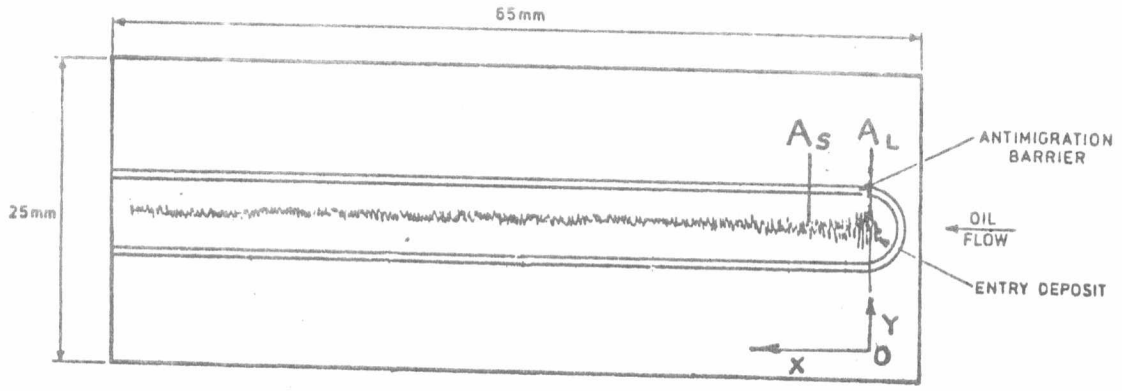

Fig. 4. Ferrogram

In the present investigation, the wear particles were detected by two different sources of light.

- for measuring the percentage area covered by all wear particles, transmitted light was used with magnification 63 x, field of view= 1.234 mm^2 (1pp = 1.572 μm).
- for determination the particle size distribution, reflected light was used with magnification 160 x, field of view =0.18 mm^2 (1pp=0.6μm)

For quantifying the wear particles, the following parameters were used:

A) From densitometric measurements

A_L :maximum percentage area covered by particles in the entry deposit at O abscissa.

A_s: percentage area covered by particles at 5 mm abscissa.

$A_{(L-1)}$:percentage area covered by particles at i mm abscissa.

Two severity indexes were calculated:

$I_s = (A_L^2 - A_s^2)$: wear severity index, was proposed by westcott [3]

$W = A_L + A_{(L-1)} + (A_{L-2}) + A_{(L-3)} + A_{(L-4)} + A_5$: nominal wear volume, was defined by Jone and all [17]

B) From the Quantimet analysis, the following parameters were studed for particles at the entry zone (O abscissa).

- total number of wear particles N
- number of particles within the size classes $< 1 \mu m$, $(1-2) \mu m$, $(2-5) \mu m$, and $> 5 \mu m$.
- count of particles of sizes $> 5 \mu m$/ count of particles of sizes $(1-2) \mu m$
- mean particles size $\bar{x}$ (along x direction) and the variance V.
- the shape factor $S.F = \frac{\Sigma I}{\Sigma C}$, was proposed by Roylance and all 15
  where ΣI = total intercept area
  ΣC = total chord width
- the mean particle size $\bar{y} = \Sigma I/N$

Mico-Geometry Analysis

A method used to characterise the surface asperities was described in

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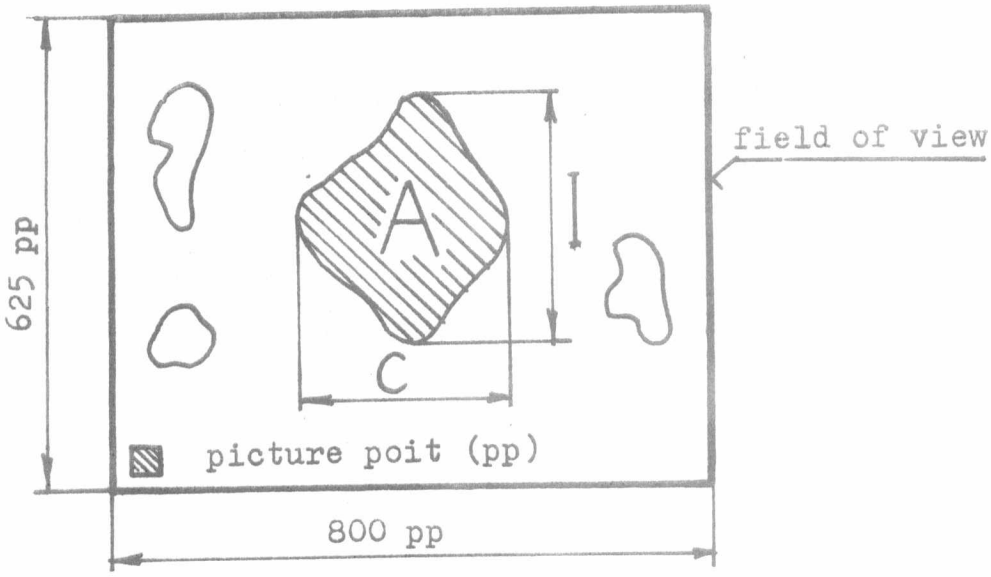

A : area
I : intercept
C : chord width
} measured in pp on standard field size of 500,000 pp

N : Number of particles within sizes > C

Fig.5. wear particle parameters measured by Quantimet 720.

detail elsewhere [18]. After registering the surface profile by a classical stylus-type profilometer the distributions of asperities heightes, peak heights, slopes, and peak radii of curvature can be expressed in the following criteria:

- RT_1 and RT_2 : maximum heights of asperites for surfaces 1 and 2.
- σ_1 and σ_2 : standard deviations of asperties heights for surface
- 1 and 2.
- β_1 and β_2 : radii of curvature of asperities peaks for surfaces 1 and 2.
- h_f : mimimum film thickness calculated according to Dowson and Higgenson.
- σ_c/h_f roughness ratio , $\sigma_c = \sqrt{\sigma_1^2 + \sigma_2^2}$

RESULTS

The only difference between the two tests is the slid/roll ratio as gi in Table 1. The results of both tests were presented in six figures rep senting the variations of the analysed parameters as function of number of cycles (given in million of cycles MC).

Fig.6 shows the variation of :

- percentage area covered by wear particles A_L, A_S

- severity wear index I_s
- nominal wear volume W

Fig.7 shows the variation of iron content as resulting from spectrometric oil analysis.

Fig.8 shows the variations of :
- total number of wear particles N
- number of particles within size classes $< 1\,\mu m$, $(1-2)\,\mu m$, $(2-5)\,\mu m$ and > 5 m .

Fig.9 shows the variations of:
- mean particle size $\bar{x}$ and the variance v of particle size distribution.
- ratio of count of particles $> 5\,\mu m$ to count of particles $(1-2)\,\mu m$.
- shape factor $S.F = \Sigma I/\Sigma C$
- mean particle size $\bar{y}$

Fig. 10 shows the variation of loss of weight of tested discs.

Fig.11 shows the variations of :
- maximum heights of asperities RT_1 and RT_2, standard deviation of asperities heights σ_1 and σ_2, and radii of curvature of peaks β_1 and β_2
- oil film thickness h_ℓ and roughness ratio σ_c/h_ℓ.

During the running-in period the morphology analysis of wear particles have shown that the studied hertzien contact generates the following types of particles:
- rubbing wear particles, Fig.12, platelet type with major dimension up to $(15-20)\,\mu m$ located at the entry zone. Particle of same type with dimensions $< 5\,\mu m$ located at 5 mm from the entry deposit.
- few numbers of cutting wear particles with spiral or bent wires shapes as shown in Fig. 13.
- pieces of griding ridges. Fig. 14, which were broken during the process of surface smoothing.
- few number of ferrous spheres as shown in Fig. 15.

At the end of running-in period, both of cutting wear particles and grinding ridges disappeared and number of rubbing wear particles decreased

DISCUSSIONS

Micro-geometry analysis shows that the tested surfaces become more favourable during the running-in period. Fig. 10 illustrates a high initial wear rate associated with the running-in process. For the present materials combination, the initial high wear was found to decrease to a low equilibrium conditions within about 3 M cylces. During the running-in period the following parameters were increased rapidly:
- severity wear index I_s and nominal wear volume W,
- total number of wear particles N and number of particles at all size classes,
- radii of curvature of asperities peaks β_1, β_2

Morever, but with less extent, the following parameters were changed:
- roughness ratio σ_c/h_ℓ
- iron content.

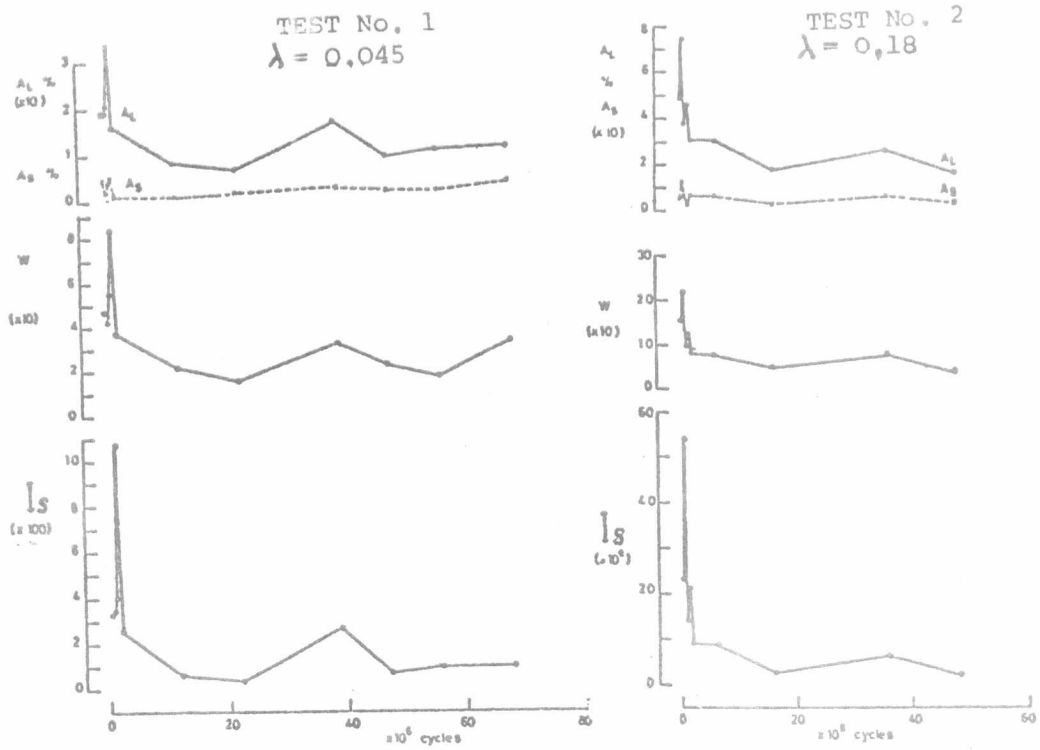

Fig.6. Variations of percentage area covered by particles A_L, A_S and the severity indexes I, W.

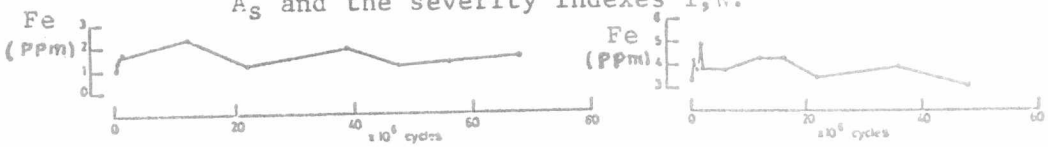

Fig.7. Variation of the iron content.

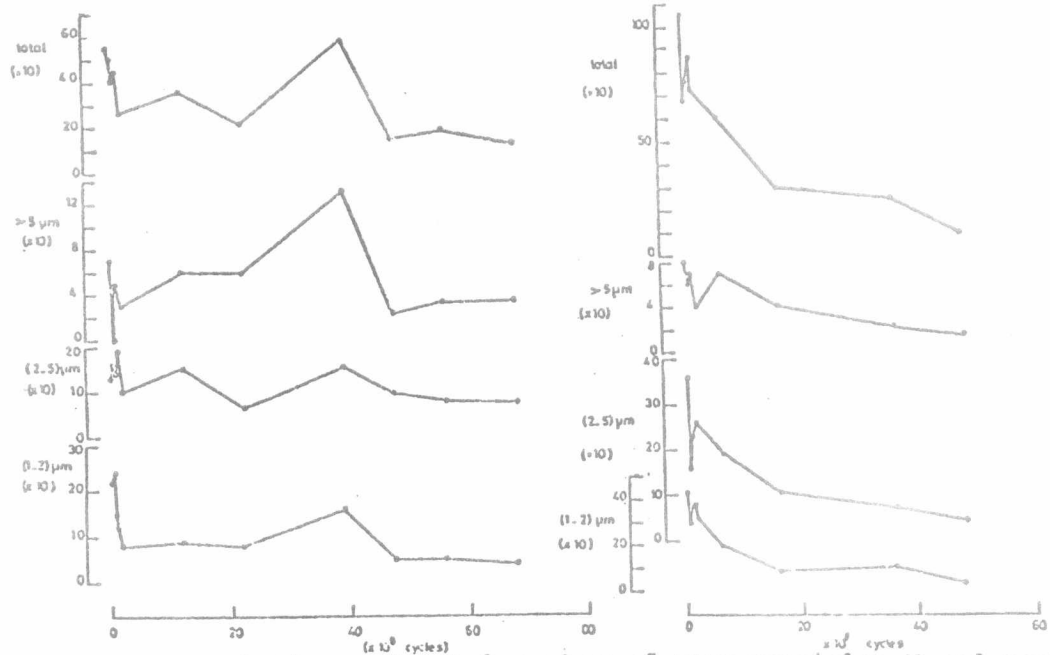

Fig.8. Variations of total number of wear particles N and number of particles within the prescribed size classes.

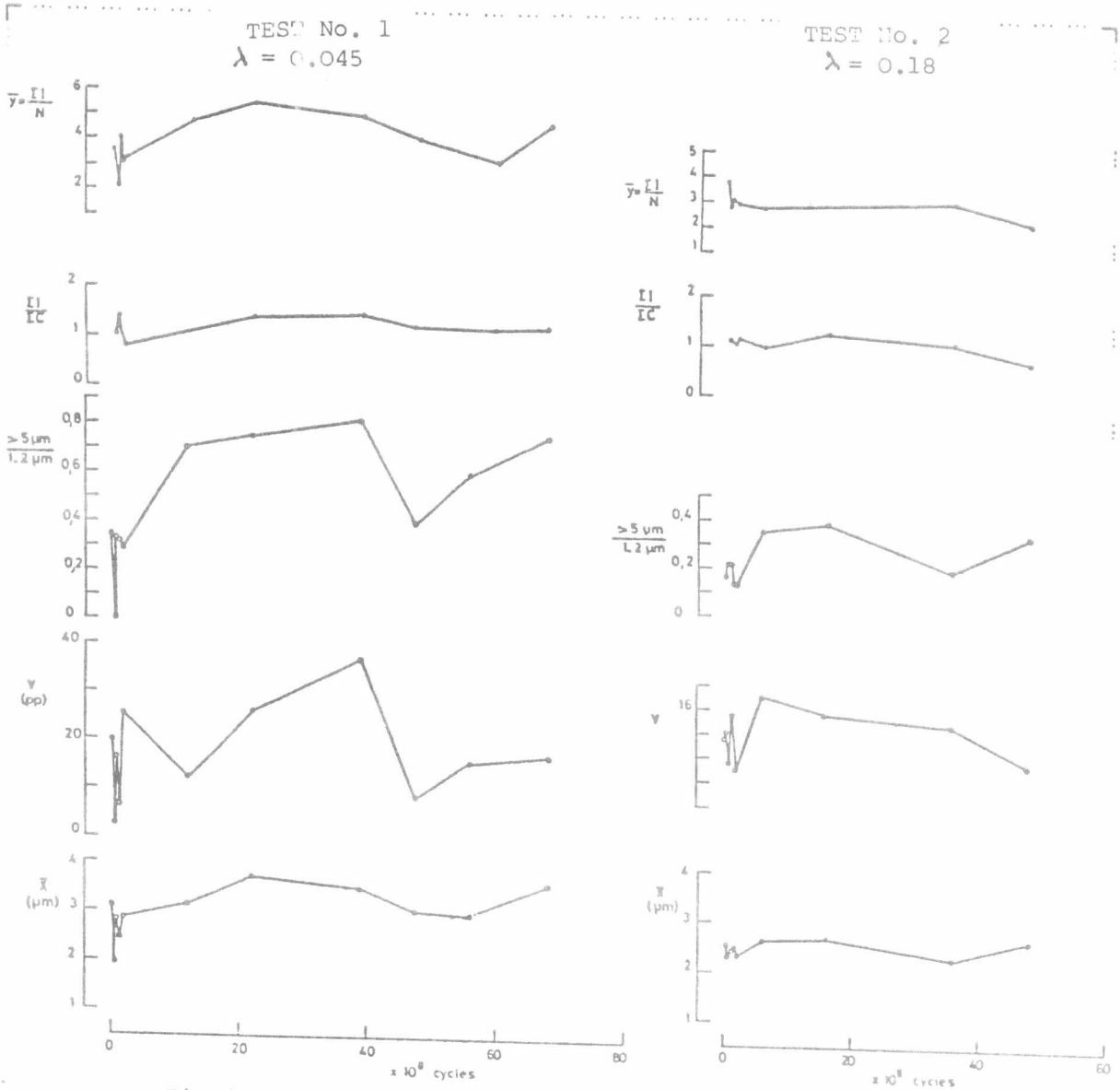

Fig.9. Variations of statistical parameter of particle sizes.

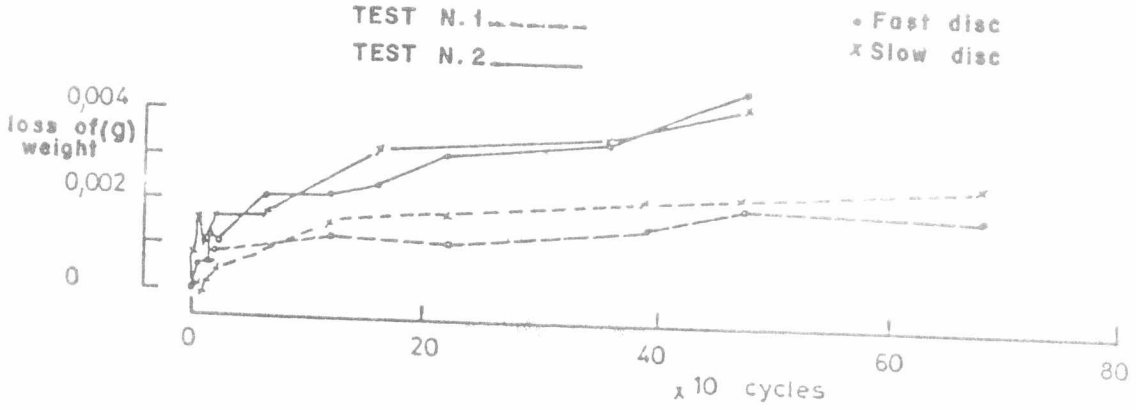

Fig.10. Variation of loss of weight of tested discs.

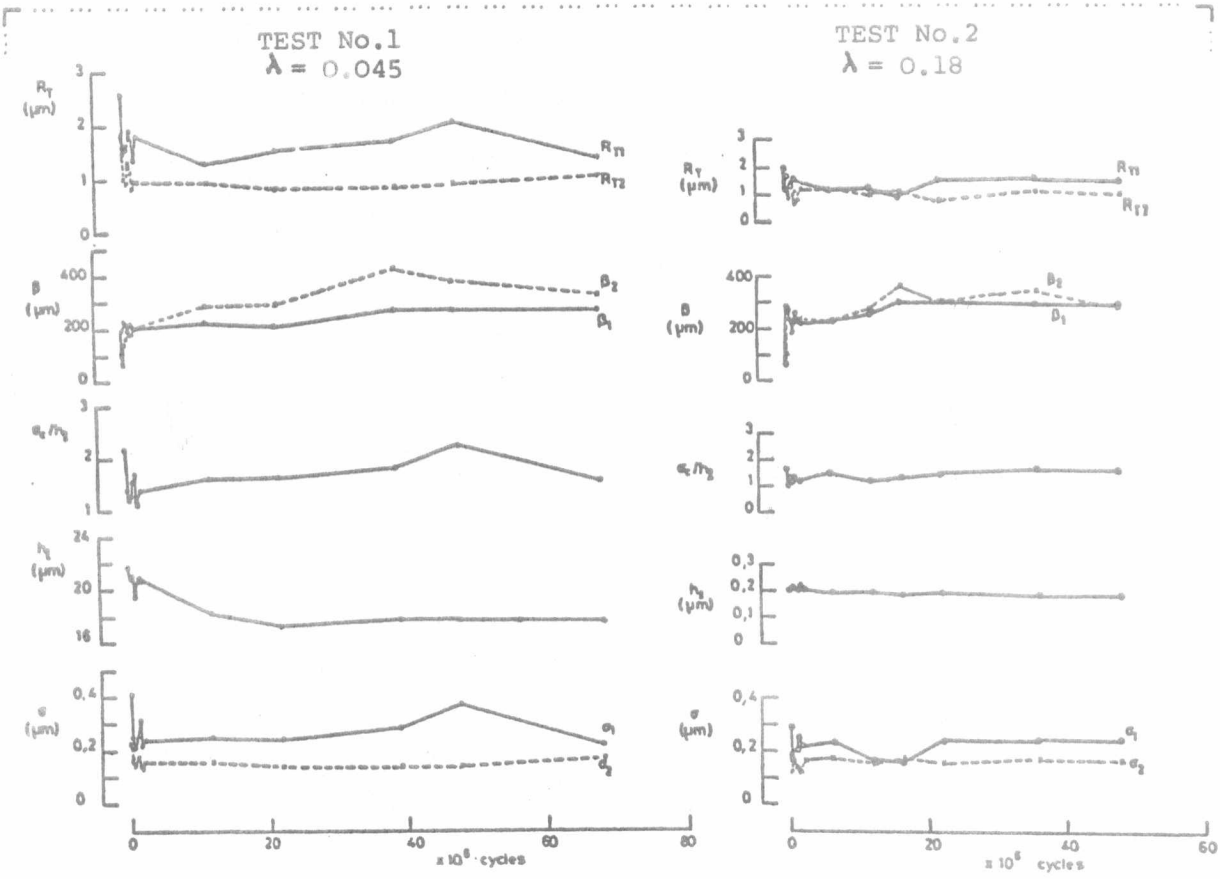

Fig.11. Variations of micro-geometry parameters, oil film thickness h_ℓ and roughness ratio σ_c/h_ℓ.

With respect to the effect of slide/roll ratio on the running-in process, it is evident that:
- mean particle size $\bar{x}$;
- roughness parameters,

vary slightly with the slide/ratio (λ), while:
- severity wear indexes I_S , W,
- number of particles N ;
- ratio of count of particles >5μm to count of particles (1-2)μm,

vary considerably with the slide/roll ratio, all increase with increasing λ instead the ratio of count of particles >5μm to count of particles (1-2)μm decrease with increasing

The present analysis suggests that the variance of the particle size distribution cannot be used to quantify the initial high-wear of running- in period.

The particles shape factor have not any considerable variation during testing

CONCLUSIONS

The following points can be drawn:

1. The running-in of the studied materials combination requires few number of megacycles to terminate the process.

2. The initial high wear rate can be effectively monitored utilizing the ferrography. The ferrographic parameters detect well this phenomena

such as the severity indexes and number of wear particles.

3. The coiled particles provide evidence of cutting-type wear particles. They are often present during the running-in process. If the running-in proceeds satisfactorily, cutting wear. particles will disappear.

4. Results indicates that the increase of slide/roll ratio (λ) causes:

- increase of severity indexes and number of particles.
- decrease the particles size.

5. The micro-geometric analysis indicat well the end of the running-in period. This analysis cannot be considered as a health monitoring method.

6. The spectrometry failed to detect the initial high wear due to its insensitivity to large particles.

As a general conclusion, it is evident that the ferrograph can be used as a sensitive tool for detecting the running-in period.

ACKNOWLEDGEMENTS

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