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EXPERIMENTAL RESEARCH AND STATISTICAL EVALUATION CONCERNING LINIAR CONTACT REABILITY

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Abstract

Many contacts localized in enclosure, under composed thermo-mechanical load, have few possibilities in repairs and direct intervention.For such contacts an reliability evaluation as preexploitation time, is an efficient economic and technical solution.The paper propose a theoretical method for an evaluation of liniar contact reliability considering thermo-mechanical fatigue as predominant type of failure in the complex thermo-mechanical macrogeometrical wear.Some preliminary results are taken into account for a statistical evaluation of liniar contact running time under thermo-mechanical load in condition of poor lubrification. A test rig is describe having a mechanical part for motion and contact loading with the specification that rolling without sliding is required.The test rig has also a thermal part, a cooling device by water and measurement abilities for temperature, speed, external load and noise and vibration level.Two different types of rollers for experimental research are also presented.

Key words *thermo-mechanical macrogeometrical wear thermo-mechanical contact fatigue, linear contact reliability,*

1. INTRODUCTION

Rolling liniar contact is present in a semnificative number of industrial application such as rolling bearings, gears, friction wheels, rolling mill rolers.The reability evaluation for rolling liniar contacts working under different solicitations (mechanical, thermical and tribological) at semnificative level of intensity, presents an economic interest in industrial application, especially as a before process evaluation.[9]
From this point of wiew, to achive an evaluating method for the lifetime of linear contacts working under thermo-mechanical solicitation, before exploitation and to fiind conditions for such contacts to realise all their potential lasting in exploitation, appears to become important for competitive industrial products.
The paper propose a theoretical evaluation method for rolling liniar contact under composed solicitations in certain functioning conditions.A test rig for some experimental researches is described and prelimenary experimental results are presented.

2.THEORETICAL BACKGROUND

Many industrial applications have a common aspect as rolling liniar contact under composed solicitation..If such contact are in enclosure, where premature deteriorations are difficult in recording, functioning in non-stop program of work, under semnificative thermo-mechanical contact loads, their lifetime is important to be at optimum size.

At the contact of two surfaces rolling under normal mechanical load and thermal tide,with poor lubrication and inner cooling, global macrogeometric thermo-mechanical wear is present.

This complex phenomenon is an atypical combination of fundamental types of wear, coexisting an interacting during the proces having a predominant position one besides others, determined by the specific condition of contact.

Global thermo-mechanical wear is like a competition between different factors, specific to contact mechanics, having a conjugate results in the distruction of contact layer.

The connections between solicitations and types of failures for a rolling contact working in conditions of thermo-mechanical macro geometrical wear is suggested in fig.1

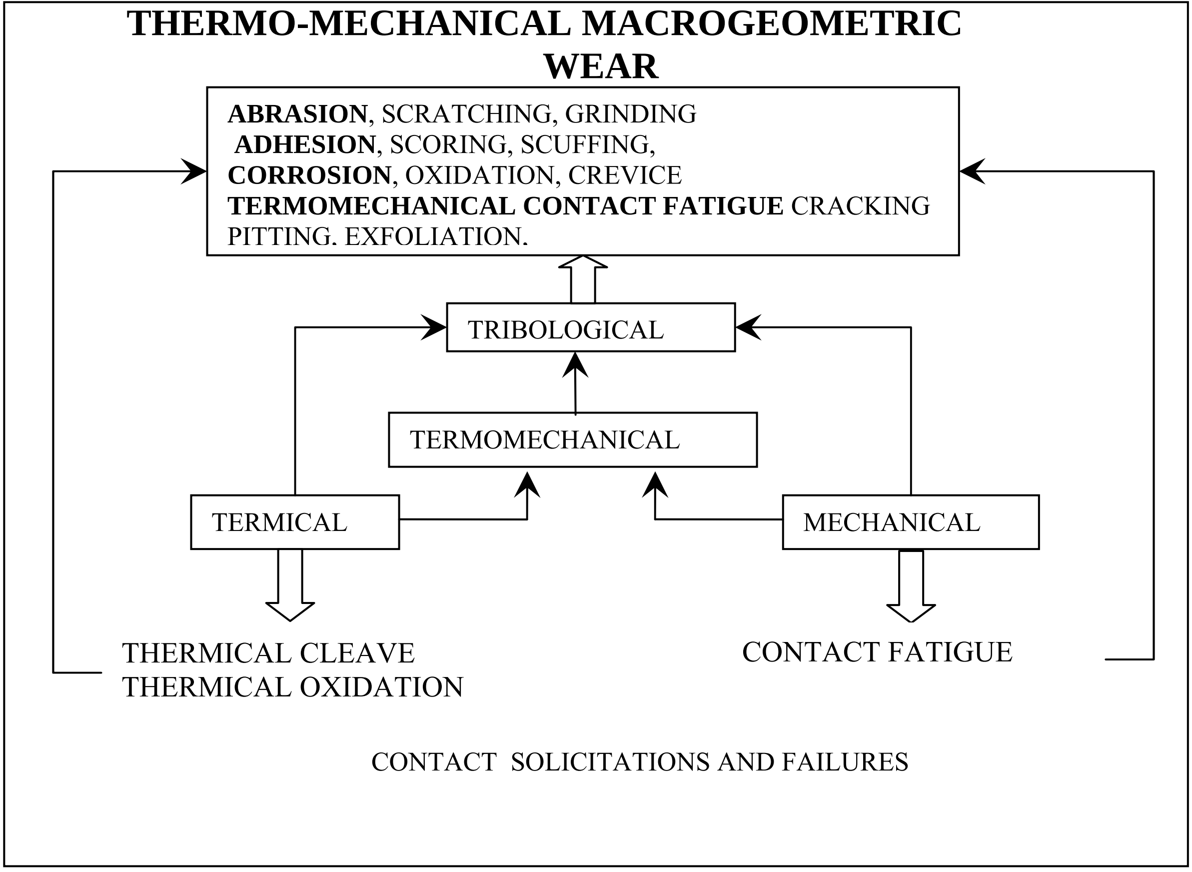

Fig.1.

Fig.1 shows that the macrogeometric thermo-mechanical wear is a complex phenomenon.A theoretical approach in order to evaluate the reability of a contact working in condition determening such a global phenomen, is difficult to resolve. The evaluation solution for contact reliability under a compose mechanical and thermical solicitation must be found in connection with the predominant fundamental wear type developed in certain condition of contact.The precise determination for contact parameters became decissive both for dominant failures types and for evaluating alghoritm of contact reliability .

A semnificative aproach in the direction of thermo-mechanical wear study is representated by the works of Ting and Winer (1989) and then Yang and Winer (1991).

They developed a theoretical method concerning thermo-mechanical wear.[10] Using two adimensional parameters, one for thermal stress (Gt) and one for normal loading and contact radius (σy0/P0), they achieved a map of materials behavior at global contact thermo-mechanical wear. The operative point which describes the test conditions with interesting aspects for our researches, is locate on Yang-Winer map in a zone with predominant thermo-mechanical contact fatigue aspect in global thermo-mechanical wear. Friction between two surfaces is reduced if sliding is preserved on a minimum value. Hence, the initialization points for macrogeometrical mechanothermical contact fatigue (M.T.-M.C.F.) are not premature eliminated with their layer and the failure of the contact is due to M.T.-M.C.F. In such conditions of contact, localize in the conditioned wear zone on Yang-Winer map, the life time of the contact is decisively limited by thermo-mechanical contact fatigue because is the main origin of failure with a high frequency of appearance and random character. For a theoretical evaluation of a lifetime linear contact under thermo-mechanical load, dry, with minimum sliding, the following steps are proposed:

A. The decisive stress calculation after the equivalent stress from Huber-Mises-Henckey theory or the equivalent decissive stress from energetic hypothesis developed by the Popinceanu, Diaconescu and Crețu (1985) and revived by Liu and Mitall (1988).[1,6]

$${}^{\sigma}{}_{EMT}(\lambda)=\frac{1}{\sqrt{2}}\begin{bmatrix}\left({}^{\sigma}{}_{xMT}-{}^{\sigma}{}_{yMT}\right)^2+\\ \left({}^{\sigma}{}_{yMT}-{}^{\sigma}{}_{zMT}\right)^2+\\ \left({}^{\sigma}{}_{zMT}-{}^{\sigma}{}_{xMT}\right)^2+\\ 6\lambda^2\left(\tau_{xyMT}^2+\tau_{yzMT}^2\right)+\\ 6\tau_{zxMT}^2\end{bmatrix}^{\frac{1}{2}} \qquad (1)$$

Where MT means equivalent, mechanical, thermal; λ is a coefficient defined as:

$$\lambda=\frac{\left(\tau_{0N}\right)_f}{\left(\tau_{-1N}\right)_f}=\frac{\left(\tau_{0N}\right)_t}{\left(\tau_{-1N}\right)_t} \qquad (2)$$

where $\left(\tau_{0N}\right)_f$ and $\left(\tau_{0N}\right)_t$ are shear and respectivly torsion fatigue limit stress for N pulsating cycles.

$\left(\tau_{-1N}\right)_f$ and $\left(\tau_{-1N}\right)_t$ are shear and respectivly torsion alternating fatigue limit stresses for N symmetrically alternating cycles.[3,4]

The mechanical components in ${}^{\sigma}{}_{EMT}(\lambda)$ ecuation (1) are the same with the mechanical stresses accepted in mechanical contacts for a linear contact between two cylindrical bodies on generation line ,under a radial load.[1]

Stress tensor components on the contact surface at the Hertzian liniar contact (adimensional expresions) are:

$$\bar{\sigma}_{xx}=2\nu\sqrt{1-\bar{y}^2} \qquad (3a)$$

$$\bar{\sigma}_{yy}=\bar{\sigma}_{zz}=\sqrt{1-\bar{y}^2} \qquad (3b)$$

$$\bar{\tau}_{xy}=\bar{\tau}_{yz}=\bar{\tau}_{zx}=0 \qquad (3c)$$

Stress tensor components in points located under the contact surface at the Hertzian liniar contact (adimensional expresions) are:

$$\bar{\sigma}_{xx}=2\nu\bar{z}\left[\sqrt{\frac{1+\bar{t}}{\bar{t}}}-1\right] \qquad (4a)$$

$$\bar{\sigma}_{yy}=\bar{z}\left[\sqrt{\frac{1+\bar{t}}{\bar{t}}}\cdot\left(2-\frac{\bar{z}^2}{\bar{t}+\bar{z}^2}\right)-2\right] \qquad (4b)$$

$$\bar{\sigma}_{zz}=\frac{\bar{z}^3}{\bar{t}^2+\bar{z}^2}\cdot\sqrt{\frac{1+\bar{t}}{\bar{t}}} \qquad (4c)$$

$$\bar{\tau}_{yz}=-\frac{\bar{y}\cdot\bar{z}^3}{\bar{t}^2+\bar{z}^2}\cdot\sqrt{\frac{1+\bar{t}}{\bar{t}}} \qquad (4d)$$

$$\bar{\tau}_{xy}=\bar{\tau}_{yz}=0 \qquad (4e)$$

$\bar{\sigma}_{ij}=\sigma_{ij}/\sigma_0$ where i,j=x,y,z σ_0 - is maximum Hertzian stress

$$\sigma_0=\sqrt{\frac{q\cdot\sum\rho}{\pi\left(\frac{1-\upsilon_1^2}{E_1}+\frac{1-\upsilon_2^2}{E_2}\right)}} \qquad (5)$$

where $q=\frac{Q}{L}$ L is real cylinder length ; Q is normal load

E,υ are elastic characteristcs for the two bodies in contact

$\bar{y}=\frac{y}{b};\bar{z}=\frac{z}{b};\bar{t}=\frac{t}{b}$

t is the bigest roots of the ecuation (6)

$$\frac{y}{b^2+t}+\frac{z^2}{t}=1 \qquad (6)$$

The contact zone is rectangular surface with 2b width and infinite length.[1]

When the cooling of the test rollers is made at the inner diameter, thermo elastic stress apper for the theoretical case of a cylinder placed in a field of variable temperature .These stresses in polar coordination are:[5]

$$\sigma_{rr}=\frac{Ea}{2(1-\mu)}\cdot\left(1-\frac{R_1^2}{r^2}\right)\cdot\left[T(R_2,t)-T(r,t)\right]$$

$$\sigma_{rr}=\frac{Ea}{2(1-\mu)}\cdot\left(1+\frac{R_1^2}{r^2}\right) \qquad (7)$$

$$\cdot\left[T(R_2,t)+\left(1-\frac{R_1^2}{r^2}\right)T(r,t)\right]-2T(r,t)$$

In ecuation (7):

R_1 – inner roller radius

R_2 – outer roller radius

T(r,t) – variable temperature, depending on r value $R_1<r<R_2$ and measurement time

t; α, E, μ rollers material constants

B. The survival probability R is calculated using Ioannides-Harris durability model for rolling contacts:

$$\ln\frac{1}{R_r}=AN^{e^*}\cdot\int_{V_r}\left[\begin{array}{c}H\left(\sigma_{EMT(\lambda)}-\sigma_{ui}\right)\cdot\\ \left(\frac{\left(\sigma_{EMT(\lambda)}-\sigma_{ui}\right)^{e^*}}{z'^{h^*}}\right)\end{array}\right]dv \qquad (8)$$

with:

$$H\left(\sigma_{EMT(\lambda)}-\sigma_{ui}\right)=\left\{\begin{array}{l}1..if..\sigma_{EMT(\lambda)}\geq\sigma ui\\ 0..if..\sigma_{EMT(\lambda)}\leq\sigma ui\end{array}\right\} \qquad (9)$$

Where H is the stage function and σui – fatigue limit stress (under this value of stress the elementary volume . ΔVi has no fatigue failure); e*, c*- constant values for already loaded material, depending on the material quality; A- independent random variable; Vr material volume under fatigue risk (in which

$$\sigma_{EMT(\lambda)}\leq\sigma_{ui\min}$$

$$\sigma_{ui\min}<\sigma_{ui}<\sigma_{ui\max} \qquad (10)$$

and z'- medium depth for decisive stress; N- number of loading cycles, h* exponent for z* .

C. Defining and calculation of rolling mill rollers dynamic capacity in order to indicate the right period between two grindings in succession, with the survival probability equation:

$$\ln\frac{1}{R_r}=N^{e^*}\sigma_{EMT}{}^{c^*}z^{1-h^*}a\Gamma L^{e^*}$$

Where: L- contact durability; a- big semiaxis of contact ellipse; . Γ - length of rolling track,

$$L=K\left(\frac{C}{P}\right)^{\frac{10}{3}}$$

Where: L- rollers contact durability; C-rollers dynamic capacity; P- equivalent dynamic load, K- correctional coefficient .[4,6,8]

3.TEST RIG

The macrogeometrical mechano-thermical contact fatigue is experimental researched in the case of linear, almost dry contact, with radial mechanical loading. Two samples are tested in the same time, named “cooled” rollers. These rollers are in permanent rolling contact with a “warmed” roller.

The test rig is presented in figure 2 and is composed by following subansembles:[9]

1. Mechanical motion subansamble (1,2,3,4,5,6,7) (electroengine, reduction rotation, couplings, and bearings) which give an equal and constant rotation for the three rollers.
2. Mechanical loading subansamble (10,11,12) (screw, screw-nut, calibrated spring). The mechanical loading is made upon the whole bearing which is mechanical guided. The rolling bearings are not supplementary loaded.
3. Thermal measurement device (8).
4. Warming device (13). The thermal tide is concentrated only on the warmed roller.
5. Cooling device (water) with poor flow (9) on the frontal/cylindrical surfaces of the cooled rollers.
6. Vibration measurement level device.

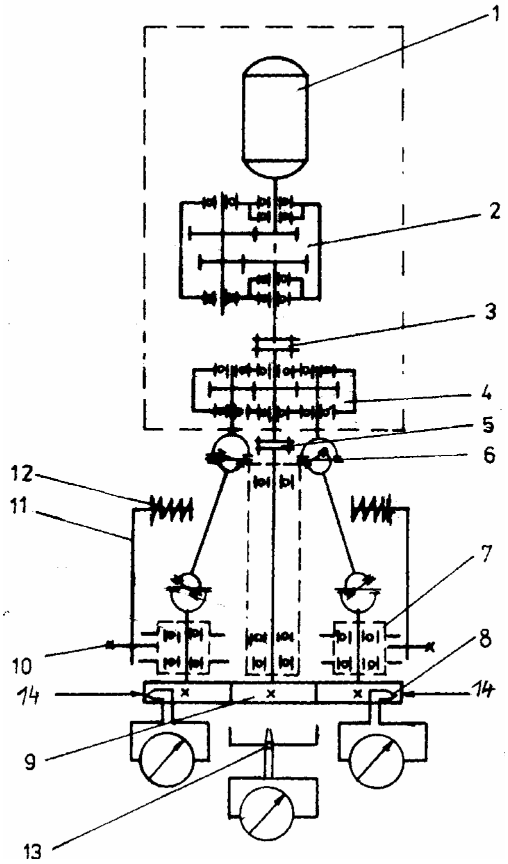

Fig.2: *Schematic view of test rig*

The two types of rollers samples are presented in fig.3 position 9 in fig.2

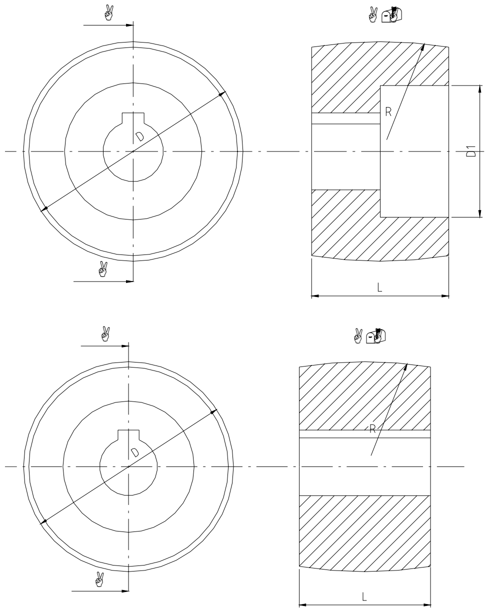

Fig.3

4. EXPERIMENTAL RESULTS

The tests were made upon some statistical lots of steel rollers. The tests were accelerated, simulated a rolling contact with small sliding (about 5% maximum) and a contact stress about max. 300 MPa.[2,9]
The rollers were cylindrically grinded in order to avoid the high amplitude vibration determined by the almost dry contact on the rough exterior cylindrical surfaces. An example of statistical treatment for the experimental results obtained by testing 1 lot of 10 similar rollers, is presented in figure 4.
The couplings were manufactured by static casting of T20 Mn14 alloy steal.
The carbon percentage of the hardened superficial layer is about 0,8- 1%.The rest of the material has 0,15- 0,2%C.
The tests were accelerated and the instant values were plotted.
The wear tests of the materials were done on roller samples fig.3.

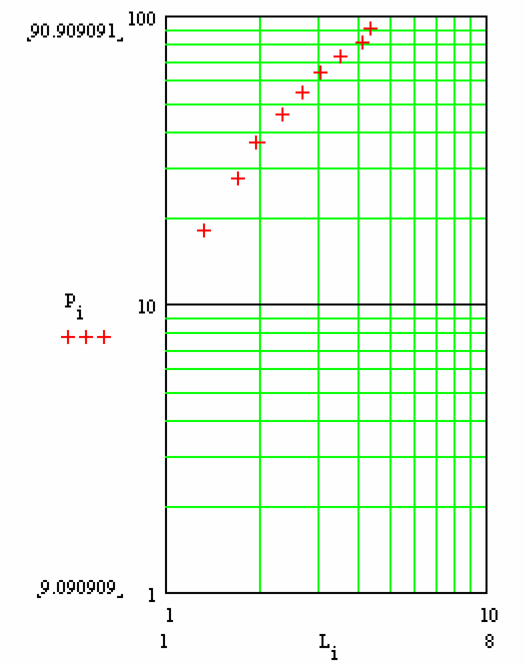

Fig.4

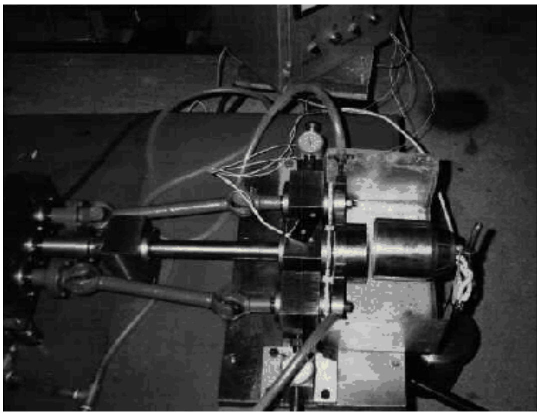

Fig.5: *Driving suply of test rig*

5. CONCLUSIONS

Roller elements such as roller bearings gears, friction wheels, traction drive transmission are subject to failure from rolling contact fatigue.Such fatigue failures cause a serious restriction on the opereating life and reliability of such devices.

1.Thermo-mechanical macrogeometric wear is a complex phenomenon, with many kinds of appearances but with a single end: total failure of conactact surface.

2.Thermo-mechanical contact fatigue is a fundamental type of termo-mechanical macrogeometric wear and become predominant in this complex phenomenon in certain condition of functioning.

3.Failures due to thermo-mechanical contact fatigue (cracking, pitting, exfoliation) has an aleatory apparence, which recomande a statistical evaluation for liniar contact reliability.

4.The preliminary tests have shown a beneficial effect of the temperature field on the sub surface stress states when the heating velocity is small.At the beginning of the rolling contact, under a heating impact, the wear rate has an increase level.

After a period of rolling ,when the heating impact decrease to a constant heating tide, the wear rate decrease too.

This phenomenon is possible explained by the different thermal dilation strains that act to relax or to amplificate the stress field in the zone located between the surface and the Hertzian depth, moving the level where the equivalent von Mises stress is found maximum at a depth bellow the conventional Hertzian depth.

6.The future tests will validate entirely the liniar contact reliability evaluation method.

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