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TRIBOLOGICAL PHENOMENON AND HEAT GENERATION IN THE RAILWAY WHEEL - RAIL CONTACT

ABSTRACT

The paper provides a description of tribological aspects and the latest type of laboratory equipment which is expected to offer particular new knowledge in the field of railway wheel - rail contact phenomena diagnostics. The main considerations stated in this work imply that the coefficient of adhesion is among others dependent on contact temperature, and therefore it is possible to theoretically predict the value of the coefficient of adhesion. This fact has not been considered in the theory of adhesive contact so far. The entirely credible prognosis of the studied unfavourable effects is hardly satisfactorily solvable in theory. Hence, the authors present a new testing device by which the predicted effects will be verified. At the same time, the oscillation effect on the state of surface will be observed in the attached formulas. The work also implies that the effects evaluating possible initiations and local degradations of the contact area of railway wheel and rail are closely bound to the tribological effects that are comprehended here as dynamic processes.

KEY WORDS

contact fatigue, railway wheel - rail contact, tribology, safety of transport

1. INTRODUCTION

It is implicit that the primary cause of the creation of effects that appear in the contact area of two real bodies (for example, the railway wheel and rail) are the force effects causing reversible as well as irreversible material changes in the surface layers. The existing opinions and findings regarding these processes are summarized in work by Kout and Kaloč [1]. Microstructural changes combined with the mechanical damage of surface are mostly declared. The thickness of the affected layer was theoretically for a wheel tread predicted in a range of 10^{-4} m. This relatively satisfactorily corresponds to experimental analyses which among others detect very thin and hard micro-structures called White Etching Layers - see work by Beneš et al. [2].

Another common feature resulting from the conclusions of performed studies and expertises is the fact that all the anomalies are located in the surface layer that not only becomes a potential area from where defects can spread into the basic and unaffected wheel material but also is determinant for the development of the tribological process. It can be then assumed that the hypothesis on the effects of the surface layer, having predominantly dynamic and non-isothermal character, can be rightly accepted. The main goal of this work is to point out the existence of contact temperatures which obviously significantly influence the character of the processes. It is surprising that this phenomenon has not been taken into account yet, especially in the theory of adhesion shift.

2. TRIBOLOGICAL ASPECTS OF ADHESION PROCESS IN THE CONTACT AREA

Running railway vehicles operate on the basis of a principle which is in technology known as adhesive transmission of force. This process is directly dependent on the general condition of contiguous surfaces that belong to the instantaneous contact area; therefore it is necessary to consider this process as a process of scalar type. As for functional purpose, i.e. when using adhesion process for driving, the term adhesion in the theory of railway vehicles is usually mentioned in connection with tensile (crank) force, i.e. with the vector corresponding to a normal wheel force through a real numeric quantity known as the coefficient of adhesion.

From the tribological point of view, the adhesive model of contact can be described as contact of two elastic media conditioned by high pressures when molecular cohesive forces form temporary connections of contiguous microparts of a wheel-rail material.

While rolling a wheel, when a continuous decay and subsequent rise of a new contact area should be necessarily considered, the dynamic deformation of the surface parts occurs followed by thermal effects. With respect to a continuous rise and decay of the contact area, the heat source can be considered as a result distributed closely around a line segment that lies axially to the wheel-tread. It was proven that there is a linear dependence between the coefficient of adhesion and the slip *s*. This dependence is called the *slip curve*.

If the Coulomb idea, indicating the dependence of normal wheel force and tangential force, is accepted, then the slip curves must have the character of smooth functions even in the case of dynamically variable normal wheel force. The authors of this work express the opinion that the existing slips in the whole range of the slip curve generate the contact heat whose influence is bound to the value of the coefficient of adhesion and since the adhesion process is quantified by this coefficient, the thermal effect can influence the general degradation of the surface of the contiguous areas, including a potential occurrence of structural changes.

3. THERMAL EFFECT ALONG SLIP CURVE

To determine the average value of the contact temperature, according to Ryžov and Kolesnikov [3], the following relation was proposed:

$$T = 1.11 \cdot \frac{\mu_a \cdot F}{A \cdot b\sqrt{L}}\left(\sqrt{v_1} - \sqrt{v_2}\right) \quad [^\circ\mathrm{C}], \tag{1}$$

where *F* is normal wheel force [N]; *L*, *A* are the measurements belonging to the statically conceived contact area [m]; constant *b* is defined by the relation which, if particular numbers are inserted:

$\lambda = 55$ J s^{-1} m^{-1} K^{-1} thermal conductivity of steel,

$\rho = 7.865 \cdot 10^3$ kg m^{-3} density of steel,

$c_p = 460$ J kg^{-1} K^{-1} specific heat capacity,

has the value:

$$b = \sqrt{\lambda \cdot \rho \cdot c_p} = \sqrt{55.0 \cdot 7.865 \cdot 10^3 \cdot 460} = 1.41 \cdot 10^4 \ [\mathrm{Jm^{-2}K^{-1}s^{-0,5}}]$$

Speed function (2) is inserted into equation (1):

$$\Phi = \sqrt{v_1} - \sqrt{v_2} \tag{2}$$

where v_1 [ms^{-1}] is circumferential speed of wheel, v_2 is gradual speed of wheel. The formula for the corresponding slip s is then:

$$s = \frac{\Phi^2 + 2 \cdot \Phi\sqrt{v_2}}{v_2} \tag{3}$$

Since the issue of adhesion belongs to the field of effects to which, from the view of probability, Laplace-Gauss arrangement conforms very well, and moreover, this effect is connected with the thermal processes, we imply (analogically to diffusive phenomenon) the dependence of the coefficient of adhesion μ_a on the slip *s* by the error function *erf*(s) which is defined by the distribution function G(s), so that:

$$erf(s) = G(s) - \frac{1}{2} = \frac{1}{2\pi}\int_0^s e\exp\left(-\frac{\mu_a^2}{2}\right)\mathrm{d}\mu_a \tag{4}$$

For common criteria (dry rail), according to Čáp [4], the value limits the coefficient of adhesion to number 0.5. The slip curve, expressed in this way, is presented in *Figure 1*. To verify the acceptance of such procedure, the comparison with Čáp's experimental results were used by Čáp [4]. For instance, for the slip s = 1.5% we obtain the value μ_a = 0.42. By means of the function erf (s) the obtained value differs only by 2.3%.

In *Figure 1* there is the calculated progress of the contact temperatures T, drawn along the slip curve, for the travelling speeds of 50 up to 200 km/hour. It is obvious that in the area of the peak V and on the return strand, e.g. in the point M, the average values of the contact temperature reach relatively high values, as show by Papoulis [5] as well as Likeš and Machek [6].

4. EXPERIMENTAL VERIFICATION OF THE PROPOSED DEPENDENCES

The theoretic prognosis of the average values of the contact temperatures leads to the need of its

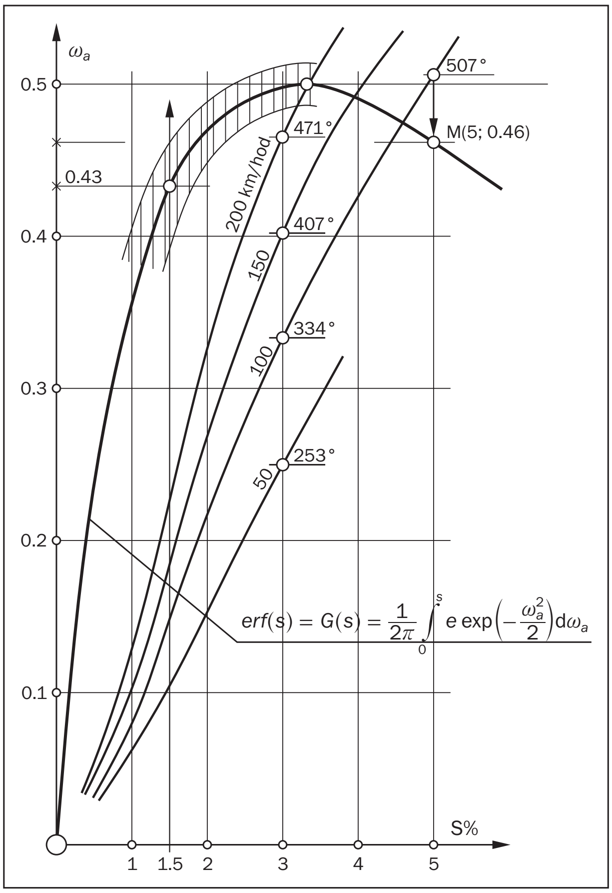

Figure 1 - Theoretical prediction of the contact temperatures T, drawn along the slip curve

experimental verification since the peak contact temperatures (so called "flash" temperatures - lasting for a very short time) will probably be considerably higher. Also their time change will not correspond to the slow diffusive transmission of heat. The top temperatures cannot be ordinarily experimentally indicated.

For the experimental study of the progresses of tangential forces at the set or variable slip s a new type of laboratory device has been developed (*in the laboratories of the Jan Perner Transport Faculty, University of Pardubice*), which is expected to verify or supplement the existing opinions, which are based on the established coefficient of adhesion μ, i.e. on the ratio between the radial loading force and the incurred tangential force.

The principle of *the experimental methodology* is described by means of a *schematic diagram* in *Figure 2*, and a *photograph of the realized testing device* in *Figure 3*. The tested samples of material 2, 3 are disc-shaped and of the same diameter.

Both discs are driven directly by the vector-controlled synchronous servomotors 4, 5. The upper system 3, 4 is located on the rest 6, which is pivoted in relation to the machine frame 1 around the indicated axis A. The servomotor 5 is located on the horizontally-sliding rest 7. The shaft of the upper disc 3 is fitted with the torsionally-flexible dynamograph 8. The radial loading of both discs can be adjusted by means of vertical drawbars 9, which are linked to the girder dynamographs 10 in the bottom part. The dynamic component of this loading is incurred by the pair of rotational vibrators 11, whose motors are equipped with programmable control. The bearing of the vibrators on

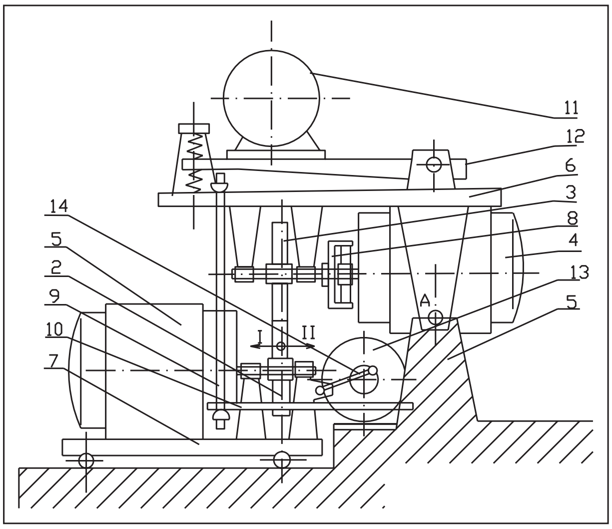

Figure 2 - Schematic arrangement of the designed special experimental testing device

the spring-loaded rest 12 enables their self-synchronization. The horizontal oscillation of the rest 7 (indicated there), which bears the servomotor 5, is controlled by the program-controlled motor 13 by means of the crank mechanism 14.

The device is proposed for two test modes. In the first mode the speeds of both motors are set so that the selected tangential slip is incurred; it is also possible to set transverse oscillation of the rest 7. The flexible dynamograph 8 sends a signal about the value of the adhesively transferred torque including its changes in time. In this way it is possible to test the working modes within the entire range of the set tangential slips with the contribution of the transverse slips. The

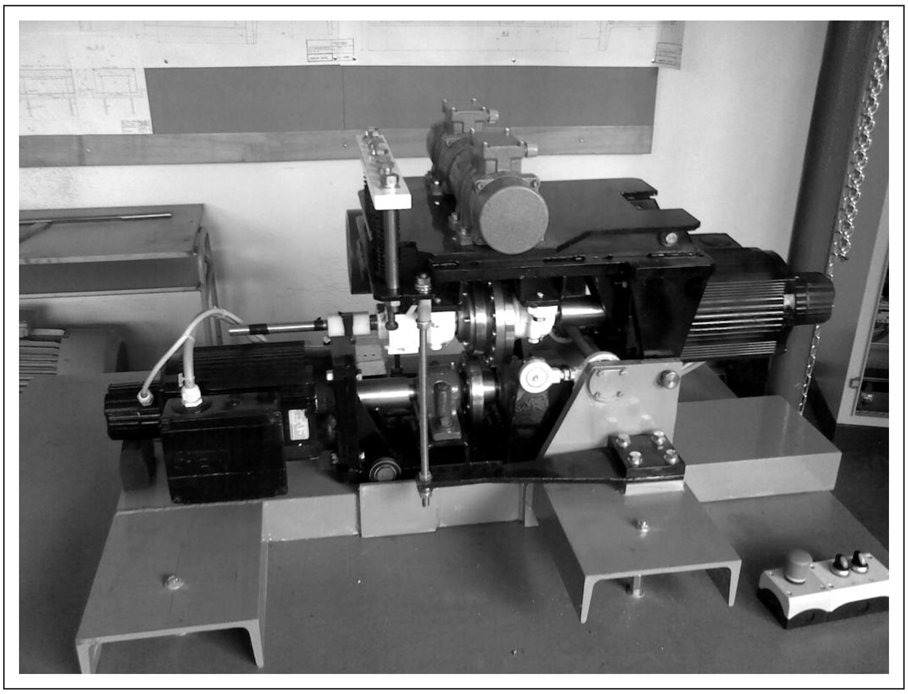

Figure 3 - View of the designed special experimental testing device

modes are tested either as stable, or as transient. The second mode of tests has a similar nature, except that one of the servomotors is controlled as a generator. In this case the slip is incurred by adhesive processes in the contact of both discs. At these tests especially the dynamic manifests of the system around the maximum of the incurred tangential force are monitored, where unstable states are presumed on the basis of the classical adhesion theory [4].

5. ASSUMED RESULTS AND IMPORTANCE FOR PRACTICE

It is generally known that the discussed considerable heat-affection of subsurface material layers, and consequently risen quenched microstructures with high hardness level can be indicated as an origin of heat and/or fatigue cracks, as well as contact fatigue and falling out of the material from the railway wheel/rail tread, mostly in case of railway vehicles with disk brakes.

However, the mechanism of conditions resulting in microstructure changes in a rail and railway wheel material is not hitherto explicated in a satisfactory way, and that is why the presented research is to be significantly applied in railway operation and practice, especially as prevention and diagnostics, see [7, 8].

Moreover, we cannot discount an idea that the rising thermally-induced cracks following the circumferential direction of the wheel surface, can change their orientation into radial direction, with a possible catastrophic failure (brittle fracture) of a wheel and imminent derailment of a railway vehicle, or a train.

From the fracture mechanics point of view, the catastrophic brittle fracture of a rail and wheel can occur when reaching the critical size of these defects (radial cracks). It is therefore necessary to study the "thermal effect" on the principle and to clarify the causes of its origin in order to achieve higher safety of railway operation.

6. CONCLUSION

The considerations presented in the previous chapters can imply that the coefficient of adhesion is, among other things, dependent on the contact temperature and that in this connection the value of the coefficient of adhesion can be theoretically predicted. This fact has not been considered in the theory of adhesion contact so far.

As for material, it seems that at the monitored input parameters there is no threat of creation of contact temperatures influencing material not even at a relatively high value of slip. And yet, if we notice the existing dynamic increase of wheel force, naturally, the contact temperature rises. This temperature means minimal rise of thermal flux in contact volume, see Lata and Čáp [9]. However, the temperature may severely influence the value of the coefficient of adhesion by tribological process in the surface layer. The adhesion process improves, however, at the expense of abrasive processes which naturally accompany the adhesion process.

The relatively high values of the normal and tangential forces are characteristic for the force effects in the contact area of railway wheel/rail. Especially the tangential forces have, due to the changes of surface layers properties of wheel tread, the significantly inconsistent character, especially due to the existence of discussed (flash) contact temperatures. The problem is even more complicated since the adhesion process takes place while the contact area deformations of the dynamic character are formed.

Since these theoretical prognoses, formulated in the area of tribology, require theoretical verification, we have just adopted the described special testing device. The concept of the research in this field stems from the belief of the solvers that it is necessary, apart from the history of loading, to monitor the cooperation of degradation processes in the contact area in connection with the definition of limiting conditions in the surface layers as processes which represent the initiatory mechanisms of the potential (catastrophic) damage of a wheel, see for example the work by Beneš and Záhorová [10].

The research work has been aimed at increasing the railway operation safety by means of reducing the occurrence of the defects in surface and under-surface layers of railway wheel tread. We can believe that better knowledge in these matters will bring some potential for improvements of service work, methods of advisable diagnostics and enhancement of reliability for the railway transport system.

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ABSTRAKT

VYBRANÉ TRIBOLOGICKÉ ASPEKTY A TEPLOTNÍ JEVY V KONTAKTU MEZI ŽELEZNIČNÍM KOLEM A KOLEJNICÍ

Článek popisuje některé tribologické aspekty v kontaktu mezi železničním kolem a kolejnicí, ve vazbě na nově vybudované zkušební zařízení (adhezní stand), od kterého se očekává významné rozšíření současných poznatků v oblasti diagnostiky uvažované kinematické kontaktní dvojice. Hlavní úvahy, podané v této práci, se zaměřují na teplotní závislost koeficientu adheze a teoretickou predikci jeho hodnoty. Tento fakt doposud nebyl v teorii adheze příliš uvažován. Teoreticky totiž nelze předložit zcela věrohodnou prognózu těchto nepříznivých jevů. Proto zde autoři prezentují i zmíněný nový adhezní stand (BeKaTest), na němž je možné verifikovat uvedené jevy, které byly doposud pouze predikované. Rovněž je pozornost věnována oscilačnímu efektu a jeho vlivu na stav povrchu. Celkově pak z provedených prací vyplývá, že jejich iniciace, resp. lokální degradace v kontaktní oblasti železničního kola a kolejnice, navazují úzce na popisované tribologické procesy a musí být uvažovány v kontextu probíhajících dynamických dějů.

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kontaktní únava, železniční kolo - kolejnice, tribologie, bezpečnost provozu

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