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TRIBOLOGICAL ASPECTS OF THE RAILWAY WHEEL - RAIL CONTACT

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Katedra mechaniky, materiálů a částí strojů

1. Introduction

It is implicit that the primary cause of the creation of effects that appear in the contact area of two real bodies (railway wheel-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 [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 10^{-3} m. This relatively satisfactorily corresponds to experimental analyses which among others detect hard structures called White Etching Layers [2].

Another common feature resulting from the conclusions of performed researches 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 be spread into a basic and unaffected wheel material but also is determinant for the development of 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 aspect of adhesion process in the contact area

Driving railway vehicles work on the basis of 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 a 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 happens 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 on a wheel-tread. It was proven that there is a linear dependence between the coefficient of adhesion and the slip **s**. This dependence is called ***slip curve***. If 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 the slip curve

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

$$T = 1{,}11 \, . \frac{\mu_a . F}{A . b . \sqrt{L}} \left(\sqrt{v_1} - \sqrt{v_2} \right) \ [°\mathrm{C}], \qquad (1)$$

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

$\lambda = 55 \ Js^{-1}m^{-1}K^{-1}$ ....thermal conductivity of steel, ρ = 7,865.10³ kg m⁻³.............density of steel,

c_p = 460 J kg⁻¹K⁻¹..................specific heat capacity,

has the value:

$$b = \sqrt{\lambda.\rho.c_p} = \sqrt{55{,}0.7{,}865.10^3.460} = 1{,}41.10^4 \text{ [Jm}^{-2}\text{K}^{-1}\text{s}^{-0,5}\text{]}$$

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

$$\Phi = \sqrt{v_1} - \sqrt{v_2}\ , \qquad (2)$$

where $\mathbf{v}_1$ [ms^{-1}] is circumferential speed of wheel, $\mathbf{v}_2$ is gradual speed of wheel. The formula for the corresponding slip **s** is then

$$s = \frac{\Phi^2 + 2.\Phi.\sqrt{v_2}}{v_2} \qquad (3).$$

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:

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

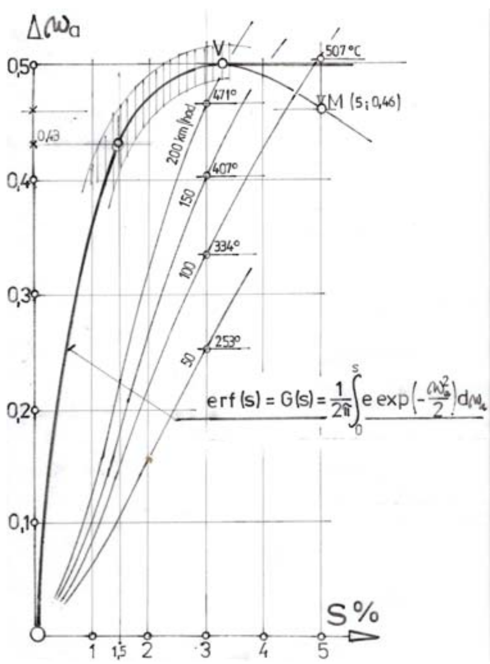

***Fig. 1** Prediction of the contact temperatures **T**, drawn along the slip curve.*

For common criteria (dry rail) according to [4] the value limits the coefficient of adhesion to number 0,5. The slip curve, expressed this way, is presented in the ***Fig. 1***. To verify the acceptance of such procedure, the comparison with Čáp's experimental results were used [4]. E.g. 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 the ***Fig. 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 [5, 6].

4. Experiment

The theoretic prognosis of the average values of the contact temperatures leads to the need of its experimental verification since the peak contact temperatures will probably be considerable higher. Also their time change will not correspond to the slow diffusive transmission of heat. The top temperatures cannot be ordinarily experimentally indicated. There is a potential possibility represented by a special experimental device, see **Fig. 2**, which was realized in the laboratories of Jan Perner Transport Faculty. This device is instrumental in the dynamic stress of a specimen of a wheel material. The tested specimen **1**, having the shape of a roller, is stressed by the dynamic forces **R(t)** and **T(t)**.

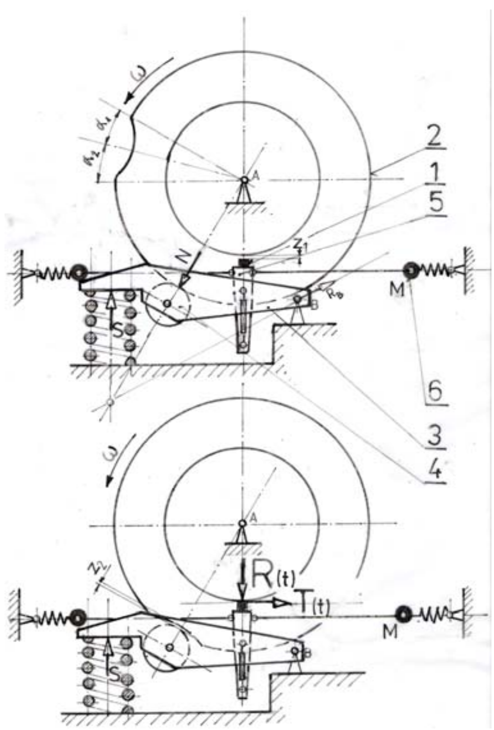

Fig. 2 *View of the designed special experimental device.*

The indication of the contact temperatures is performed by a thermo-element that has the diameter of 0.025 mm, so the expected time of response is approx. 3,0 milliseconds. The dynamic forces that affect the tested specimen **1** are invoked by the spring force **S**. The time behaviour is determined by the shape of a cam part on the disk **2** with the help of a thrust lever **3** and a generating roller **4**. The adequate tangential force **T(t)** is automatically invoked by a flexible binding of a specimen carrier **5** in the tangential direction. Modal tuning is supported by the placed substances **M** and springs **6** and the disk **2** is supported by a vari-speed motor where the glide strain rate can be adjusted. The device is designed so that it would be possible to invoke a real value of the wheel force **R(t)**, whereas the tangential force **T(t)** is dependent on the glide strain rate and on the character of the flexible binding of the specimen carrier **5** in the tangential direction.

5. Conclusion

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 abrasive processes in the contact area in connection with the definition of limiting conditions in the surface layers as processes which represent the initiatory processes of the potential (catastrophic) damage of a wheel.

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Resumé

TRIBOLOGICKÉ ASPEKTY V KONTAKTU MEZI ŽELEZNIČNÍM KOLEM A KOLEJNICÍ

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Je nesporné, že prvotní příčinou vzniku jevů, které se odehrávají v kontaktní oblasti dvou reálných těles (kolo - kolejnice), jsou silové účinky, způsobující vratné i nevratné změny materiálu povrchových vrstev. Hlavním záměrem předpokládané úvahy je poukázat na výskyt kontaktních teplot, které charakter dějů zřejmě podstatně ovlivňují. Je do jisté míry překvapivé, že s tímto fenoménem není v oblasti studia adhezního přenosu dostatečně kalkulováno. Koncepce výzkumu v této oblasti vychází z přesvědčení autorů, že je nezbytné vedle historie zatížení sledovat spolupůsobení abrazivních dějů v kontaktní oblasti, a to v souvislosti s definováním mezních stavů v povrchových vrstvách, jakožto dějů, které představují iniciační procesy možného porušení kola v podobě katastrofického porušení.

Summary

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It is implicit that the primary cause of the creation of effects that appear in the contact area of two real bodies (railway wheel-rail) are the force effects causing reversible as well as irreversible material changes in the surface layers. 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. The concept of the research in this field stems from the belief of the authors that it is necessary, apart from the history of loading, to monitor the cooperation of abrasive processes in the contact area in connection with the definition of limiting conditions in the surface layers as processes which represent the initiatory processes of the potential (catastrophic) damage of a wheel.

Zusammenfassung

TRIBOLOGISCHE ASPEKTE IM KONTAKT ZWISCHEN DEM EISENBAHNRAD UND DEM GLEIS

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Die Krafteinwirkungen, die sowohl die zurücknehmenden als auch die dauernden Oberflächenveränderungen des Material verursachen, sind die primäre Ursache der Phänomenenentstehung, die sich im Kontaktbereich der beiden realen Körper (Rad-Gleis) abspielen. Das Hauptziel der zu erwartenden Überlegung ist der Hinweis auf das Aufkommen der Kontakttemperaturen, die den Charakter der Veränderungen wohl maßgeblich beeinflussen. Es ist daher erstaunlich, dass man bisher mit diesem Phänomen im Bereich des Studiums der Adhesionsübertragung nur ungenügend gerechnet hat. Dei Forschungskonzeption in diesem Bereich geht aus der Überzeugung der Verfasser, dass es notwendig ist neben der Belastungsgeschichte auch die Zusammenwirkung der abrasiven Vorkommnisse im Kontaktbereich zu verfolgen und zwar im Zusammenhang mit der Definition der Grenzzustände in den Oberflächenschichten, als Vorkommnisse, die die Initiationsprozesse der möglichen Radbeschädigungen in der Form einer katastrophischen Beschädigung.