Peculiarity of side wearing of rails in curves of rapid city railway line

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Abstract **– The paper presents the investigation results relevant to excessive side wear-out of rails occurring in bends of the Rapid City Railway line of Gdansk – Gdynia. To find out the cause of the phenomenon there were carried out uninterrupted tests of the technical and geometric conditions of the rail tracks at a dozen experimental sections. Using the data it was possible to determine the wear-out progression along the circular arc and the transition curves. It has been proved that the operation of a homogeneous railway rolling stock, electrical articulated train sets, EN57 and EW58, has a significant effect on the occurrence of the phenomenon under consideration. There have been found some links between the wear-out magnitude and the measured geometric shape of the track in the horizontal plane. Various measures taken to limit the intensity of the side wear-out of rails have been discussed. Attention has been centred particularly on the worked out conception of the rail lubricator - Sm 88 whose implementation has given some favourable results.**

1. Introduction

A characteristic phenomenon occurring for many years in the Rapid City Railway (RCR) line of the Tri–City complex of Gdansk, Sopot and Gdynia was an intensive wear of rails in the bends (in exterior stretch of rails). Taking account of the fact that the long-distance track (of similar geometrical parameters) running parallel to the RCR was not affected by this phenomenon, it was possible to take into consideration an extensive lateral wearing of rails in the RCR. Rails with a considerable degree of lateral wear pose a direct threat to the safety of travelling by train. An improvement in the railway system between Gdansk and Gdynia was achieved by using thermally treated rails with harder flanges around the wheels. However, it is worth taking a closer look at the problem, since it is connected with the peculiarity of the operational use of the fast municipal railway systems.

The peculiar operational use of the fast municipal railway systems consists in the homogeneity of the rolling stock (electric traction units) engaged here and a very high frequency of trains. The phenomenon of wear itself is undoubtedly related to the way in which the wheel sets move along the horizontal curvatures (circular arcs and transition curves). A decisive role is played by the size of the wheel pressure against the rail. Of course, the wearing of the rail is accompanied by the wearing of the wheel flange. The rolling stock used by the fast municipal railway lines indicates a much bigger wear of flanges in comparison with analogical rolling stock employed at other railway lines. The wear of the wheel flanges occurs in all wheel sets and in principle, at a uniform rate, that is, its magnitude does not depend on the position of the axle along the length of the train set.

Thus, the problem should be looked upon as a system of closely related elements. When trying to lessen the intensity of the lateral wear of rails, it is also necessary to take into account the simultaneous reduction in the wear of the wheel flange. This principle should constitute the fundamental rule for taking any preventive measures.

2. Tribological model of the system: wheel flange – the rail

A tribological model of the mechanical system, the wheel flange and the rail is very complex [2, 5, 8, 9]. In the model it is possible to distinguish the following constituent parts (Fig. 1):

a) structure of the model:

- - constituent parts: rail Sz, wheel K, lubricating substance S, surrounding atmosphere in friction (ambient air, dust pollution) A;
- - properties W of constituent parts: geometric and material macro- and micro-propertis $W(Sz)$, $W(K)$, physical-chemical and rheological properties $W(L)$ and others;
- - reactions R between constituent elements of the system;

b) external interactions:

- - input X: load P, speed v, temperature T;
- - output Y: friction resistances F_T, side wear of rail Z, wear of the wheel flange Z_K, accompanying processes P_t;

c) functional characteristics of the system: relationships describing the transformation of input (interaction) magnitudes X into output ones Y.

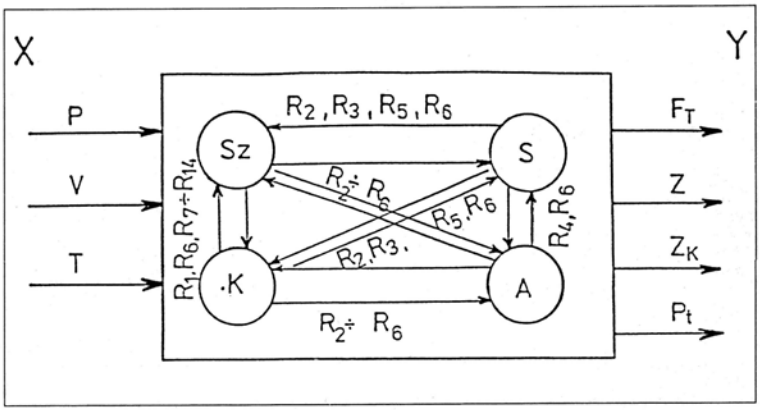

Fig. 1. Model of the tribological "wheel – rail" system

The properties of the rail and the wheel can be divided into:

a) geometric ones: shape of the rail head and the wheel flange, and their accuracy related to dimensions and configuration (macro-properties), parameters of roughness and corrugation of the active surface of the rail and the wheel flange (micro-properties);

b) material properties including physicochemical (chemical composition, density, metallographic structure, free energy of surface), mechanical (temporary tensile strength, yield point and elastic limit, fatigue strength, hardness, residual stresses) and individual micro-properties (crystalline structure and network parameters, packing density, co-ordination number, binding energy of atoms); and complex properties:

c) geometric: nominal surface of contact, real surface of contact, radii of curvatures;

d) material properties: equivalent longitudinal modulus of elasticity, tear and shear strength of adhesive-bonded joints, chemical affinity, intersolubility, interfacial energy of material connection, diffusivity.

Individual (specific) properties of a lubricating substance are:

- - physicochemical properties, and
- - rheological properties.

On the interfacial surfaces (wheel − lubricant, rail − lubricant) it is possible to distinguish some complex properties, as for instance: surface interfacial energy, chemical affinity in relation to the surface, ability to absorb and chemisorb, capability of plastifying the layer just below the surface.

The dynamic state of the system under consideration takes account of external influence, whereas each element of the system interacts with the remaining ones possibly accompanied by adhesion R_1, adsorption R_2, chemisorption R_3, oxidation R_4, corrosion R_5, diffusion R_6, elastic strain R_7, plastic strain R_8, microcutting R_9, grooving R_{10}, scratching R_{11}, tearing R_{12}, break of friction joints R_{13}, structural and phase transformations R_{14}. The intensity of the occurrence of particular relations is very diverse, some of them can be negligibly small. In literature one can hardly find any specific data on the subject. It is also worth mentioning that external interactions at the inlet cause changes in the relations inside the system, as well as changes of the properties of its elements. Kinematic and dynamic interactions (rubbing speed and rolling velocity), loading or pressure per unit area, are fundamental factors exciting relations $R_7 \div R_{14}$. Thermal and environmental interactions affect only the character of each of relations $R_1 \div R_{14}$.

The tribological system under investigation is in non-stationary (phase I), stationary (phase II) and stochastic state of dynamic equilibrium (phase III). During the running-in there takes place the matching process of the surface microgeometry. Also advantageous changes in the metallographic structure of the surface layers of the cooperating elements are involved in this process. In phase III the physical image of the phenomena apparently remains unchanged. The material wear and tear in this phase is primarily due to violation of optimal requirements of the rail track exploitation (overloading, insufficient lubrication, negotiation of wheel sets).

3. Magnitude and character of the rail wear-out

3.1 Characteristics of the occurring rail wearing

In order to determine the course of the phenomenon of side wearing, for several years there were carried out research works on the selected track sections. The scope of these tests comprised the measurements of the side wearing of rails and the measurements of the geometrical system of railway track. These tests comprised in all 14 circular arcs of various dimensions of the radius (R = 199 ÷ 900 m). The measurements of the side wearing were conducted with the use of track slide calliper − the distance between two measuring points being one meter. The obtained adequacy was 0,1 mm. Examples of diagrams illustrating the rail wear-out (referring to measuring section no. 3) are given in Figure 2.

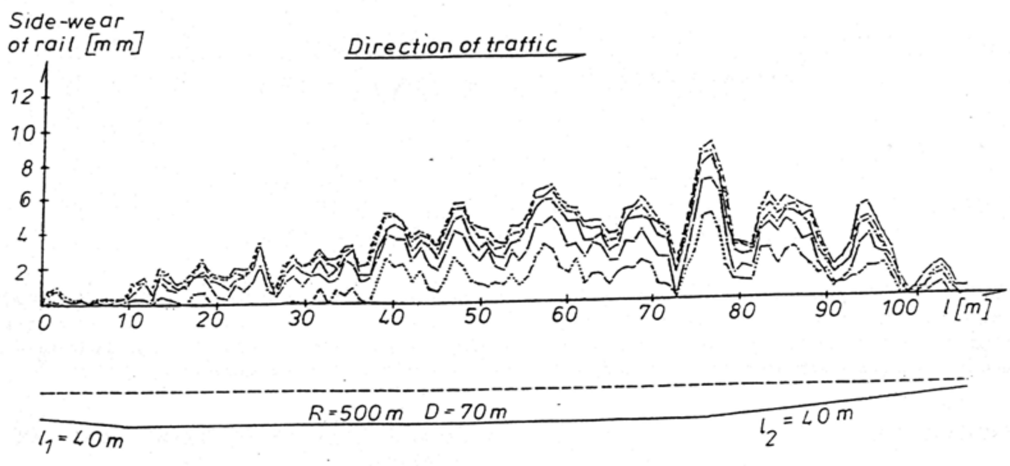

Fig. 2. Progression of the lateral rail wear along a selected length under test

In order to have more knowledge about the exploitation conditions that accompany the Rapid City Railway lines of Gdansk – Gdynia, advantage was taken of annual rolling loadings of the railway line and measurements of real travelling speeds developed by trains along the lengths tested. The RCR lines are serviced by two types of electric units: EN57 and EW58-type. The annual loading magnitudes (obtained from calculations) namount to about 19,9 Tg in tracks no. 501 and 502 (line Gdansk Central Station – Gdynia Stocznia) and to about 4,6 Tg in track no. 500 (line Gdansk Central Station – Gdansk Nowy Port).

The maximum speeds for particular lengths determined by measurements were used for calculating the theoretical superelevation. It has been proved that in most cases the trains speeds in the bends tested are much lower than the accepted rate for the RCR line, which is v_{max} = 70 km/h, whereas the values of the occurring superelevations are definitely higher than their theoretical equivalents. This is the result of measures taken by maintenance service in order to limit the side wear-out of rails. The undertakings have proved to be a complete failure.

A detailed analysis of the measurements was related to the following problems:

- appraisal of the railway track location in horizontal plane,
- distance between consecutive maxima in a wear diagram,
- the nature of the wear progression,
- relationships between the wearing-out and the horizontal configuration of the track.

3.2 Appraisal of the railway track location in horizontal plane

Figure 3 gives an example of horizontal configurations for testing length no. 1 (R = 199 m). This diagram, as well as the remaining ones, indicates that all the testing lengths are characterized by improperly shaped curvature. The measurements have also shown that each transition curve is encumbered with incorrect measurements of ordinates in comparison with their theoretical values. A similar situation, even though to a relatively minor extent, is found with respect to the mentioned earlier superelevation.

Apparently the irregularities found in the curves shape in the horizontal plane can have a disadvantageous effect on the increment of the side wear-out of rails.

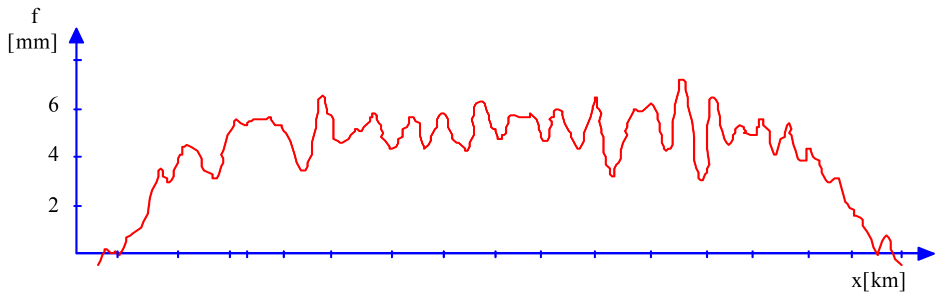

Fig. 3. Diagram of horizontal configurations for testing length no. 1 (R = 199 m)

3.3 Distance between consecutive maxima in a wear-out diagram

To understand if the structure and the relevant manner of the wheel sets' negotiations have influence on the rail wear-out value, there were determined intervals between consecutive wear-out maxima for respective measuring lengths on the basis of the wear-out diagrams. It has been proved that the parameter analysed assumes values within a wide range (3 ÷ 15 m). An average distance between wear-out maxima (i.e. also between points of the largest side pressure of the wheel against the rail) is of the order of 7 ÷ 9 m, considering a standard deviation of approx. 3 m. This does not depend on the value of the radius of curvature (for R = 325 ÷ 900 m). Thus, the negotiation of a set of railway truck is a complex problem However, the rigidity of the draft of cars seems to play the dominant role.

On typical bends of the RCR with radii above 500 m the side wear-out of rails is of oscillatory character and for this reason it is possible to talk in this case about excessive wear-out occurring locally along relatively short lengths. Changes of the wear-out magnitudes (between consecutive extremes) can be large and, as it is generally understood, can occur along a length not exceeding, on average, 5 m; and as a consequence can cause a sudden variation in the track width, which is directly connected with the question of traffic safety, threatening to derail, due to breach of the permissible values of the track width gradient.

3.4 The nature of the wear progression

In order to establish whether the nature and the side wear-out magnitude are related to the direction of the trains movement, the successive maxima in the wear-out diagrams are connected together by a broken line (Figure 4 exemplifies rail track length no. 5).

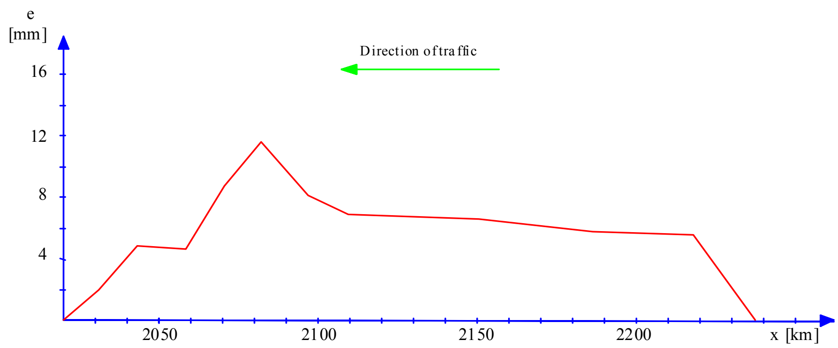

Fig. 4. Envelope of side wear-out maximum values for rails in measuring length no. 5 (R = 600 m)

From the obtained diagrams it follows univocally that the wear-out increases according to the direction of the trains movement (as can be seen in Figure 2). The largest wear can be noted at the outlet from the system: transition curve – circular arc – transition curve (i.e. in the area close to the end of the transition curve on the side of the descent), since the transition curve is in this case an exciting factor. These facts find confirmation in the symmetric (with respect to the central part) distribution of the wear-out in the rail sections where the traffic along the given track moves in both directions (measuring sections no. 1 and 2).

3.5 Relationships between the wearing-out and the horizontal configuration of the track

Making use of the performed measurements of the horizontal configuration by the curvature corrector and the side-wearing-out of rails it was possible to determine for particular measuring lengths the correlation between the horizontal configurations (at points of taking the wearing-out measurement) and the wearing-out values. Simple regression lines of the wearing-out in relation to the horizontal configuration magnitudes were also determined. An illustrative diagram for measuring rail track length no. 10 is given in Figure 5.

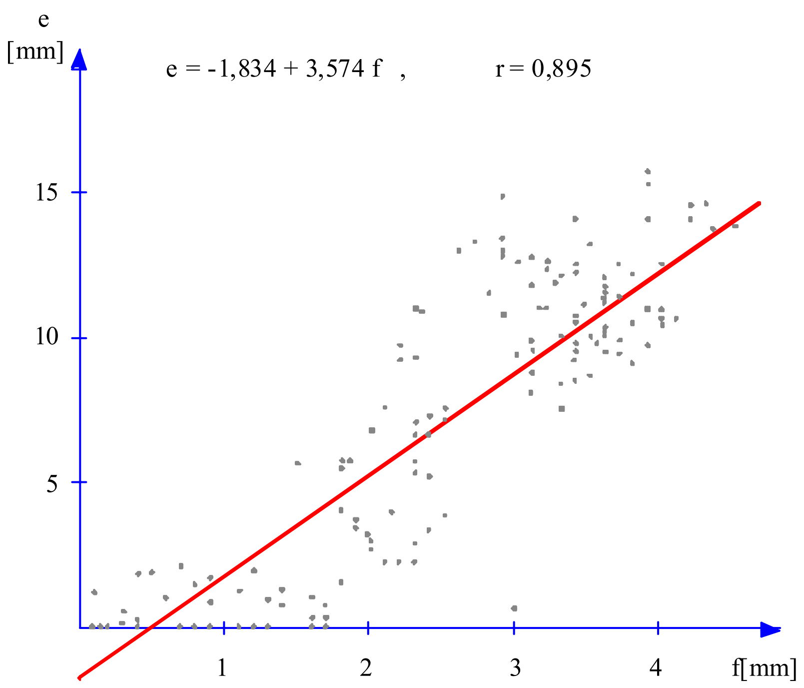

Fig. 5. Diagram of simple regression line of the side-wearing-out of rails in relation to horizontal configuration magnitudes for measuring length no. 10 (R = 325 m)

The values calculated for the correlation coefficient (using a great number of data) in most cases, range between 0,6 and 0,9. The biggest value, r = 0,895 occurred along measuring length no. 10 characterized by the most intense wear-out. From the analysis it follows that the rail shape of the track in horizontal plane has a very great effect on the wearing-out of rails. The top wear-out values take place at places of suddenly changing horizontal configurations, that is, at points where some irregularities in the geometric shape of the track have been noticed.

4. Preventive measures taken

The measures, taken in different periods of time (discussed in the paper), aimed to diminish the lateral rail wear were of threefold type and related to:

- changes in the geomeric system of the tracks,
- use of thermally treated rails in some bends,
- application of rail lubricators.

4.1 Changes in the geometric system of the tracks

Changes in the geometrical system of the railway track consisted mainly in a radical increase of the track superelevation on the curve. This operation was found to be not very efficient. Within the framework of the investigations being conducted an attempt has been made to assess the range of the operation. It appeared that the values of the horizontal configurations are evidently higher than their relevant theoretical magnitudes, sometimes even several times. Comparing the data with the excessive side wear-out of rails in the RCR line, it is possible to conclude that the impact of centrifugal force is not the basic cause of this phenomenon. In this situation, an increase of track superelevetion appears to be purposeless. Sometimes it may bring about negative effects – it leads to expanding the rail head of inner stretch and to forming flows (and, in places, to the occurrence of wavy wear). Besides it was notised that for low speeds (about 25 km/h) the train fails to react to the superelevetion. The traction stock running on an increased superelevation should then press the inner stretch of the rails because of the existence of a considerable transverse force. As a matter of fact there occurs a noticeable distance between the flanged wheel and the internal rail, which is surely connected with the peculiarity of the negotiation of the draft of cars.

4.2 Use of thermally treated rails in some bends

Thermally treated rails (full hardened) are commonly applied in bends of small radii. In course of the investigations they were used for four testing sections. The side wear-out of the rails definitely departed from the type of wear-out along the remaining sections. The wear-out in the thermally treated rails is uniform with occasional disturbances, whereas in other bends it takes the form of oscillations. This is an advantageous phenomenon because it is adequate to the occurrence of relatively minor maximal wear-out and the extension of the operational use of the rail in the track.

However, conspicuous advantages gained from using thermally treated rails should not underestimate the fact that their application might cause an instant and intensive rise of the wearing-out of the wheel flanges. At the beginning of the process it was necessary to replace the wheel flanges every two weeks in the railway rolling stock servicing the line Gdańsk Central Station – Gdańsk Nowy Port, taking advantage of hardened rails despite a several times lower load of the line. Such a situation requires that the railway service discipline be satisfied, in particular in areas with no hardened rails. The modified structure following the thermal treatment of steel is of primary significance not only with respect to the wear-out of the rails but also the wheel flanges (increase of abrasive wear-out and fatigue wear-out). The minimal wear-out of the tribological pair, rail – wheel flange, occurs when the applied steel hardness variations in the applied steel hardness are insignificant. However, the problem calls for more detailed experimental (laboratory and field) investigations on rails and hardened wheel flanges. The enhancement of the wheel flanges' hardness enables to extend the applied range of the thermally treated rails.

4.3 Application of rail lubricators

The problems arising in the RCR line have inspired a group of researches from the Gdańsk University of Technology to verify the conception of lubricating the rails of the track. This is a conception that has been developed for years in many countries [1, 3, 4, 6, 7, 10]. It has been decided to make use of a Polish project of L-4/62-type lubricator [2] the production of which was stopped, although there were made in it some constructional changes substantial in operational use of the appliance. The constructional modifications made, related to the oil pump, the feeder and the oil tank. In consequence of observations made on consecutive prototype versions and improvements successively put into effect there was constructed a new device fully satisfying the exploitation requirements. The lubricator was assigned the identify mark Sm 88.

The structure of the lubricator of Sm 88 type (Fig. 6) consists of four assemblies: an oil reservoir A, a sleeve pusher B, an oil feeder C and oil pump D. The oil reservoir A is connected by a pipe with the oil pump D. It is situated in such a way, that its bottom is over the suction and force chamber of the plunger pump. The pump is set in motion by cam follower B, actuated by the wheels of moving rail-vehicles; as a result, oil is sucked into suction and force chamber and delivered to oil feeder C.

The proper location of this lubricator in the track is of primary importance for achieving the desirable effects of lubrication. Location of the lubricator in the track has great significance for obtaining the desired lubrication effect. In a dual-track of single-direction traffic the lubricator should be installed at a point along a straight line before a bend in order to enable all wheel flanges to get in contact with oil-soaked rail edge (along the length of approximately 700 mm). In case of bidirectional railway traffic the lubricator should be installed in the middle of the curve. The average lubrication range is 2 ÷ 3 km.

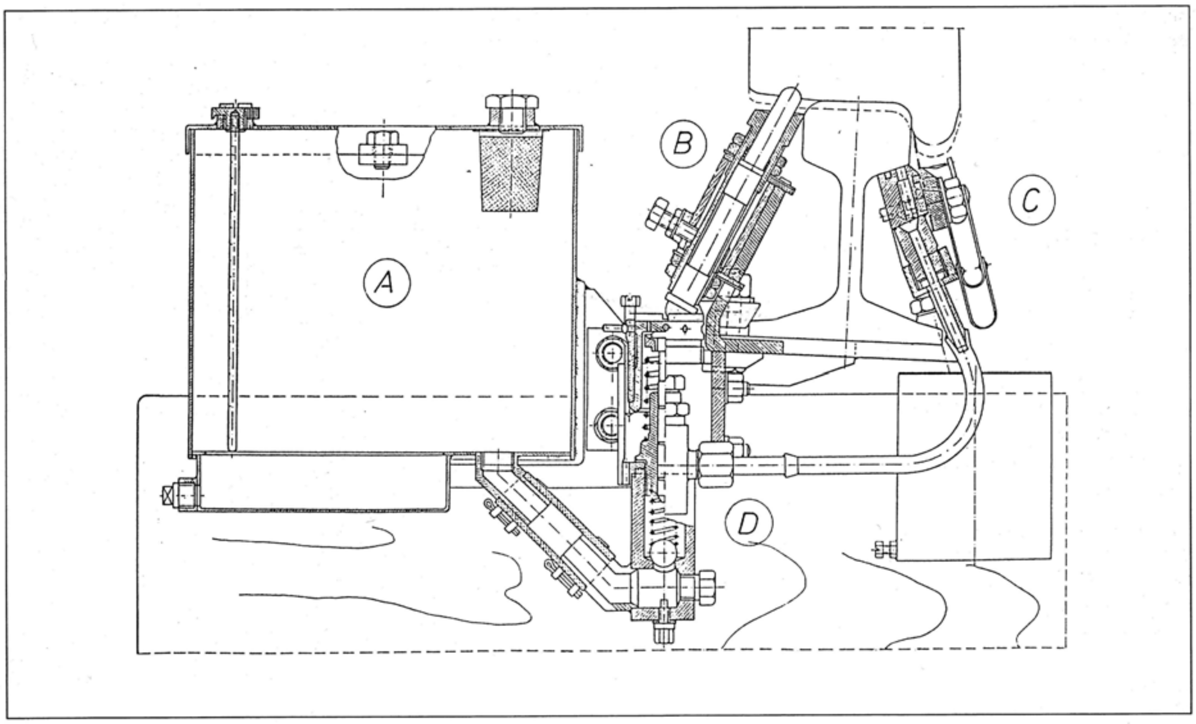

Fig. 6. Lubricator Sm 88 – cross section: *A* – oil reservoir, *B* – pusher unit, *C* – oil feeding set, *D* – volurnetric pump

For the purpose of assessment of the effectiveness of using the rail lubricator - SM 88, the above mentioned appliance was installed at several selected points along bends of the RCR line. At the beginning of the investigations the lengths along the bends were used for testing the side wear-out in non-lubricated rails (for R = 233 ÷ 500 m). A linear growth of the wearing in time was noted, both for lubricated and non-lubricated rails. In all the considered cases, the correlation coefficients appeared to almost equal one, whereas the ordinates of the function $e = f(t)$ for the non-lubricated rails were much higher.

In this situation, the regression coefficient b can be the measure of the intensity of the wearing. The dependence of this coefficient upon the magnitude of the curve radius R was examined. For non-lubricated rails, there was obtained the equation of simple regression $b = f(R)$ having the form:

$$b_{ns} = 0{,}0776 - 0{,}0001184 \cdot R \quad , \qquad r = -\,0{,}825 \qquad (1)$$

For the lubricated rails, however, there was obtained equation:

$$b_{s} = 0{,}0175 - 0{,}0000124 \cdot R \quad , \qquad r = -\,0{,}308 \qquad (2)$$

Figure 7 shows how function $b = f(R)$ is shaped for non-lubricated and lubricated rails. As it can be seen, for lubricated rails radius R has no significant influence upon the intensity of the wearing (there appears almost horizontal course of the graph of the function $b = f(R)$). This influence is – on the other hand – quite evident for non-lubricated rails.

The quotient of the wear-out intensity illustrates clearly the decrease in the side wear-out of rails owing to the use of lubrication when comparing it with the non-lubricated rails. The quotient can be defined in the following form:

$$I = \frac{b_{ns}}{b_s} \qquad (3)$$

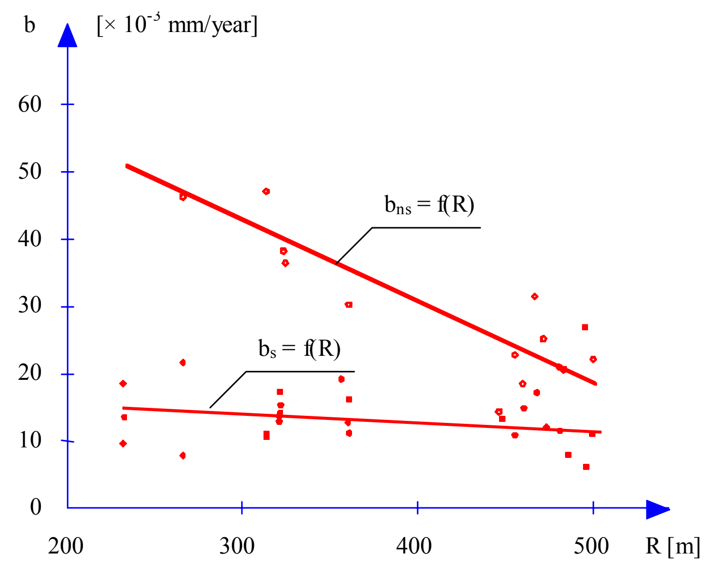

Fig. 7. Correlation between intensity of side wear-out of rail and radius of bend (b_{ns} – for unlubricated rail, b_s – for lubricated rail

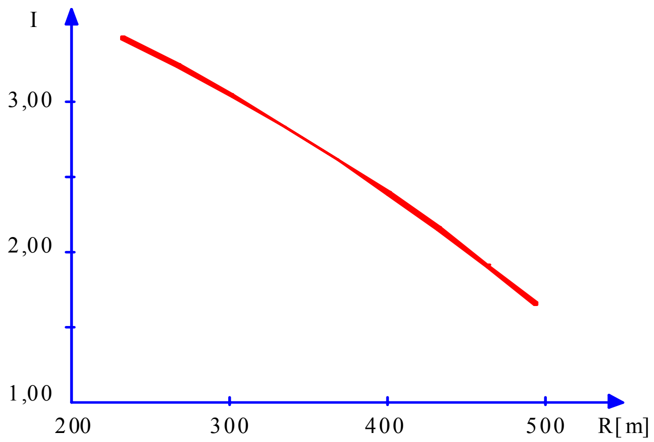

Fig. 8. Diagram $I = f(R)$ for condition of Rapid City Railway line servicing between Gdańsk – Gdynia

From expression (3) the values b_{ns} and b_s result from equations (1) and (2). The graph $I = f(R)$ is presented in Figure 8. The wear-out intensity of non-lubricated rails for R = 300 m is threefold, for R = 400 m – almost two-and-half fold greater than for lubricated rails. In the case of R = 500 m, values b_{ns} are in excess of b_s by approx. 50% . Regarding bigger radii of circular arcs the obtained lubrication result would be smaller. Thus, under exploitation conditions of the RCR line of Gdańsk – Gdynia when R > 600 m the rail lubrication is useless.

5. Conclusions

- The intensity of side wearing of the rails on the curves of the Rapid City Railway is significantly bigger than on typical railway lines having similar geometrical parameters. It is connected with the specific operating conditions existing here as well as with the irregularities in the geometrical shaping of the track, discovered in the course of the measurements.
- Among the difference ways to counteract this disadvantageous phenomenon, the lubrication of rails deserves particular attention. The advantages resulting from lubrication of rails are obvious also from the energy saving point of view, as well as the reduction of noise, one of the fundamental conditions of the natural environment protection.
- The choice of the rail lubrication technique by track lubricators, or lubricating devices attached to railway engine, presents another problem. However, it cannot be treated as an alternative, but use should be made of both the solutions. Local conditions may play a significant role in this case.
- The application of lubricators in the RCR lines has prolonged several times the operational use of rails in bends and thereby contributing to evident economical profits and also eliminating to a considerable extent disturbances in regular running of trains caused by frequent replacement of rails. This is of particular importance in the populated urban agglomeration of Gdańsk and Gdynia where the RCR line is the main communication axis.

6. References

[1] ALLEN R.A.: Rail lubrication saves energy as well, *Railway Gazette International*, 1985, No. 2.

[2] BARYLSKI A., KOC W.: Schmierapparate der Stadtschnellbahn in Gdansk, *Tribologie und Schmierungstechnik*, 1993, No. 6.

[3] BARYLSKI A., KOC W., MIELOSZYK E.: Seitliche Abnutzung der Schienen in Bögen bei der Stadtschnellbahn, *Tribologie und Schmierungstechnik*, 1992, No. 1.

[4] BEJENKA K., MEDWIN M., MARCINIAK Z.: Flanged wheel lubrication system in diesel shunting lokomotive S–2000 (in Polish), *Trakcja i Wagony*, 1998, No. 12.

[5] CHICHOS H.: Tribology a system approach to the science and technology of friction, *Lubrication and Wear Tribology*, Amsterdam: Elsevier Scientific Publishing Company, 1980.

[6] MARCINIAK J., MEDWID A.: Results of investigation on an appliance for lubricating railway wheel flanges (in Polish), *Trakcja i Wagony*, 1985, No. 4-5.

[7] PIEC P.: Effect of wear-out process on the durability of rail vehicles (in Polish), *Problemy Eksploatacji*, 2000, No. 3.

[8] PIEC P.: Contact processes in constituent elements of rail vehicles (in Polish), Radom: ITE Publishers, 1999.

[9] RABINOVICZ E.: *Friction and wear of materials*, New York: Wiley Inter-science Publishers, 1995.

[10] ŠAŠKOVIČ O.N.: Ekonomia lokomotivnogo topliva za sčiot smazyvania relsov, *PSŽD*, 1986, No. 46.