CM2003

Proceedings vol I

6th International Conference on

Contact Mechanics and Wear of Rail/Wheel Systems

Gothenburg, Sweden, June 10–13, 2003

AVANCEZ 1829

CHALMERS

'Enhancing safety, environment and economy through research'

CHARMEC

www.charmec.chalmers.se

volume I

Proceedings

6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems

CM2003

June 10–13, 2003
Gothenburg, Sweden

Editors
Anders Ekberg, Elena Kabo & Jonas Ringsberg

Volume II

6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003) in Gothenburg, Sweden June 10–13, 2003

RESEARCH OF INFLUENCE OF SURFACE PROFILES FOR DIFFERENT WHEEL - RAIL PAIR ON DISTRIBUTION OF CONTACT STRESSES

Marek Sitarz, Aleksander Sładkowski, Zbigniew Żurek
Silesian Technical University, Chair of Railway Transport
Krasiński str. 8, Katowice, 40-019
POLAND
sitarz@polsl.katowice.pl, sladk@polsl.katowice.pl

Abstract

In this article research of influence of interacting wheel and rail profiles on distribution of contact zones and stresses is carried out. Influence of contact efforts on deformation of rolled carload wheels and rails, and also influence of this deformation on redistribution of contact stresses is investigated.

The quasi-Hertz method as well as a finite element method was included in a basis of mathematical simulation methods. With their help distributions of contact zones for different angles of attack wheel sets were defined. The problem was solved in three-dimensional statement.

INTRODUCTION

One of the most important questions of exploitation of cars and locomotives on the railways of the Central and Eastern Europe countries is the increased wear of a working surface of wheels. Especially it concerns their flange zones. Thus lateral surfaces of the railheads also wear out as well. The specified wear is various for different sites of a track and of a rolling stock. It has both character plastic deformation, and character abrasion of surfaces. The reasons for this phenomenon can be high dynamics of interaction in pair a wheel - rail that is caused by rather bad maintenance, both of a rolling stock, and ways; absence of effective means and appropriate use of lubrication of wheels in a flange zone.

However the most important questions arise in connection with correctness of a choice of wheels and rails profiles. It is quite obvious, that these profiles should correspond to each other and change of one of them should not occur without change of another. Exploitation practice of railways in some countries says the opposite. Here changes of profiles of a working surface of wheels without change of profiles of the railhead and on the contrary were carried out.

In considered job attempt to analyze contact interaction in pair a wheel - rail for various profiles of wheels and rails, including worn out, is made.

TECHNIQUE OF THE SOLUTION OF THE CONTACT PROBLEM

The analysis of a problem was realized by the finite element method. For the solution of the specified problems geometrical modeling of the considered objects was carried out in one of the CAD-programs. Their geometrical image was next imported to the finite - element program. Discretization of considered objects was carried out in a semi-automatic mode. It was not possible to use an automatic mode of discretization completely because in this case finite - element grids with the big number of degrees of freedom were created, and the solution of it with the satisfactory accuracy was very difficult to find.

On fig. 1 the FE grid for considered rail P65 is shown. Construction of a grid is executed as follows. The area of possible contact of a wheel and rail is allocated on the surface and for this surface generation of a surface grid is carried out. The specified grid was regular with the constant size of finite elements. Further the automatic generator of a grid has created final the FE grid of the head of a rail. This grid has turned out to be irregular.

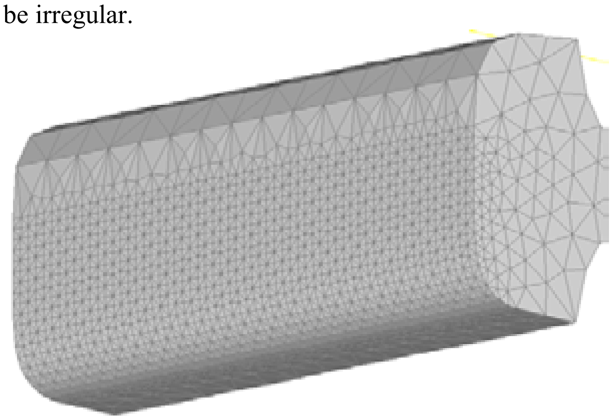


figure 1 Irregular FE grid of rail head

Let's note, that the shown grid was created by means of the generator of grids of program MSC.Visual NASTRAN for Windows. The FE grid for a wheel was created in a similar way.

Unfortunately, opportunities of the specified software do not allow to solve contact problems for any FE grids of a wheel and rail. The opportunities of use of the contact Slide Line elements are realized in package NASTRAN. The specified elements assume, that groups are being formed of contact nodes originally located in one plane. It is also supposed that after deformation they appear on one line along which they can slide. The name of the elements speaks for itself.

Package MSC.MARC gives considerably large opportunities for the solution of contact problems. Here there are no special contact elements, groups of preliminary created elements are simply united in contact bodies. These contact bodies can have FE grids that are unmatched among one another. However, there can be a vital issue of insufficient accuracy of the received solution. In particular, the following algorithm has been used. The data for profiles of interacting wheels and rails were described with the help of AutoCAD. Thus the worn out profiles of wheels and rails could be set as well as the new ones. Unique restriction was that profiles should be described by means of pieces of straight lines or arches. These restrictions are connected with the opportunities of import of the files with expansion DXF in program NASTRAN.

Then FE grids of a wheel and a rail were prepared, boundary conditions, loadings working on a wheel and a rail were set with help of NASTRAN. Received the FE model was exported into the package MARC where contact bodies were set, and also parameters of the solution of a problem, i.e. required accuracy of the solution, used operative memory, etc.

Unfortunately, the described technique did not provide the set accuracy of the solution. Problems arose here owing to an irregularity and inconsistency of FE grids of a wheel and a rail. In particular, on fig. 2 distribution of equivalent Von Mises stress in the contact area is shown.

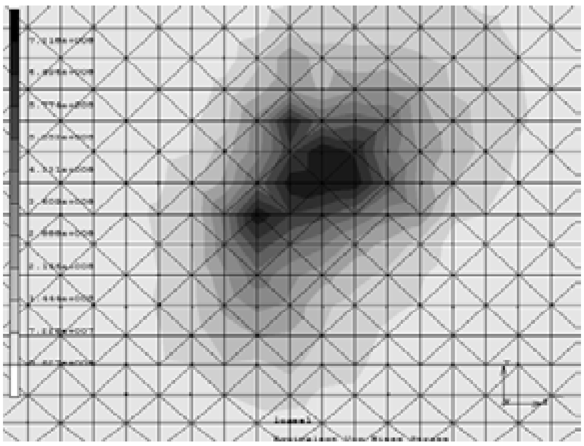


figure 2 Distribution of equivalent Von Mises stress for irregular grids

The resulted distribution is received for the central arrangement of a wheel with a new profile GOST 9036-88 concerning new rail R65.

For elimination of similar errors of calculations it is offered to create regular FE grids for near contact zones of interacting wheels and rails. These grids take into account real profiles of the surfaces. They are created with corresponding sections of a wheel and a rail. The example of such flat grid is shown on fig. 3.

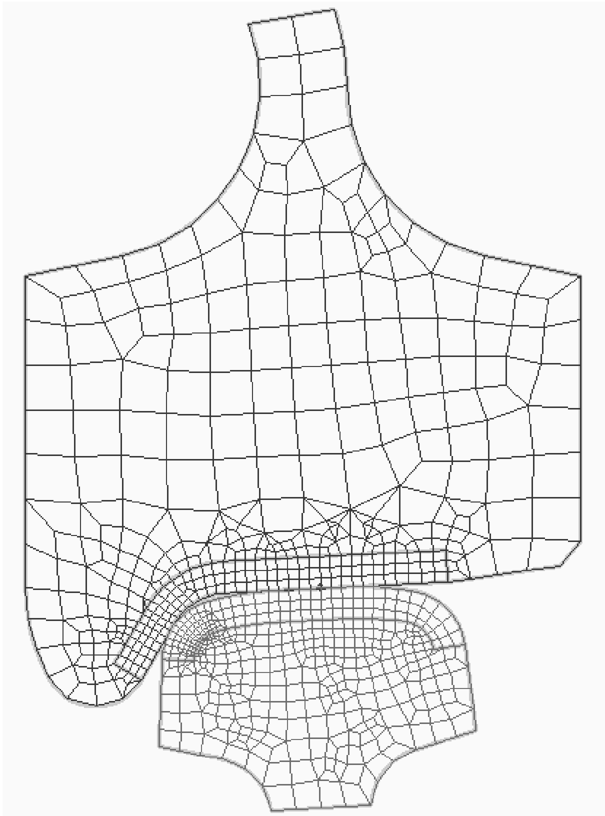


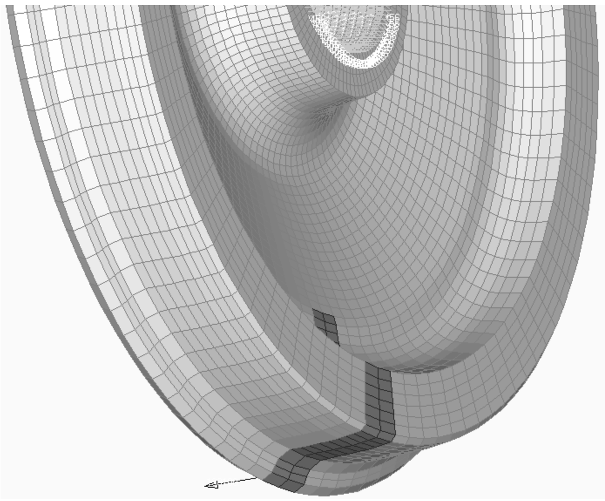
figure 3 Example of an initial flat grid in sections of a wheel and a rail

For the creation of special near contact areas sizes of which depend on the size of contact zones, sizes of separate elements in these zones and allowable number of degrees of freedom of a final FE model are allocated. Other parts of considered wheels and rails can have splitting irregularity. Then "sewing together" of FE grids of a wheel and a rail was done.

After that it is necessary to transform flat grids of sections in spatial, which is possible to be made by means of commands Extrude and Revolve. Thus it is also necessary to coordinate FE grids on the third coordinate (along the surface of a rail and on circumferential coordinate of a wheel).

The separate question is an assignment of boundary conditions for considered areas of a wheel and a rail. It is obvious that it is impossible to examine a full grid for a wheel and a rail. Such grid will have a very big number of degrees of freedom. The decision of a contact problem is nonlinear, therefore it demands significant time of the account with use of high-efficiency computers. Taking into account that it is necessary to carry out calculations for various positions of a wheel and a rail, as well as for different profiles of interacting surfaces, it is expedient to consider deformation of wheels and rails separately under action of all set of loadings. Thus FE grids can be rare enough. These grids should be of such a kind so that it was possible to allocate contact areas for which the exact discretization described above can be already carried out. On fig. 4 discretization of a wheel with the allocated zone for which the specified discretization (fig. 4a) was carried out, as well as deformation of a considered site under action of the enclosed contact forces (fig. 4b) is shown.

a



b

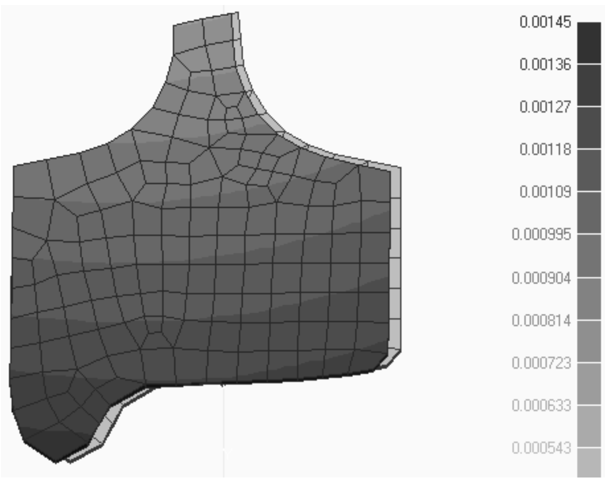
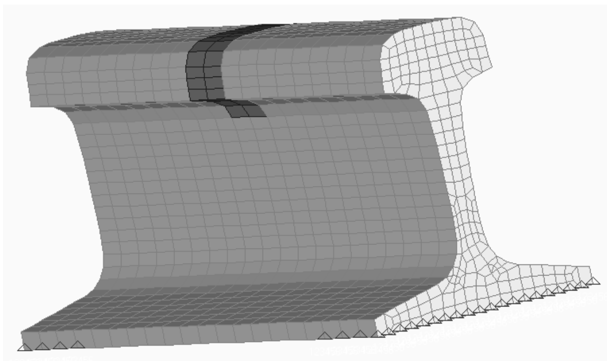


figure 4 *a) FE discretization of a considered wheel with the allocated contact zone; b) displacement of nodes of a grid for the allocated zone*

Above figures have been received for a problem in the following statement. The considered wheel is fixed in nodes on a contour of a hole in a center of a wheel. Node forces which can be determined, for example, by the use of modeling of dynamics of carriage by means of program ADAMS are enclosed on a contact surface. Deformation of a wheel under the influence of the thermal loadings caused by block braking can be also considered.

Deformation of a rail was considered in a similar way. Thus contact areas of a rail were allocated for which the specified generation of a grid had been carried out. On fig. 5 discretization of a considered part of a rail with the allocated contact area (fig. 5a), as well as the distribution of the displacement for the specified area (fig. 5b) is shown.

a



b

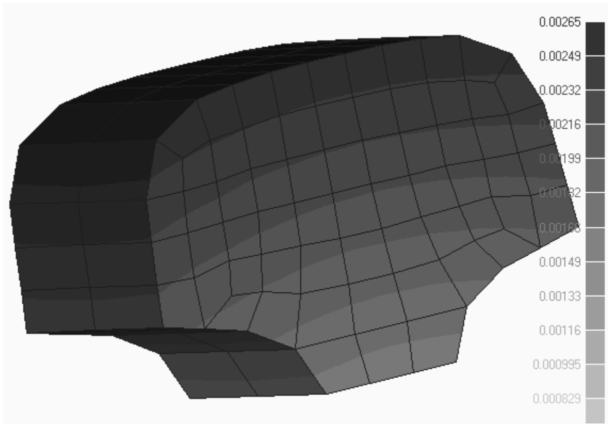


figure 5 *a) FE discretization of a considered rail with the allocated contact zone; b) displacement of nodes of a grid for the allocated zone*

DISCUSSION OF THE RESULTS RECEIVED WITH THE HELP OF FEM

As a result of the use of the technique described above three-dimensional FE model of contact interaction, which is submitted on fig. 6, has been developed.

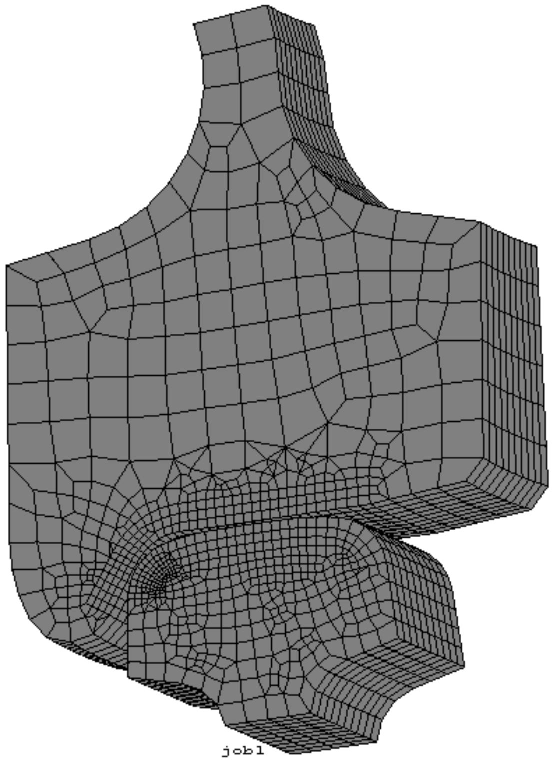


figure 6 Considered FE model of contact interaction of a wheel and a rail

On fig. 7 results of calculation of contact nodal normal forces (analogue of contact stresses) for a new carload wheel with a standard (for the countries of the former USSR) profile of a surface are shown in its interaction with new rail R65.

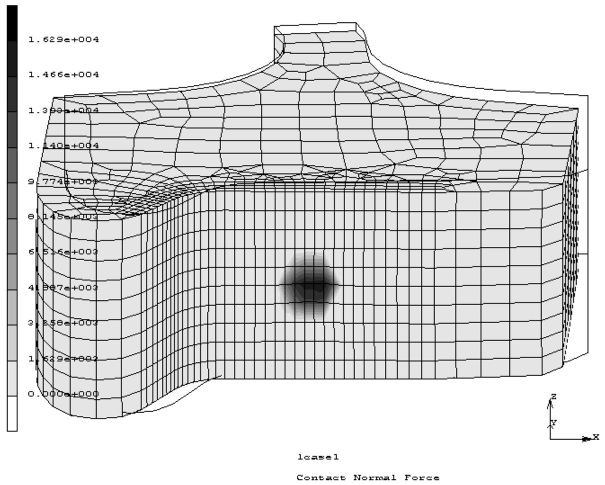


figure 7 Distribution of contact nodal normal forces in case of one-zoned contact

So that it was possible to see a contact zone, only the wheel is shown in the figure. Change of position of a wheel concerning a rail was considered and calculations were carried out for various relative positions of contacting bodies. Above mentioned figure is received in case previous to the contact of a wheel and a rail in a flange zone. Thus one-zone contact takes place. The form of contact patch comes nearer to elliptic, i.e. distribution of stresses close to Hertz distribution takes place. Nevertheless there are differences if comparing with Hertz distribution. This is caused by deformation of a wheel disk. On fig. 7 not deformed arrangement of a wheel is also shown. As we can see in the increased kind, the wheel rim becomes a little warped under influence of the normal force. Thus nodes in the left part move to the left and downwards, and nodes in the right part move to the left and upwards. It causes redistribution of contact forces in a contact zone. This distribution differs from the parabolic one in some way. The nodes located in the left part of a contact zone are loaded more than nodes in the right part.

In the following figure 8 distribution of contact nodal normal forces when two-zone contact takes place is shown.

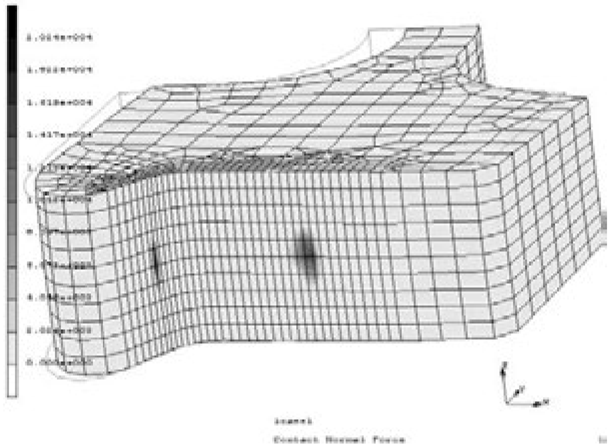


figure 8 Distribution of contact nodal normal forces in case of two-zone contact

Such relative arrangement of a wheel and rail takes place in case of displacement of a wheel to the left concerning its initial position. Thus the wheel flange starts to contact with a lateral surface of the rail head. At such relative arrangement of a wheel and a rail it two contact zones are formed. One zone is located on the center, the second one in a flange zone. Loading of a wheel in a flange zone results in occurrence of significant lateral force. On the other hand there is a redistribution of stresses between zones. The more the wheel to the left will be displaced, the bigger lateral force will effect a flange. Thus the size of flange zone increases, as well as contact stresses in it. Thus the size of the central zone of contact and the level of stresses in this zone decreases. At the further cross-section displacement of a wheel the case of one-zone contact in a flange zone is possible.

USE OF THE QUASI - HERTZ APPROACH FOR THE ANALYSIS OF CONTACT STRESSES

The finite element method in application to the solution of contact problems has the advantages and drawbacks. Opportunities of the FEM analysis of contact interaction concerns the number of such advantages at various relative positions of a wheel and a rail, at nonzero corners of attack of wheels, at presence of several zones of contact, at presence of plastic deformations in contact zones. However FEA in application to contact problems also has essential drawbacks. For increase of accuracy of the solution in contact and about contact area of interacting bodies there should be a rather large number of finite elements. Maintenance of the specified requirement results in substantial growth of number of degrees of freedom of considered model. In view of non-linearity of a problem it can lead to physical impossibility of its solution. Complexity of generation of a FE grid and assignment of boundary conditions is also a drawback.

In view of the fact that problems of creation of new designs of profiles of working surfaces of wheels and rails require to carry out plenty of calculations, use of the quasi - Hertz approach is expedient. It has been developed by authors [***1***], the algorithm of calculation and the computing program were done for it. It means that profiles of a surface are set pointwise without dependence from the fact whether there is a drawing of a profile or the given profile is scanned from real wheels and rails. Therefore, approximation of profiles for any initial pairs of the points which are the centers of contact zones, in which it is possible to define local radii of curvature, is carried out. As a result with use of formulas Hertz - Beliaev it is possible to define approachment of superficial layers under action of contact efforts. It is obvious, that if total contact efforts working in a contact zone are known, the sizes of zones and distribution of contact stresses can be determined.

The problem arises when two-zone contact takes place. In this case distribution of efforts between contact zones is not known. For their definition the compatibility condition of deformations sets and distribution of contact forces is defined by the iterative way. The design procedure has been described in work [***2***].

On fig. 9 and 10 comparison of distribution of contact zones in case of two-zone contact for various profiles is shown. The first figure (fig. 9) is used to show the case of contact of standard new wheels and rails. Thus, two formed contact zones are placed on significant distance from each other. They have a significant difference in local radii. Consequence of it is the significant size relative slip in points of surfaces of a wheel and a rail first of all in a flange zone. On the other hand the size of the maximal contact pressure in a flange zone of contact reaches 3600 MPa, that considerably exceeds a yield point (the problem is solved in elastic statement). Thus, plastic deformation and wear of a surface occurs in the specified zone. This phenomenon is well-known in practice of exploitation of a rolling stock on railways in the countries of the former USSR.

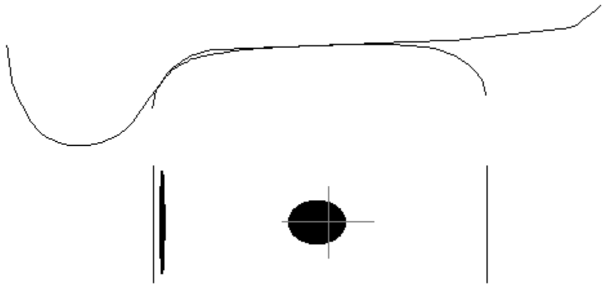


figure 9 Distribution of contact zones at contact new wheel and rail with standard profiles of surfaces

On fig. 10 similar distribution of contact zones for a new design of carload and locomotive wheels is submitted. The developed profile of a surface possesses advantage, that at interaction with a rail in a flange zone it is essential (in 2 times) that the level of contact pressure is reduced. The two formed zones of contact are located close from each other. Approachement of sizes of local radii for these zones promotes decrease in wear of wheel flanges.

figure 10 Distribution of contact zones at contact new standard rail and wheel with new profile of surface

The offered profiles have found the application in practice of exploitation of cars and locomotives in the countries of the former USSR. Intensity of wear of working surfaces, first of all, in a flange zone has decreased for them. Such profiles now are effectively used for turning wheels of locomotives in Ukraine, Russia and other countries. According to various depots intensity of wear of wheels has decreased from 20 to 50 per cent. Similar results have been received in using new profiles for railway tanks. But the greatest efficiency is received in using new profiles on an industrial railway transport. It is caused by the fact that in conditions of ore mining and processing enterprise wear has essentially abrasive character. Reduction of sliding in a flange zone reduces intensity of such a wear. As a result of it with use of the described development it was possible to lower essentially intensity of wear for wheels of cars and locomotives on a number of the largest ore mining and processing enterprises.

Now two varieties of profiles of working surfaces are used for cars and locomotives. They are shown in comparison with a standard profile on fig. 11. At the first type flange thickness is the same, as at a standard profile, i.e. 33 mm. The second type has the reduced flange thickness (30 mm). Last profile is recommended for regenerative repair in depot conditions and consequently has received the name repair. For restoration of a surface of a wheel on the specified profile it is required to remove practically twice less metal that allows to save a resource of wheels essentially.

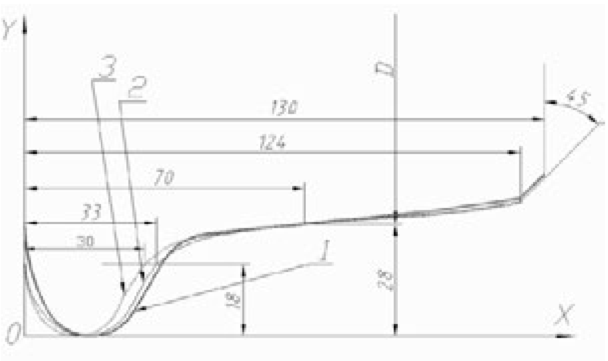


figure 11 Comparison of profiles of a working surface of carload wheels: 1 - a standard profile; 2 - a new profile with flange thickness of 33 mm; 3 - a new profile with flange thickness of 30 mm (repair)

Thus, as a result of the carried out researches distributions of contact zones, stresses for various profiles of working surfaces of wheels and rails have been determined. Research of intensity of wear process of wheel pairs was carried out. Recommendations on improvement of profiles, both wheels, and rails are given. In particular, new designs of the rail heads are developed, rolled and now are tested on railways of Ukraine. The first results have shown, that stability of work of such rails in direct sites of a way has increased. They are less subjected to overturning and accordingly to increase of gage.

CONCLUSIONS

As a result of carried out researches the following technique is offered. Preliminary for various conditions of exploitation of wheels and rails researches should be carried out in the interaction with use of the quasi - Hertz approach. The given researches are the basis for development of new designs of profile of a surface of wheels and rails which would have the raised wear resistance. Next the specified calculation with use FEM is carried out.

Directions of the further researches is stipulated to consider dynamic processes in a wheel - rail pair, as parts of track - carriage system. Thus, it is planned to use dynamic dependences for contact forces and relative arrangements of surfaces in a wheel - rail pair that it is possible to define by means of program ADAMS. First steps in this direction have been already made by authors. It is considered, that such approach is necessary for designing wheels and rails for a high-speed rolling stock.

References

1. ESSAOOLOV V P & SLADKOVSKY A V, **Contact interaction and wear examination of the wheel-rail couple**, *Proceeding of the International Symposium on the Tribology of Friction Materials*, Yaroslavl, USSR, vol 2, pp 288-293, 1991
2. YESSAULOV V, KOZLOVSKY A SLADKOVSKY A & ETC., **Studies into contact interactions of elastic bodies for improvement of wheels and rails**, *Contact Mechanics IV*, WIT Press, United Kingdom pp 463-472, 1999