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USE OF ANSYS AND NASTRAN PROGRAMS IN RAILWAY ELEMENTS CALCULATIONS

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Stresses in a Wheel Pair, Finite Element Method (FEM), Termical Loads

Introduction

Now for calculation of durability of parts and assemblies of a carriage rolling stock of railways the software basing on application of a finite element method is used successfully. The most universal among such packages are ANSYS, NASTRAN, PATRAN, MARC, ALGOR, COSMOS, LS-DYNA and a number of others. On the main applicability these packages may fulfil identical functions and may be used on possibilities of their acquisition. The latter is influenced with their free market price (rather high), presence of service centres, regional dealers etc. The analysis of operation results introduced on the latter 13 Congress on wheel pairs (Rome, 2001) has shown, that in the corporations producing production for needs of a railway transportation, ANSYS packages, COSMOS and NASTRAN are used more often. All these packages are of general purpose though each of them has the differences. COSMOS package has more applied character, orientation to immediate usage by designers and consequently it may be built as the separate unit in such CAD packages as SolidWork, SolidEdge, Mechanical Desktop, Pro/ENGINEER and others. Thus creators of the package approve, that within one month the designer using the CAD systems, can master the new unit. Though there is also COSMOS/M package which is independent.

ANSYS and NASTRAN packages have more research character. Their main difference consists that ANSYS has the graphic interface which completely allows to carry out creation and a model study through resources of the package. NASTRAN was initially oriented to the batch mode of information processing. And originally NASTRAN was solver for which the user should prepare the information on a considered sample piece by the defined rules, and then after the carried out evaluations to process it either manually, or by additional resources which were not included into the program. Thus, the process of the assaying of any sample piece consists of 3 stages: preparation of the information on a considered sample piece (pre-processing), its numerical assaying with usage of a finite element method, handling of calculation results, numerical or graphical (postprocessing).

Now there are some mining of the packages basing on primal NASTRAN which are developed by different corporations. Among them the most known is NASTRAN MSC.Software Corporation corporations. And such NASTRANs are two. The first uses the software product of same PATRAN corporation in quality of the pre- and the postprocessor, and the second uses pre- and postprocessor FEMAP of Enterprise Software Products corporation, Inc. Here again there are defined complexities for the user, connected with preferability of choice of the software product. It is necessary to mark, that the most convenient graphic interface which is completely oriented to possibilities of Windows 98, as well as Windows 2000, has FEMAP package and, accordingly, integrated NASTRAN package for Windows. The indicated package has also that advantage that allows to import geometry of a considered sample piece from practically anyone CAD systems or to carry out import of a sample piece entirely if it was created in FEA system.

There exists complete analogy to export. These qualities allow many users to prefer the mentioned above software product. Unfortunately, this package has the disadvantages connected with FEMAP not complete realising possibilities of base NASTRAN package. For example, there is no possibility of the definition for difficult (depending from temperature) rheological properties of a material.

Usage of PATRAN package in quality of pre- and postprocessor allows to use possibilities of base NASTRAN package in full. Above mentioned data promoted that in researches circumscribed below the stressed - deformed state of railway wheels, axes and wheel pairs as a whole, some FEA packages were used.

Research of the process of creation of wheel pairs

Among different sorts of loads to which railway wheels while in service are subjected, there are some sorts of stresses which have residual character. It, first of all, the true residual stresses, stipulated the process of heat treatment of sprockets during production. Very frequently they have rather a high level, and the task of manufacturers is to create such allocation of residual stresses which will have a favourable effect on reliability and fatigue resistance of wheels in the further.

Stresses which result from machining job, also have residual character, but their level is much lower and they are localised mainly in surface stratums of metal.

Stresses in wheels which arise owing to creation of wheel pairs, have rather significant level. Their field usually is expanding, that unfavourably influences common allocation of stresses. And during creation of wheel pairs the level of stresses in a centre of a wheel may be so high, that there are plastic deformations.

For calculation of such fields of stresses different FEA packages may be used, but usually thus it is necessary to use nonlinear algorithm and special contact elements. The authors developed algorithm [1, 2] which has allowed to use possibilities of NASTRAN package in linear setting.

In fig. 1 allocation of radial stresses in a sprocket having a construction on Polish norm PN-92/K-91019 920/200s, at it pressing on an axis represented, to appropriate construction PN-92/K-91048 B 200s is presented. Three positions of a sprocket concerning an axis in pressing process are reduced. As calculations display, the level of stresses in original and intermediate positions is much higher, than for formed wheel pair. And, for a maximum permissible tightness of the sprocket equal of 0,25 mm, origin of the plastic zones localised in a zone, adjoining to an internal surface of a hole in a nave of a sprocket is possible. Accordingly, similar plastic zones may take place on according parts of an axis.

The process of creation of wheel pairs is enough a crucial technological operation during which change of pressing effort is fixed during creation of wheel pair. The obtained profile is recorded and forms the basis for the rejection of formed wheel pairs. Such profile should match theoretical one which is obtained by design way. In fig. 2 the indicated profile for above mentioned wheel pair is represented. It is necessary to mark, that the construction of a considered wheel provides execution of a special hole and groove for pressing-out wheel pair. On the introduced profile in an average part there is the local wave, shown as an arrow. This wave will match the moment of the beginning of interaction of a wheel and an axis in a zone of the indicated groove.

Thus, usage of FEM allows to analyse the stressed - deformed state of wheel pairs during their creation to estimate the contribution of these stresses to a common picture of stresses, and also to specify technology requirements to the process of creation of wheel pairs.

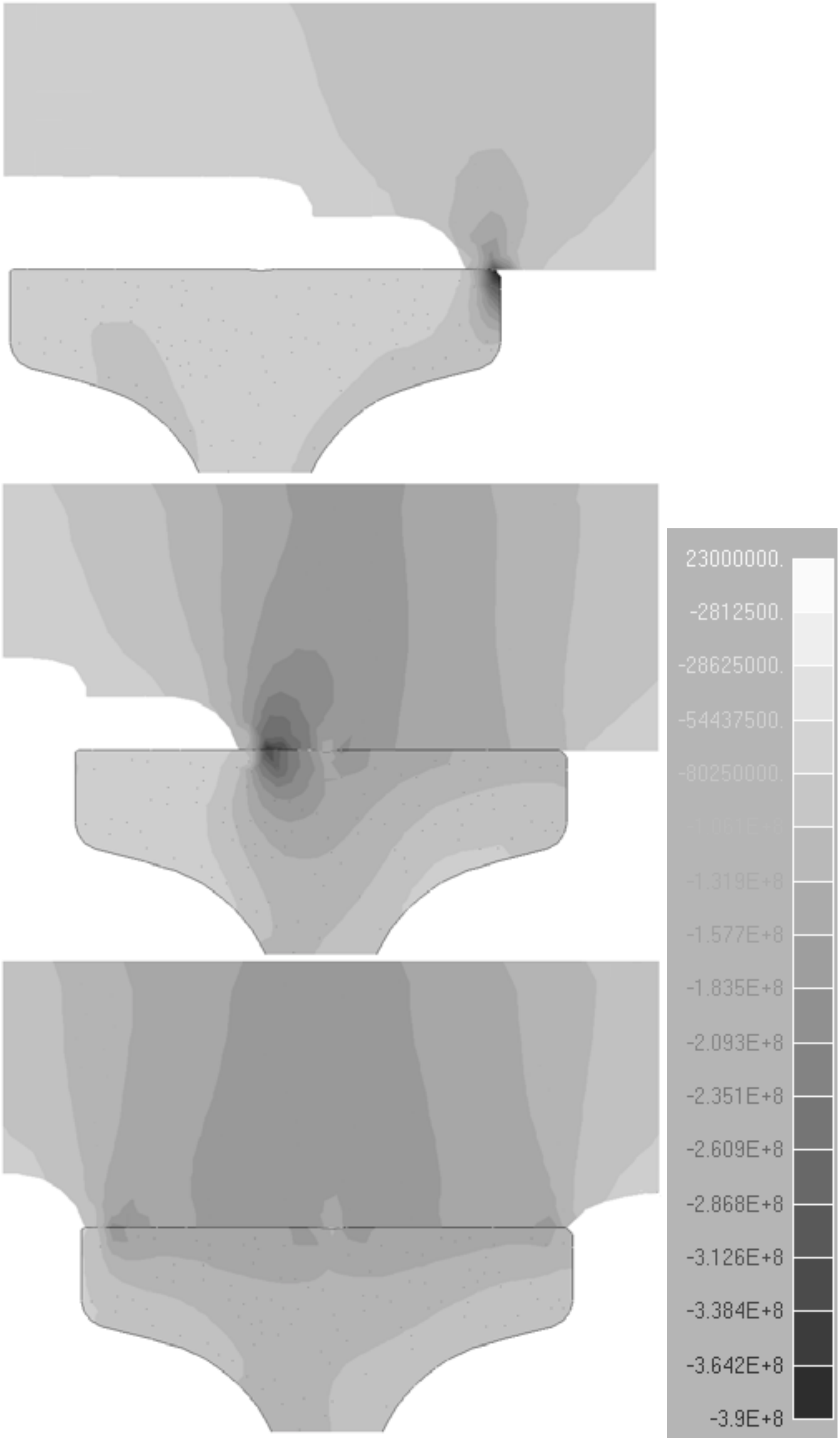

Fig 1. Allocation of radial stresses in a wheel and axle during creation of wheel pair

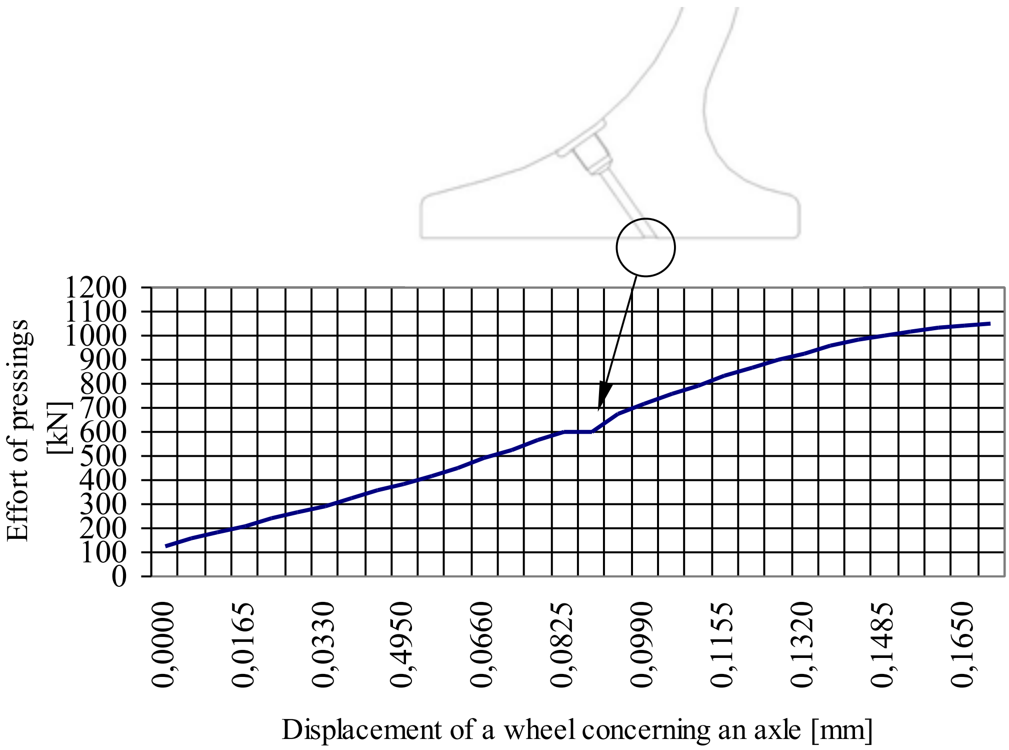

Fig. 2. Dependence of effort of pressing on a relative position of a wheel and an axle during creation of wheel pair

The analysis of thermal durability of railway wheels

One of the most dangerous in sense of durability of sorts of load is the thermal load, stipulated contact interaction of a working surface of wheels with wheel chocks. In many respects it stipulates that for a high-speed carriage rolling stock started being applied disk braking. However, till now to the majority of sorts of a carriage rolling stock block braking is applied. Therefore, in conditions of different tenders which are declared on mining of new constructions of sprockets, a condition thermal calculation of wheels is indispensable at different modes of block braking.

As an example we shall consider one of calculations of new constructions of wheels which was executed by authors. Thermal influence on a wheel was modelled by the task in elements which form a surface of driving of a wheel, the thermal stream working on their surface sides. The general width of a surface to which thermal loading is enclosed is 80 mm. The density of a thermal stream is set in W/m^2. For its definition all area of a surface of the wheel subjected to action of a thermal stream was considered. The given area for a new wheel makes 0,23 m^2.

According to conditions of the tender the following condition of thermal loading is considered. It models long braking of various intensity. In view of that it is offered to analyse stepping loading power 20, 30, 40 and 50 kW, the density of a thermal stream is set as follows

$$q = k(\tau)Q \quad , \qquad (1)$$

where Q - density of a thermal stream at the initial stage of thermal loading 86900 W/m^2 (corresponds to power in 20 kW), $k(\tau)$ - function from time of the braking, taking into account its stepping character. The given dependence is submitted in fig. 3.

Apparently from the profile (fig. 3) we consider loading by growing in steps thermal streams duration of 45 minutes (on an axis of abscissas time in seconds is postponed) with the subsequent time pieces of cooling which were accepted to be equal 1 hour. After last stage of thermal loading cooling is 4 hours. We accept, that the reference temperature of a wheel is equal 20°C, that corresponds to an ambient temperature.

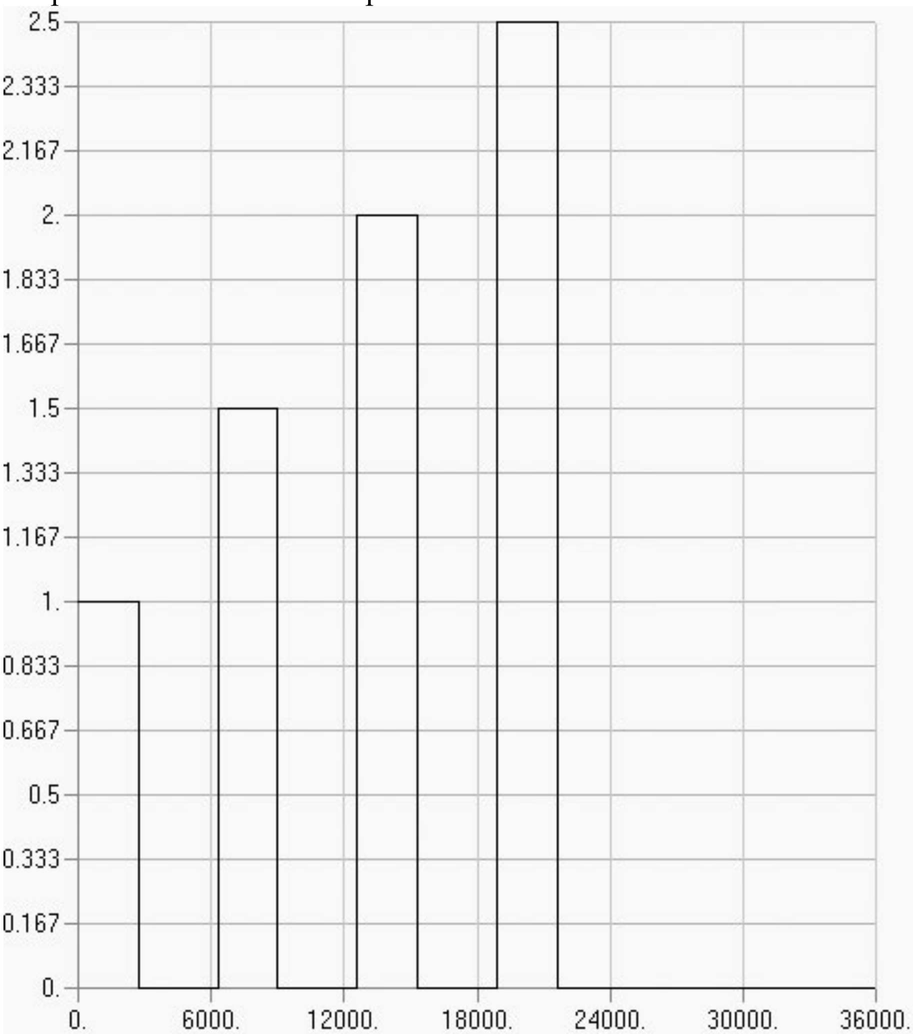

Fig. 3. Dependence of factor *k* from time of braking τ

It was necessary to set also the parameters influencing intensity of cooling of a body. We consider, that heat emission is carried out from all surfaces of a wheel, including its working surface as the most part of time the working surface is outside of a zone of contact with brake blocks. Heat emission is possible by means of thermal radiation and convective heat transfer. In a basis of radiating heat exchange in the program Stephen - Boltzmann law is fixed, therefore Stephen - Boltzmann constant itself was set equal 5.668×10^{-8} W/m$^2\cdot$°C^4, and also factor of thermal radiation of a steel surface 0,8.

It was more difficult to set conditions of convective heat transfer as the factor of the heat emission depends on speed of the air stream blowing in a wheel. Reynold's number for speed of movement of crew 80 km/h was determined. On the basis of the received data it is determined, that at the given speed the air stream is turbulent. Then for heat exchange between a surface of a wheel and flowing round air the formula [3] may be used

$$Nu_{lx} = 0.0296\,\mathrm{Re}_{lx}^{0.8}\,\mathrm{Pr}_l^{0.43}\left(\mathrm{Pr}_l/\mathrm{Pr}_a\right)^{0.25} \quad , \qquad (2)$$

where Nu_{lx} - Nusselt's number for air at t = 20°C.

$$Nu_{lx} = \frac{\alpha x}{\lambda} \quad , \qquad (3)$$

α - a heat emission factor of surfaces to a turbulent stream of air;

λ - a heat conductivity factor of air at t = 20°. $\lambda = 2.59 \cdot 10^2 \dfrac{W}{m \cdot {}^{O}C}$;

x - a coordinate of a characteristic (average) point of a wheel, we accept $x = r = 0.458m$.

In the formula (2) we also use $\Pr_l$ - Prandtl's number for air at t = 20°C. $\Pr_l = 0.703$. Also $\Pr_a$ - Prandtl's number for air near a surface of a wheel. We accept for average temperature t = 300°C $\Pr_a = 0.674$.

Re_{lx} - Reynold's number for a stream of air moving with speed $w(\tau)$

$$\mathrm{Re}_{lx} = \frac{w(\tau)x}{\mu} \quad , \tag{4}$$

here μ - viscosity of air at t = 20°C. $\mu = 15.06 \cdot 10^{-6} \dfrac{m^2}{s}$.

Then in the program it is necessary to set heat emission factor a convection which with use of above mentioned formulas may be received as

$$\alpha = 0.0296 \cdot \frac{\lambda}{x} \cdot \left(\frac{w(\tau)x}{\mu} \right)^{0.8} \Pr_l^{0.43} \left(\Pr_l \Big/ \Pr_a \right)^{0.25} . \tag{5}$$

The heat emission factor, determined under the formula (5) depends on speed of a thermal stream. At $w = 80$ km/h receives $\alpha = 67\,\mathrm{W/m^2}$.

The received thermal characteristics were used for a solution of a problem of heat conductivity for a wheel. In table 1 the maximal temperatures in a wheel are submitted, which are reached on a surface of driving (a column 2) on time of braking (a column 1). In fig. 4 distribution of temperatures after last (maximal) stage of thermal loading is shown. The maximal temperature of a wheel is equal 542°C. Other distributions of temperatures are similar to the given. Received with use of package NASTRAN temperature fields were further used in package ANSYS for the analysis of the thermal stresses caused by received distributions of temperatures.

For the analysis of the intense condition of wheels at action of thermal loading the package of applied programs ANSYS release 5.5.1 was used. As at thermal influence on a wheel, the connected with long or similar times repeating braking, the high temperatures reaching 600°C properties of wheel steel cannot be counted taking place constantly. Besides the level of the intense condition at intensive thermal loading results in formation of zones of plastic deformation. For the account of the specified factors in calculation the rheological properties of a material submitted in fig. 5 which correspond to real wheel steel manufactured by the Nizhnedneprovsky Tube-Rolling Plant were accepted.

On profiles fig. 5 diagrams a stress of tension σ - deformation ε are shown for various temperatures (T1 corresponds 20°C; T2 - 100°; T3 - 200°; T4 - 300°; T5 - 400°; T6 - 500°; T7 - 600°; T8 - 700°). All data are given in system of SI.

The received distribution of temperatures has served as the entry condition for a solution of a nonlinear problem of termo - elastic - plasticity for a considered wheel. In table 1 for each stage of thermal loading maximal radial u_r (column 3) and axial u_z (column 4) displacement; maximal and minimal radial σ_{rr} (columns 5, 6) and hoopential $\sigma_{\theta\theta}$ (columns 7, 8) stresses; VonMises stresses σ_{ms} (column 9); total deformations ε_{mst} (column 10) and plastic deformations ε_{msp} (column 11) are given.

The analysis of intense - deformed conditions shows, that at the first stage of loading (20 kW) a level of stresses is enough low and zones of plastic deformation, and, accordingly, residual stresses do not occur. At the second stage of loading (30 kW) there are zones of plastic deformation, but the level of residual (plastic) deformations in them is insignificant.

The table 1

Time	Temperature	Displacements		Stresses					Deformations	
τ	t	u_r	u_z	$\sigma_{rr\,max}$	$\sigma_{rr\,min}$	$\sigma_{\theta\theta\,max}$	$\sigma_{\theta\theta\,min}$	σ_{ms}	ε_{mst}	ε_{msp}
[s]	[°C]	[mm]	[mm]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]		
2700	252	0.983	1.68	404	-181	242	-223	314	0.00204	-
6300	24.7	0.0234	0.0299	9.00	-3.67	4.38	-3.29	7.12	0.0000463	-
9000	359	1.43	2.44	579	-266	352	-328	439	0.00311	0.000280
12600	27.2	0.0363	0.0493	10.8	-7.85	9.55	-5.09	9.26	0.000234	0.000280
15300	454	1.82	3.14	670	-343	439	-421	491	0.00435	0.00119
18900	30.5	0.0554	0.0854	21.1	-54.8	22.6	-11.3	77.4	0.000723	0.00119
21600	542	2.18	3.78	711	-411	516	-508	507	0.00594	0.00265
36000	20.0	0.0366	0.0703	42.9	-179	35.3	-48.4	193	0.00143	0.00265

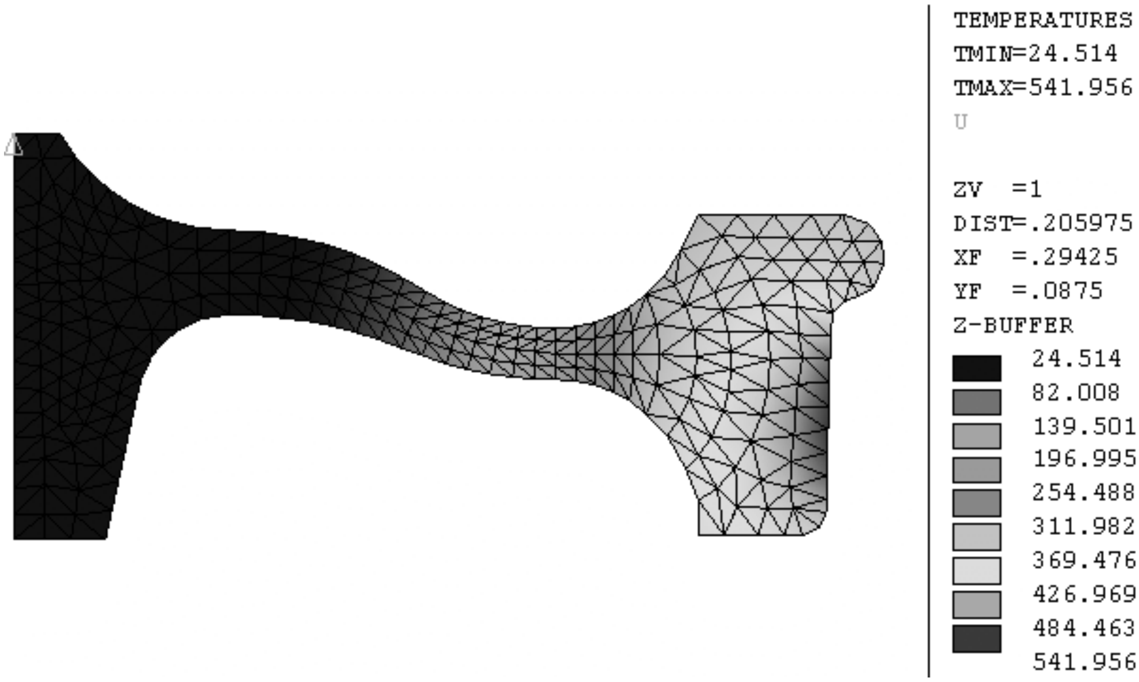

Fig. 4. A field of temperatures in a wheel by the end of last stage of thermal loading (50 kW)

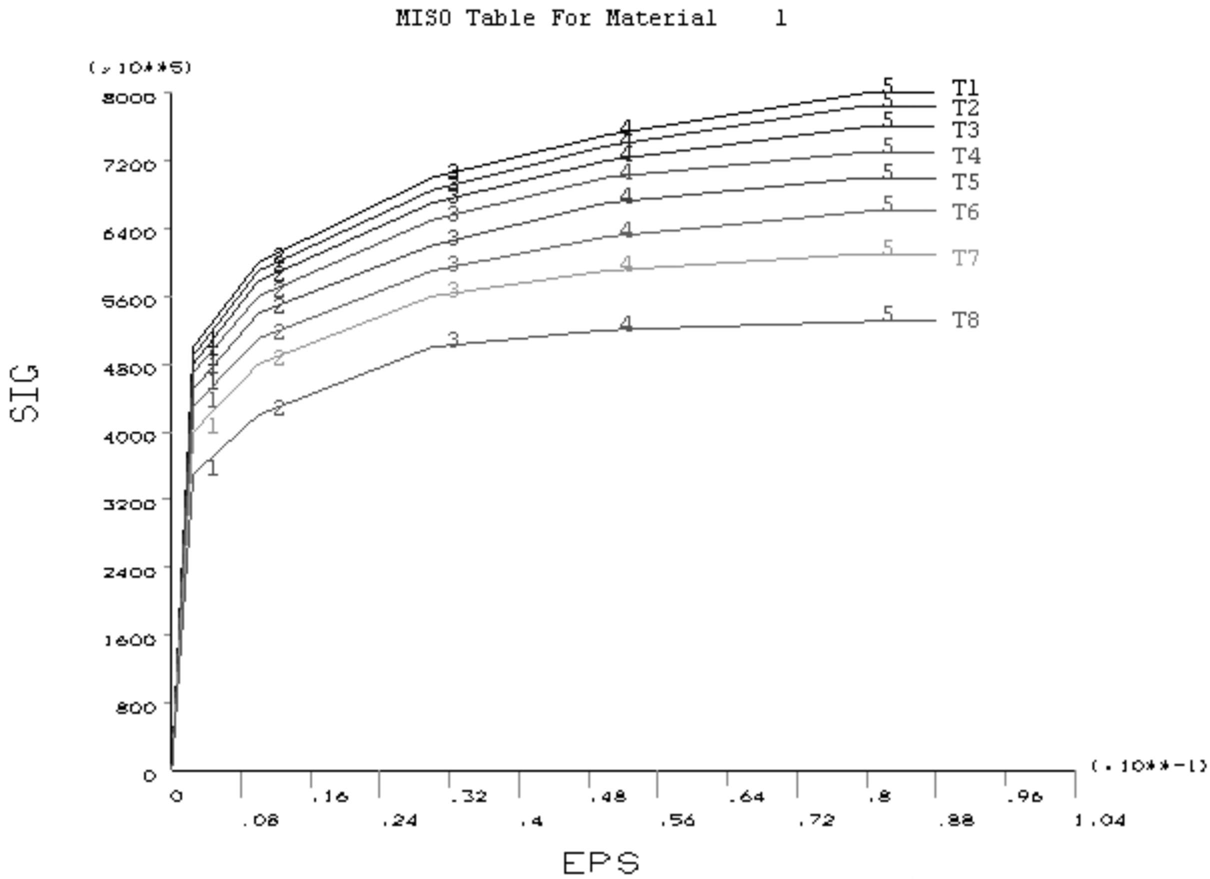

Fig. 5. The rheological characteristics of wheel steel accepted in FE calculation

At the following stages of loading plastic deformations grow almost in 10 times and there are enough expressed zones of plastic deformation. We shall result distributions of moving, stresses and deformations for the moment of time A, appropriate to the maximal thermal loading (the end of a stage of loading of 50 kW) and for the moment of time B practically complete (after 4 hours) cooling.

In fig. 6 the picture of deformation of a FE grid is submitted in the increased kind at the moment of time A (21600 s). Thermal expansion of a rim of a wheel results as though in straightening its disk. Thus axial displacements u_z = 3.78 mm exceed radial u_r = 2.18 мм (the top figure - a complete rim). Similar results turn out in a case of extreme reconditioned wheels - the bottom figure.

In fig. 7 fields of radial stresses σ_{rr} are given at the moment of time A (complete thermal loading - the top figure) and the moment B (complete unloading - the bottom figure). Apparently from the top figure in section of a wheel at complete thermal loading there is a zone of the maximal stresses at a place of transition from a disk to a wheel center, and on lateral aspect of a wheel there is a maximum of tensile stresses equal σ_{rr} = 711 MPa, and on internal - a minimum of cramping stresses σ_{rr} = -411 MPa. These extremums are marked in figure. However, it is necessary to notice also the second extreme zone - a zone of transition from a disk to a rim. Here maximum and minimum of stresses are on opposite sites, and their intensity is lower. Therefore it is not surprising, that in the bottom figure at complete unloading of a wheel there is a field of residual stresses σ_{rr} , at which the minimal cramping stresses are in zones of the maximal stresses in the previous figure. These stresses define residual deformation of a wheel. In the figures appropriate to time B a contour of section has such deformation which is considerably increased (the big scale).

In fig. 8 complete given deformation in section of a wheel by VonMises criterion is shown. These deformations arise to the moment of time A, and then remain constant up to the moment of time B as unloading is carried out linearly. In the specified figure zones of significant plastic deformations are obviously visible.

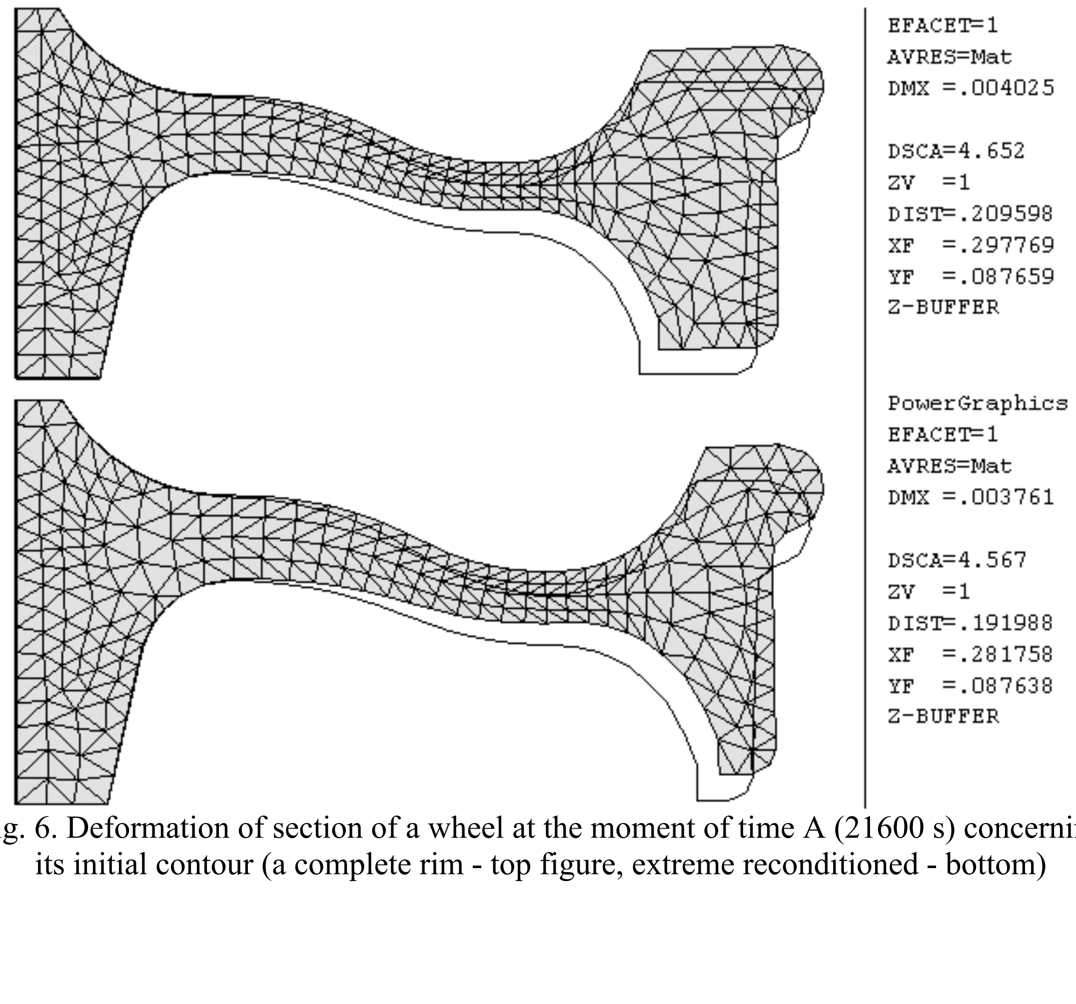

Fig. 6. Deformation of section of a wheel at the moment of time A (21600 s) concerning its initial contour (a complete rim - top figure, extreme reconditioned - bottom)

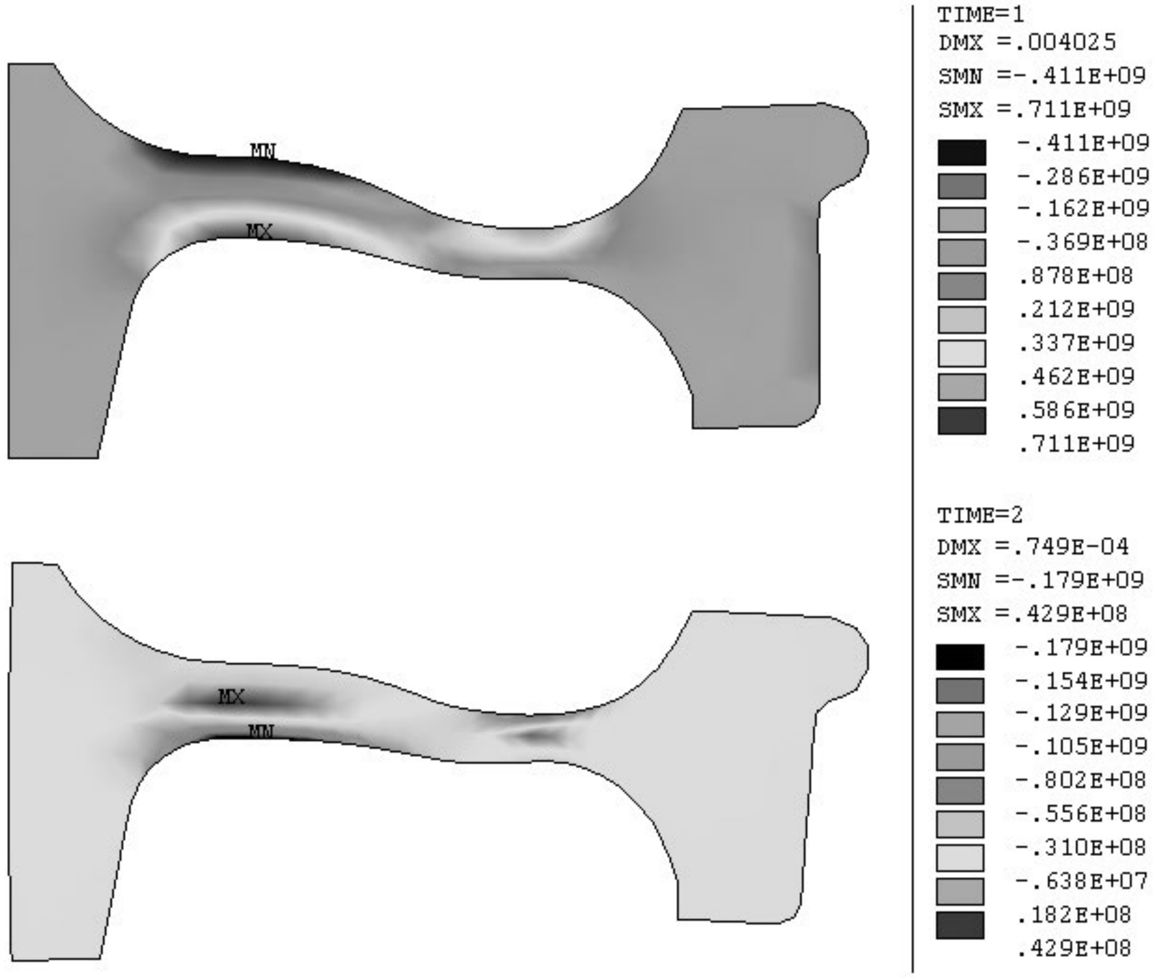

Fig. 7. Distribution of radial stresses σ_{rr} at the moment of time A (21600 s) - the top figure and at the moment of time B (36000 s) – the bottom figure

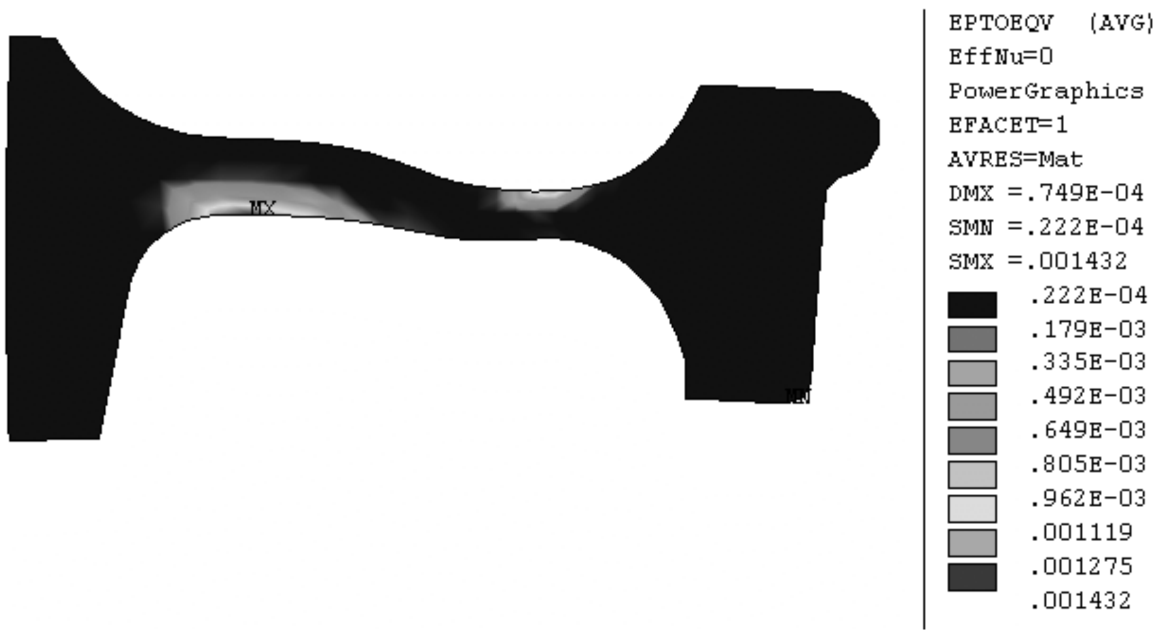

Fig. 8. Distribution of the given complete deformations by VonMises criterion σ_{mst} at the moment of time B

Conclusions

FEM was applied for the analysis of contact interaction in the wheel - axle pair, both in the formed wheel pair, and in pressing process. Distributions of stresses, including contact, and also deformations and displacements which are caused by a press interference are received.

Influence of conditions of braking on the stressed - deformed condition of carload wheels is also studied. Possible residual (plastic) deformations which may take place under the most difficult thermal conditions of loading are determined. The rheological properties of wheel steel are taken into account. Thus the analysis of temperature fields was carried out with use of package NASTRAN, and appropriate the stressed - deformed condition with use of package ANSYS.

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Sitarz M., Sładkowski A., Janeczek T., Kuminek T. Use of ANSYS and NASTRAN programs in railway elements calculations
FEM was applied for the analysis of contact interaction in the wheel - axle pair, both in the formed wheel pair, and in pressing process. Distributions of stresses, including contact, and also deformations and displacements which are caused by a press interference are received. Influence of conditions of braking on the stressed - deformed condition of carload wheels is also studied. Possible residual (plastic) deformations which may take place under the most difficult thermal conditions of loading are determined.

Ситаж М., Сладковский А., Янечек Т., Куминек Т. Использование программ ANSYS и NASTRAN для расчетов деталей железнодорожного транспорта
МКЭ был применен для анализа контактного взаимодействия в паре колесо – ось, как в сформированной колесной паре, так и в процессе запрессовки. Получены распределения напряжений, в том числе и контактных, а также деформаций и перемещений, которые обусловлены прессовым натягом. Исследовано также влияние условий торможения на напряженно-деформированное состояние вагонных колес. Определены возможные остаточные (пластические) деформации, которые могут иметь место при наиболее сложных термических условиях нагрузки.