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CASE STUDY ON THE BREAKING OF A RAIL AXLE

SLUČAJ LOMA VAGONSKE OSOVINE

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Abstract

Mechanized construction, maintenance and repair operation of the railway require a wide range of equipment, heavy railway machines for achieving quality, productivity and acceptable costs.

The necessity of performing maintenance operation of the railway infrastructure, such as the cutting of vegetation, the loading and unloading of materials and heavy pieces (rail, sleepers, assembly parts, crushed stone etc.), replacing of rails and sleepers, cleaning of ditches, the tamping of replaced sleepers etc., have solicited from the railway industry machine engineering a multifunctional machine. Another important function that this multifunctional machine had to fulfil was the ability to travel self-propelled both on rail and road, so that the machine can reach the operation site or the parking site without affecting railway traffic.

The fracture of a railway axle on a multifunctional machine is one of the major dangers for traffic safety, with possible major property damage and human casualties in the railway transport of goods and people, as well as in the maintenance and repair of the railway infrastructure. The study and detailed analysis of the causes and factors that led to fracture, through various methods (analytical, laboratory or using FEM), provide important information and conclusions that lead to the prevention of similar cases, and also to improving the solutions for design, manufacturing or technological, testing, control, diagnosis and evaluation for operating in complete safety.

Izvod

Mehanizovana izrada, održavanje i operacije popravke šina zahteva široki raspon opreme, teških železničkih mašina radi postizanja kvaliteta, produktivnosti i prihvatljivih troškova.

Potreba za izvođenjem železničke infrastrukture, kao što je sečenje vegetacije, utovar i istovar materijala i teških komada (šine, pragovi, sastavni delovi, tucani kamen, i sl.), zamena šina i pragova, čišćenje rovova, nabijanje zamenjenih pragova, itd., imalo je za posledicu razvoja industrije i železničkog inženjerstva uvođenje multifunkcionalne mašine. Još jedna funkcija koju je multifunkcionalna mašina morala da obezbedi jeste mogućnost samohodnog kretanja na šinama i na drumovima, na takav način da mašina može da se izmesti na mesto operacije ili na mesto parkiranja, bez ometanja železničkog saobraćaja.

Lom železničke šine na multifunkcinalnoj mašini jeste jedan od glavnih opasnosti za bezbednost u saobraćaju, sa mogućim prouzrokovanjem velikih šteta i ljudskih nesreća pri železničkom transportu dobara i ljudi, kao i u održavanju i popravci železničke infrastrukture. Studija i detaljna analiza uzroka i faktora koji dovode do loma, primenom raznih metoda (analitičkih, laboratorijskih ili primenom MKE), pružaju važne informacije i daju zaključke kojima se omogućava sprečavanje sličnih slučajeva, i takođe dobijaju poboljšana rešenja u projektovanju, proizvodnji ili u tehnologiji, ispitivanju, kontroli, dijagnozi i proceni funkcionalnosti u potpunoj bezbednosti.

INTRODUCTION

Multifunctional railway machines, such as the T 3500 machine (Fig. 1), are built using at the same time the principles (rules) for designing construction machines but also those for designing railway machines. This type of machine is like an excavator that can run both on rail and road, having developed standards for rail and road traffic.

The machine is equipped with various operation accessories which enable a wide range of technological processes for the maintenance or construction of the railway. For traveling by rail, the multifunctional machine is equipped with special rail axle that allows it to move on the railway as any rail vehicle (Fig. 2).

In the case of the T 3500 machine, the rear railway axle is fastened (fixed) with respect to the chassis, while the front railway axle is able to oscillate (Fig. 2).

Both railway axles are also motor axles, for direct transmission of motion/torque needed to move the machine, with no contact between the rubber road wheel and the steel railway wheel (as in the case of other types of multifunctional machines). To ensure an easy maintenance and repair of the railway motor axles, they were built from two parts, half-axles (Fig.3).

Figure 1. Multifunctional machine – rail travel position.
Slika 1. Multifunkcionalna mašina – položaj kretanja na šinama

Figure 2. Multifunctional machine – oscillating rail axle.
Slika 2. Multifunkcionalna mašina – oscilujuća vagonska osovina

Figure 3. Multifunctional machine – railway half-axle.
Slika 3. Multifunkcionalna mašina – vagonska poluosovina

The checking, testing, diagnosis and assessment of the technical condition of rail machines, their maintenance, overhaul and repair, the failure analysis, the conclusions and improvement measures based on a maintenance system for safe operation, therefore, have been proposed in this paper, taking into account previous papers /1-4/.

THE BREAKING OF THE RAIL AXLE

During the travelling for construction works in railway mode of a multifunctional machine, a breakage of the left rail axle had occurred in the direction of movement (Fig. 4).

Figure 4. Overall position after the breaking of front left rail axle.
Slika 4. Položaj nakon loma prednje leve vagonske osovine

The machine, with a weight of 173000 N, was moving with a speed of 9 km/h, with the working articulated arm in front of it, having installed a working accessory (milling) for cutting vegetation, with a weight of 4000 N.

After the breaking of the rail axle the machine falls off the railway and rests on rubber automobile wheels and broken end of the rail axle in limited equilibrium position (Fig. 5). Through specific technical measures (repositioning and balancing of loads, of masses which are not in equilibrium) the turning over and damaging of the machine is avoided. The machine is placed back on its rubber wheels for traveling by road.

Figure 5. Position after the left rail axle failure – front view.
Slika 5. Položaj nakon loma leve vagonske osovine – s preda

The multifunctional machine has a lifespan between 8 and 12 years and the machine manufacturer does not indicate a specific lifespan, leaving the user to determine its lifespan in compliance with his laws and regulations. The manufacturer assumes liability for the technical condition of the machine just for the warranty, which starts from 1–2 years, with an additional 2 years (max. 4 years), under certain conditions.

The actual duration of use of the machine when the rail axle fractured was 10 years. In this period, the machine performed a total of 5275 hours of operation (running hours), covering 7423 km and a total of 5.6×10^6 rotations of the axle.

No replacements of the motor rail axle were made, the machine having the original ones when the fracture occurred.

THE ANALYSIS OF RAIL AXLE FRACTURE

The rail axle of the multifunctional machine (Fig. 6) is built with a central part where the conical group (conical gears), brakes, hydraulic motor are mounted and two lateral parts, where the axle, bearings, planet gears and other assembly elements are mounted.

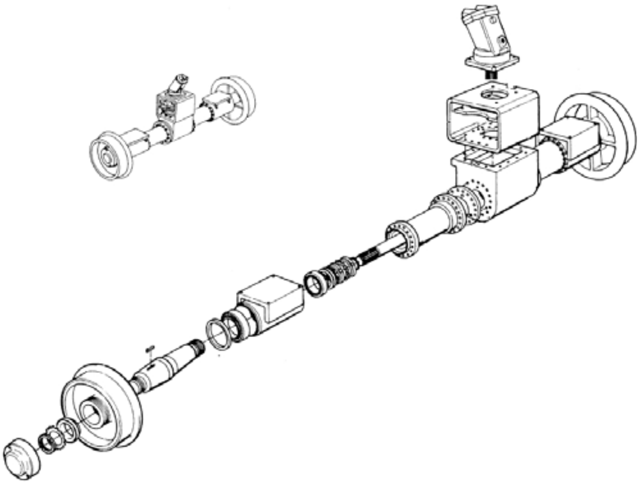

Figure 6. The motor rail axle of the multifunctional machine.
Slika 6. Pogonska vagonska osovina multifunkcionalne mašine

Many types of multifunctional machines have the railway transportation system in the form of free railway axles and the movement of railway wheels is done by friction with the rubber wheels, which are pressing on the railway wheels.

The transformation of free railway axles into motor axles is made by the manufacturer of the machine by adopting a system similar to axles of auto-vehicles.

The rail axle (Figs. 7, 8, 9) is designed and built to fulfil its functional purpose, with size, shape and surface qualities specific to the parts of conjugate machines with which it is mounted (bearings, simmering, railway wheel etc.).

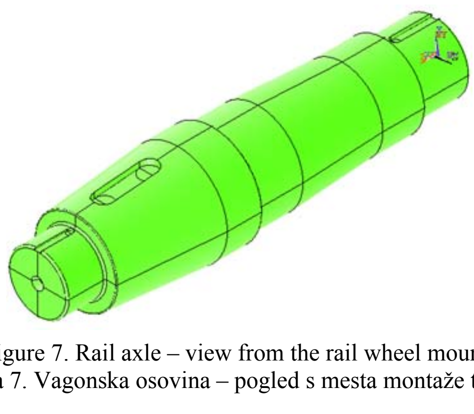

Figure 7. Rail axle – view from the rail wheel mount.
Slika 7. Vagonska osovina – pogled s mesta montaže točka

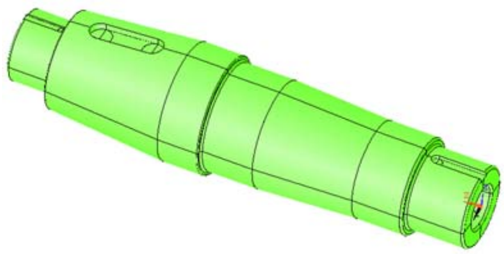

Figure 8. Rail axle – view from the planet gear mount.
Slika 8. Vagonska osovina – sa položaja planetarnog zupčanika

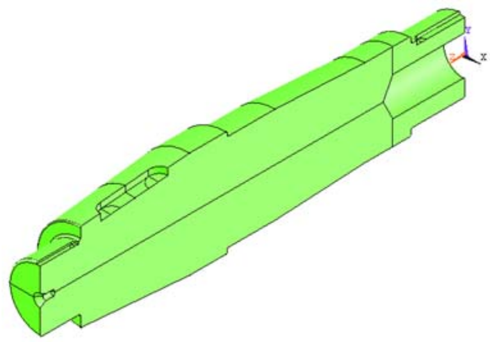

Figure 9. Rail axle – axial section.
Slika 9. Vagonska osovina – aksijalni presek

The risk of having stress concentrators that can become dangerous increases, corresponding to the connection between the surfaces of the axle and conjugate parts or to other causes (defective materials, improper treatment, inappropriate technology etc.).

In the design phase these influential factors are generally taken into consideration, but only experience and practice can confirm the correctness of the design and the manufacturing technology.

The breaking of the rear left rail motor axle occurred in the zone between the rail wheel and the nearby bearing, (Figs. 10-12).

Figure 10. Fracture of the rail axle, near to the rail wheel.
Slika 10. Lom vagonske osovine, blizu vagonskog točka

A tension concentrator is noticed in the fracture zone of the rail motor axle, identified as a variation zone for sizes (size steps) with a very small connection radius (2 mm), between the cylindrical step with smaller diameter (for the bearing) and the cylindrical step with larger diameter (the passage area from the bearing to the rail wheel).

This is non-compliance from a technological point of view, because the tool tip produced a channel (ditch).

Figure 11. Section of fracture towards the rail wheel.
Slika 11. Presek loma prema vagonskom točku

Figure 12. Failure section towards the bearing.
Slika 12. Presek loma prema ležištu

In the breaking section (Figs. 11 and 12), several crack initiation could be identified, placed at angles of approximately 90 degrees, with an evolutionary behaviour.

The breaking section could not be observed from outside without completely removing the rail axle, since it occurred in the inner ring of the outer bearing. The technical state of the axle cannot be verified without complete disassembly.

The machine in rail travel mode is not fitted with damping and suspension systems (springs, elastic elements etc.) to prevent/damp the shocks when moving over rail joints, crossings, etc., these requests being also taken (endured) by the rail axle.

The material of the rail axle is 34 MoCrNi15 (SR 791), also identified through laboratory analysis.

The material characteristics are well suited for axles and shafts that undergo high stress solicitations having: 0.30-0.38% C; 0.17-0.37% Si; 0.40-0.70% Mn; $\leq 0.025\%$ P; $\leq 0.025\%$ S; 1.4-1.7% Cr; 1.4-1.7% Ni; $\leq 0.30\%$ Cu; $\leq 0.05\%$ V; 0.15-0.30% Mo; $R_m(\sigma_r)$ = 800-1300 N/mm^2; $A_5 \geq 18\%$; $R_c(\sigma_c) \geq 600$ N/mm^2; $Z \geq 55\%$; σ_{-1} = 518 N/mm^2.

The rules regarding the verification of the rail axle of the machine that should have been elaborated by the machine's manufacturer are not clear enough, not having technical regulations (rules), procedures (methodology), technical documentation relating to non-destructive inspection and testing procedures.

FEM ANALYSIS OF SOME STRESS CASES

A railway vehicle found at rest is subjected to static loads (own weight, weight of its load, etc.) and in circulation is subjected to dynamic stress resulting from traction and braking forces, the railway profile (curves, ramps, slopes etc.), the wave motion of the vehicle, the wind, etc.

Some of the resistance elements in the frame of railway vehicle may be subject to other additional demands caused by manufacture or repair technologies. These additional demands may be of thermal stress nature such as casting, forging, welding or heat treatments, or may come from fitting by tightening to obtain the assembly of wheels on axes, or from raising, orientating/positioning, handling the chassis or other sub-assemblies on production or repair flows, /5/.

Calculation schemes take into account the loads and stresses grouped into:

- vertical loads, static or dynamic, due to own weight and the weight of the load;
- lateral loads, produced by the uncompensated centrifugal force and wind pressure;
- longitudinal loads that occur in the traction and collision device;
- loads due to traction torque on motor vehicles;
- loads produced during braking;
- asymmetric vertical loads,
- loads caused by contact forces between wheels and rails, in curves;
- residual stresses from manufacture or repair.

The calculation and construction of sub-assemblies and parts that go into the composition of a railway vehicle are made in order to achieve a solid structure, reliable in use, capable to withstand the forces and stresses to which it is subjected in operation and, at the same time, weight as less as possible, and cost as low as possible, while also allowing simple use, maintenance and repair, /6-13/.

Besides the resistance condition, deformation conditions must also be fulfilled, which require from the vehicle as a whole or parts of it, a certain elasticity and respectively stiffness, on which depends traffic safety and the quality of movement of the vehicle.

The acting forces on an axle, Figs. 2 and 6, are generated by the weight of the machine (static and dynamic vertical forces), horizontal forces (sides) by inertia while moving through curves, as well as by wind and forces and moments due to braking or traction.

The rail axle is checked in terms of stress state by means of FEM /8-11/, Fig. 13. The most important stress factors that can act simultaneously on a rail axle are analysed: the weight of the machine and accessory, arm position, wheel torque, braking torque and shock, in combination with several stress conditions (geometry profile and condition of railway), which may lead to limit stress cases (Fig. 14-15).

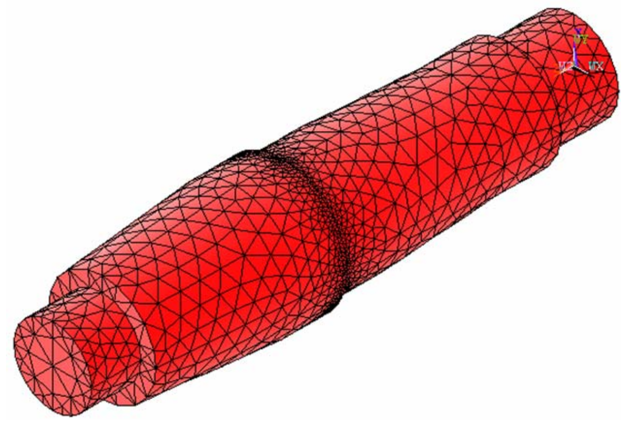

Figure 13. The meshing of the rail axle.
Slika 13. Mreža vagonske osovine

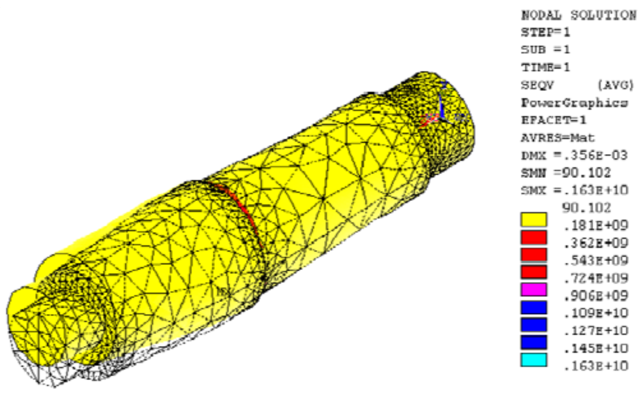

Figure 14. Equivalent tension state (von Mises) – stress case 1.
Slika 14. Ekvivalentno stanje napona (fon Mizes) – slučaj 1

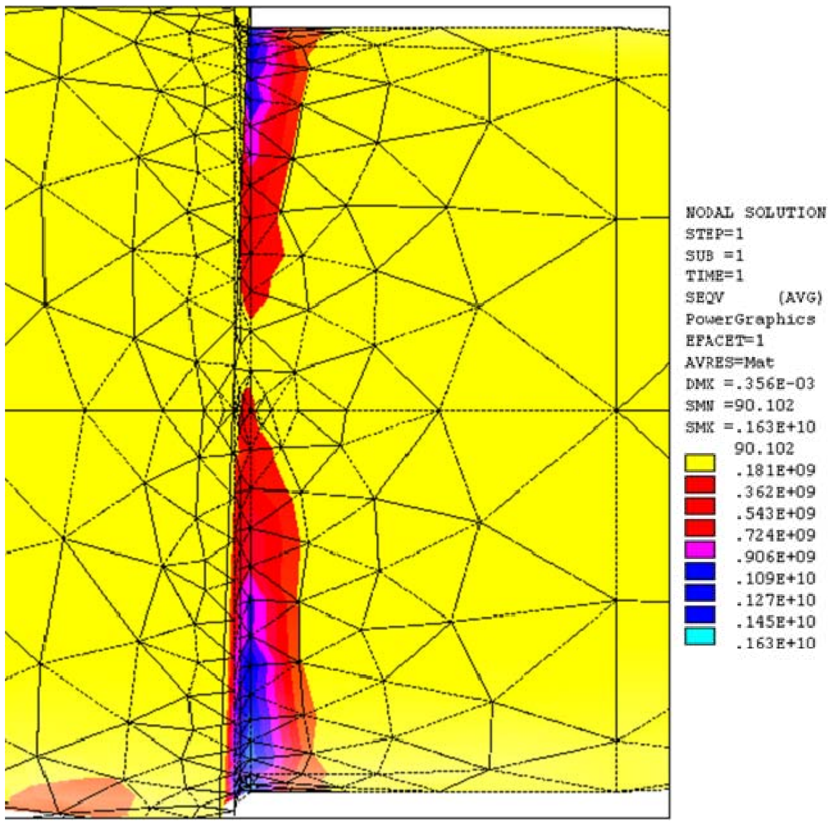

Figure 15. Equivalent state (von Mises) – stress case 1- detail.
Slika 15. Ekvivalentno stanje (fon Mizes) – slučaj 1 - detalj

In the case of moving at constant speed, without consideration of variable resistances (wind, ramp or slope, positive or negative accelerations - braking etc.), the traction torque is determined by the power output given by the two hydraulic motors of the type H1C.108.S / VM / R, one for each railway axle. Since railway axle is not equipped with differential mechanisms for moving straight (excluding curves), it can be considered that the power and the torque are distributed equally on the two axes of the same rail axle.

Braking is also achieved through the rail axes, unitary and uniform. In terms of braking at the limit, without slipping, with keeping the balance condition of the vehicle, it can be considered that the entire vehicle weight is distributed on one rail axle.

Additional stress due to the position of the car during travel or work that leads to different distributions of stress (weight, ramps, slopes, super-elevation in curves, lifting a load in a certain position of the turret or arm etc.) are neglected.

In the case of the rail wheels (rail axle) moving over rail joints, dynamic stress is produced by shock.

The analysis of this case shows the occurrence of critical areas of tension in the same position where the rail axle has failed (Figs. 14-15).

The case shown has been selected between the cases analysed due to relevance of stress cases encountered in practice.

CHECK, CONTROL AND TECHNICAL DIAGNOSIS

To prevent similar incidents and to regulate the technical measures for verification and preventive control, a disassembling of all rail axes on the machine is done in order to examine by non-destructive methods, (Fig. 16).

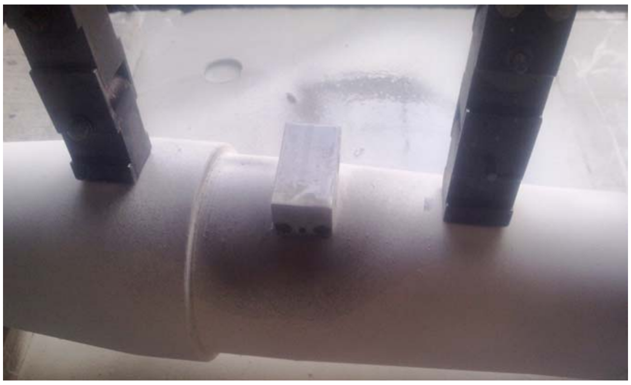

Figure 16.Magnetic particle inspection of T3500 railway axles.
Slika 16. Ispitivanje T3500 vagonskih osovina magnetnim česticama

After disassembling, non-destructive checks can be made using penetrating liquids, magnetic powders or ultrasonic tests, which would show any internal material flaws (voids, cracks etc.) to prevent breakage in use.

For the analysed case, a magnetic particle inspection is made (Figs. 16-17), considering the simplicity, ease and speed of this test method. It was found that also the other three rail axles showed symptoms (signs) of fracture, under the form of cracks (Fig. 17), in the same area where the fracture occurred. A measure was taken to replace all 4 rail axles with new ones.

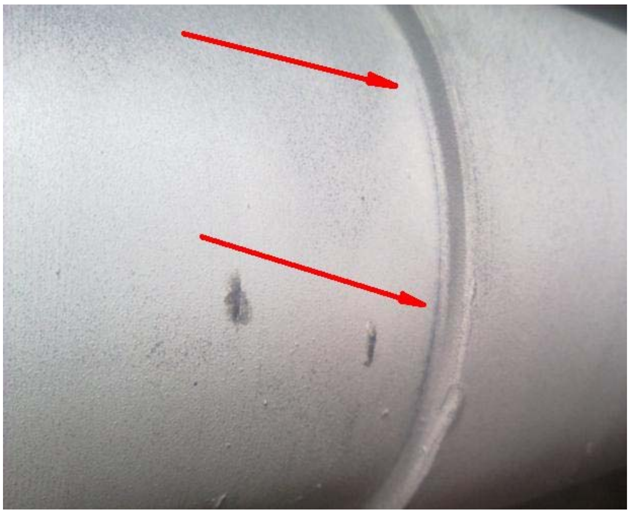

Figure 17. Crack in the maximum stress area.
Slika 17. Prslina u oblasti najvećih napona

CONCLUSION

The failure of a rail axle is one of the major dangers for traffic safety, with possible major property damage and human casualties in the railway transport of goods and people, as well as in the maintenance and repair of the railway infrastructure. The study and detailed analysis of the causes and factors that had led to fracture by various methods (analytical, laboratory or using FEM), provide important information and conclusions that lead to the prevention of similar cases, and also improve the solutions for design, manufacturing or technological, testing, control, diagnosis and evaluation for operating in complete safety.

It is necessary to check and control the rail axles using penetrating liquids or magnetic particles, for all multi-functional machines, on their first planned intervention and every subsequent planned major intervention, by totally disassembling the axles.

The regulation of compulsory verification and non-destructive periodic control of the axles of special rail building machines is necessary, similarly to the technical norms of verification and control of mounted railway axles.

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