Stress/Strain analysis in the bogie in linear motion

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Abstract. The railway wheel, together with the axle, represents one of the very important parts that support the safe operation of railway vehicles. Wheels support the entire weight of cars. Therefore, the reliability is demanded in terms of accuracy. Accordingly, the most important and fundamental characteristic in designing wheels is strength. The investigation of dangerous area in bogie is one of important area of study in railway manufactured. This essential information is required in structural integrity, failure and fatigue calculation to determine lifetime for scheduling the maintenance and regrinding necessity. The aim of this work is to determine the stress/strain in a bogie to common working in operating conditions using the 3D finite element method (FEM). The FEM results carried out using 3D elements allows the stress/strain distribution with good accuracy. Knowing the maximum stress/strain value in a bogie, prevents an unsafe construction from the design stage, and consequently increases safety in rail traffic.

1. Introduction

Nowadays, the main aims of railways industry, including trains producers are the traffic safety and reduction of transport costs with increasing the transport capacities. These can be carried out by improving design and construction of freight wagon body structures using the newest technology and following the progresses steps within improved in-service security, lightweight structures and high capacity, reducing the costs of manufacture, in-service maintenances and repairs. Majority of studies regarding railways vehicles are focused on the design of main components of the railway wagon as axles, bogie bolster, side frames, coil springs, wheel-sets with steel axle, mono-block wheel, profile of wheels and other components, including requirements as design techniques, evaluation methods, testing and safety [1].

The bogie is an essential component of a train car, have high significance in supporting the full weight of a freight wagon, controls wheel-sets to guide it along the track and carries the suspensions, brakes, axles and wheels. Thus, during the design techniques, the geometries shall support modifications, simulations are essential in foreseen the behavior of bogies under loading [2-4].

One of the most important tasks in describing the dynamics of any type rolling stock is a simulation of the movement of wheelsets in a rail track. The greatest difficulties in describing the movement of wheelsets are search for areas of contact of wheels with rails and the determination of the forces acting in the contact areas wheels - rails. Below are the main provisions of the methodology for determining contact areas and forces operating in these areas in relation to the present to research. These
techniques are described in details in literature [5-7].

Rail–wheel complex transform energy by friction, wheel–rail complex being submitted to damage by the rolling junction and slip/stick phenomena (wear or crack development in the rails), this problem must be fully understood. The contact mechanism as stress and strain distributions) shall be estimated as cracks propagations. The wearing of wheel-rail set is simulated under 3D stress - strain [8, 9].

The analysis of the literature shows that the calculation of distribution of stress is carried out by Hertzian contact procedure. Thus, crack propagations, deformations, wears during functioning is examined [6-10]. These problems must also be experimentally proved and simulations by FEM shall validate the results.

The object of the paper is to build a numerical simulation of freight wagon bogie in rectilinear motion. The bogie consists of a bogie bolster, bogie frame, primary suspension, centre pivot, wheel sets and axle bearing box. The results obtained from the analysis should be useful for optimizing the design of the bogie assembly. A FEM procedure is developed as an example of 3D-model for rail and bogie.

Figure 1 presents the analysis stages of the bogie assembly and rails is taken into consideration: design of rail and bogie assembly, imposing the bi-linear material model, physics, boundary conditions and loadings, mesh, contact conditions where the friction coefficient is included, matrix equation, solver and results processing.

In this work, the contact areas and their migration in the process of lateral shifting of the wheelset (y) reported to the axis of the track were determined in preliminary stage of calculations.

2. Analysis method

For this study is used a bogie prototype with the railroad itself. The component of bogie assembly is bogie bolster, side frames, coil springs, wheel-sets with steel axle, mono-block wheel, profile of wheels S78 [11], diameter of wheels 650 mm. The dimensions involved in UIC 60 rail [12] are: the axle tilting the rail is 1/20, the gauge has 1435 mm, the inner offset of the two wheels is 1360 mm, 0° angle of attack. Bogie assembly shown in Figure 2 was created in Autodesk Inventor 2018.
The model of material is adapted from the standard data, where for wheels and rails is used a bilinear elastic-plastic properties and for the other parts of assembly was assumed linear-elastic properties.

The mechanical and physical properties of materials are shown in Table 1, Figure 3.

### Table 1. Properties of assignment materials.

| Steel                        | \(\rho\) [kg/m\(^3\)] | \(\sigma_a\) [MPa] | \(\sigma_r\) [MPa] | \(E\) [GPa] | \(\nu\) |
|------------------------------|-------------------------|---------------------|---------------------|-------------|--------|
| R7T (wheel)                  | 7850                    | 390                 | 870                 | 210         | 0.3    |
| A2 (Axle)                    |                         |                     |                     |             |        |
| OL 44-3k (Bogie frame)       | 7850                    | 250                 | 490                 | 0.3         |        |
| 900A (rail)                  |                         |                     |                     |             |        |
| Steel 60Si15A (Coil spring)  | 1270                    | 1470                |                     | 200         |        |

**Figure 3.** Adopted materials properties of the system.

3D assembly imported in CAD are meshed with solid187 4-node tetra mesh elements, contact zone between rails and wheels is mesh very well and shown to in Figure 4 a), the contact interaction is simulated with the conta174 elements for wheel and target170 for rail. The FEM model mesh has 171867 nodes and 87933 elements for all parts of system. Loading conditions is shown in Figure 4, velocity of 1 km/h was imposed on bogie body Figure 4 b), 400kN vertical force is applied on the central pivot point, Figure 4 c), the top bogie frame are fixed at lateral frames, axle box are fixed at lateral frames, bearings are replaced by a kinematic rotation joints. The coil springs are fixed by bolster frame at the top and by side frame at the bottom. Wheels were fixed to the axles, rails were fixed at bottom surface at all direction for preventing the system displacement, Figure 4 d). The FE model tends to present as much as possible the realistic geometry for load transfer between the bolster frame – springs – side frames - axles – wheels – rails. The coefficient of friction used in the simulation was \(\mu_1 = 0; \mu_2 = 0.15; \mu_3 = 0.2\). Thermal loads have been neglected.
3. Numerical results

Strain and stress contour plots of the bogie in motion are plotted in Figure 5 a); b). Acceleration and velocity contour are plotted in Figure 6 a); b).

Figure 4. Mesh model and Boundary conditions and loadings: a) Mesh; b) Velocity; c) Force; d) Fixed support

Figure 5. Strain and stress contour plots of the bogie assembly in motion: a) Equivalent von-Mises strain; b) Equivalent von-Mises stress
Figure 6. Contour plots of the acceleration/velocity of the bogie assembly: a) Acceleration total; b) Velocity total.

In Figure 5 a), contour of von Mises stress is presented for global model for $\mu_3 = 0.2$. In bolster frame, the maximum stress is around the 202 MPa, for side frame the maximum stress value is around the 175 MPa. The maximum stress value from the global model is inspected inside of outer surface of rail in depth of 2.7 mm being around 520 MPa and for wheels, maximum stress is discovered inside the treads of wheels in depth of 3.2 mm being around 478 MPa, which are above the limit of proportionality for rail/wheel material for three contact nodes. The maximum accelerations calculated for the global model are recorded on the wheel and is about 710 mm/s$^2$, meanwhile the minimum one is recorded on bolster frame and into the rail, being 0 mm/s$^2$. The velocity distributions are presented in Figure 6b, the maximum velocities are also recorded on the wheels, being 740 mm/s.

The contour plots of the pressure/frictional stress between wheel/rail are plotted in Figures 7.

Figure 7. The contour plots of the pressure/frictional stress between wheel/rail: a) Contact Pressure; b) Frictional stress

4. Conclusions
In this paper, the investigation of the strain and stress levels and distribution patterns of a bogie model for the freight wagons has been evaluated by numerical methods. Strain and stress concentration zones appraised by finite element analysis (FEM). The stress concentration areas were considered on top surface pivot areas of the bogie bolster in the proximity of the applied vertical load, around the crossing zones of the side frame and the bogie bolster, wheel and rail near the contact zone. The maximum von Mises stress zones indicated around the contact zone between wheel/rail. All of the stresses for the all parts of bogie assembly were under the yield line of Goodman diagram. The prototype of the bogie assembly contented the fatigue and strength safety. The pressure distribution and von Mises equivalent stresses are according bi-linear material model, for interaction between the wheels with S78 profile and the rails with UIC 60 profile, with rail tilting of 1/20 and friction coefficients having 0; 0.15 and 0.2 values. The friction forces at the contact determine asymmetrical
distribution in plane of von Mises stresses, increasing of maximum value of stress, location of maximum values in small depths. Relative value of von Mises equivalent stress increasing and the closing of maximum point by contact surface, have a negative influence on the fatigue state of the contact wheel-rail during functioning. The aforementioned effects become more accentuated once with increasing of the friction coefficient.

The study on strength aspects was performed using the finite element method and not was validated using experimental data. Future works will imply the experimental tests on engine’s bogie produced in Romania and comparing the results with those from FEM.

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