World Applied Sciences Journal 24 (Information Technologies in Modern Industry, Education & Society): 208-212, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.24.itmies.80041

Passenger Car Safety Prediction

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Submitted: Aug 10, 2013; **Accepted:** Sep 21, 2013; **Published:** Sep 25, 2013

Abstract: We propose the predicting passenger railway rolling stock safety technique. The technique is based on the methods of mathematical modeling using the world-famous industrial software systems. The criteria for passenger rolling stock safety is to ensure traffic safety and dynamic parameters, regulated by the normative documents, the strength of load-bearing structures in all operational modes, reliability and durability. When evaluating safety parameters we use solid modeling, finite element analysis of static and dynamic setting, taking into account geometrical and physical nonlinearities, cycle fatigue model, given in the linear fatigue damage summation hypothesis, as well as nonlinear fracture mechanics approaches and structure survivability. We consider the rolling stock operation modes, taking into account the traffic on the road straight sections, in curves and turnouts, starting and braking, as well as shunting collisions. Technique was successfully tested on the passenger car modern design, produced by the Tver Carriage Works and is implementing at the Russian car-building enterprises.

Key words: Forecasting · Safety · Technique · Passenger car · Traffic safety · Dynamics · Durability · Endurance · Fatigue life · Reliability · Rolling stock · Finite element model · Solid modeling · Stress-strain state

INTRODUCTION

Modern conditions of passenger transport market are placing greater demands on the traffic safety and comfort [1]. To ensure the competitiveness of Russian passenger rolling stock manufacturers, we must have clearly built a product safety parameters predicting technique at the design stage. On the development of this technique for a long time, a team of specialists from Bryansk State Technical University "Railway rolling stock" department works. [2] Because of the current economic conditions and the timing of new rolling stock design do not allow to perform a large amount of exploratory experimental studies, on the developing technique basis we propose mathematic modeling methods. [3,4].

Passenger Rolling Stock Safety Prediction Technique: Technique considers the following passenger rolling stock safety aspects: traffic safety and providing the dynamic parameters regulated standard documentation; the passenger rolling stock load-bearing structures strength in all operational modes; reliability and durability of the rolling stock.

The developing methodology core is the car operation mathematical model, including the simulation of rolling stock units motion as a passenger train part on real uneven road at speeds up to structural, fit the road profile: on straight road sections and in the different radius curves; the different turnouts types; in the modes of pulling away, deceleration and braking; during shunting collisions. Instrumentation techniques are industrial solid modeling software systems and finite element analysis, having world-famous.

The proposed rolling stock safety prediction method consists of the following steps:

- Creating a solid-state dynamic model of the rolling stock operation. The model takes into account all operating conditions typical for considered unit. As a modeling result, we estimate traffic safety criteria, regulated by the normative documents, as well as a correspondence of the vehicle specifications dynamic characteristics [5] and the reference terms. Also on the first stage, the dynamic forces acting on the supporting body structure are defined.

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- Development of the vehicle main load-bearing elements detailed finite element models. Evaluation of stress-strain construction state in th static and dynamic staging on the static loads action, corresponding to the calculating regimes, regulated by the standards [5] and dynamic loads obtained in the first stage. Safety is assessed by comparing the static and dynamic stresses with tolerance, given in [5].
- Evaluation of the rolling stock supporting structures elements sustainability, working on compression. Safety is assessed by comparing the effective stresses to the critical, calculated for current construction.
- Determination of the most loaded bearing structures areas and the detailed finite element models development. The adjusted estimate of the supporting structure node stress-strain state, using the method of successive areas selections. Safety is assessed by comparing the adjusted stresses values with tolerance [5].
- Analysis of the fatigue life and survivability of welded joints. Safety is evaluated by comparing the calculated values ??of the service life up to structural failure with the specified vehicle service life.

The technique was tested by analyzing the passenger rolling stock safety, manufactured by Tver Carriage Works.

Traffic Safety Evaluation and Passenger Cars Dynamic Characteristics Prediction: Traffic safety was evaluated for the following running gear dynamics parameters: vertical, horizontal acceleration of the body and the main running gear components; coefficients of vertical and horizontal body dynamics; the coefficient of run smoothness; the rail squeezing forces; frame strength; friction forces power at the wheel-rail contact points on the rolling circle and at the crest; wheelset stability against derailment coefficient; car tipping over stability coefficient; critical motion speed [6].

The smooth progress ratio is determined based on obtained in the car motion simulation of vertical and horizontal accelerations on the vehicle floor in the pivot block region, when calculating the smooth progress ratio we take into account filtered acceleration in the frequency range from 0.5 to 20 Hz.

Friction forces power at wheel-rail contact are defined as the scalar product of the creep strength and wheel speed relative to the rail in contact point. The specified parameter can be used to comparative assess the wheel rolling surface wear.

Wheelset stability coefficient against derailment is calculated in three ways: by the technique, recommended by regulatory guidelines for the car design[5], as well as the criteria of M. Nadal [7] and G. Wineshtock [7].

To assess the passenger cars safety we developed a passenger train dynamic model, consisting of eight-axle passenger electric DC locomotive brand CS-7 of the Czech company "Skoda" and twenty passenger compartment cars with air conditioning units model 61-4440 manufactured by Tver Carriage Works (Fig. 1).

The dynamic model of the train is formed in an environment of the multibody system kynematics and dynamics modeling industrial complex "Universal Mechanism" (UM) using the subsystem method [8].

Subsystem "Passenger car" is a body in the form of a rigid body with real inertial and geometric characteristics that take into account the actual location of equipment and passengers through special elements based on running parts solid models that are represented as lower-level subsystems. Truck dynamic model is a system of rigid bodies connected by joints and force elements.

Subsystem "Locomotive" is similar to the car model and completed the electrical and mechanical subsystems, describing the traction electrodrive and forming wheelset traction forces taking into account the on-board systems. In the modeling running resistance forces were taken into account, related to the wheel rolling-resistance, climbs, track curved sections and weather conditions.

Fig. 1: The passenger train dynamic model:
1 - Subsystem "Locomotive", 2 - Subsystem "Passenger car"

When describing the wheel-rail contact interaction we consider two block outs - in rolling circle and in wheel ridge and rail possible contact area Creep forces calculation - is a part of the FASTSIM algorithm, based on the Calker linear theory [9,10]. This algorithm is used in bi-contact conditions to calculate the creep forces at the two points taking into account possible wheel and rail wear. Curve track sections macrogeometry in terms determined from the curve passage rate. Road microirregularities are taken in accordance with the data obtained when measuring the actual path sections according to their state. Elastic-dissipative characteristics of the upper track structure are accepted for the summer at a satisfactory road condition and rails of 25 m long laid on concrete sleepers.

Subsystems "Locomotive" and "Passenger car" interaction is described by the specialized coupling devices models, representing a solids aggregate, the rotational joints, contact and elastic-dissipative elements.

Conclusions about the considered car safety are based on the comparison of the obtained parameters with threshold values, ??given in the standard documentation.

Passenger Cars Load-bearing Structures Strength Evaluation in the Operating Conditions: Strength evaluation is performed in two stages. The first step is the structure strength analysis in a static setting from acting forces, corresponding to the operation modes, regulated by normative documents [5]. Analysis tool is the finite element method, implemented in the industrial software systems. In this study we used a software system Siemens PLM Software Femap 9.0 with Nastran NX solver. At the second stage, the refined estimation of strength in a dynamic setting is conducted. Calculations are made on the dynamic forces, acting on the structure during operation. Graphs of forces variation in time are determined by car operation solid modeling using the models, described above.

Evaluation of stress-strain state of the construction is based on the method of nodal displacements equations direct integration or modal method, depending on the existing computing resources and models dimension. In modeling load-bearing structures, depending on the requirements, the different ways of model discretization are used: plate-rod design diagrams, plate models and volumetric elements models.

Internal friction consideration in the calculation scheme is carried out on the Voig hypothesis. When modeling the load-bearing structures oscillation dynamic, set of existing dissipative forces is replaced by an equivalent viscous damping, determined from the equality of these forces work and viscous resistance for the oscillation period. Determination of the equivalent viscous damping coefficient is based on the structural damping coefficient due to the internal friction forces work. Structural damping transformation to the equivalent viscous damping is produced by the first structure bending vibrations natural frequency.

The resulting construction stress-strain state calculation patterns are analyzed and if a most loaded areas detailed study is necessary, we perform their isolation using the area sequential allocation method[11]. As an example, Figure 2 shows the finite models of the most loaded body areas (bolster to the cap welding place - Fig. 2a) and truck frame - Fig. 2b.

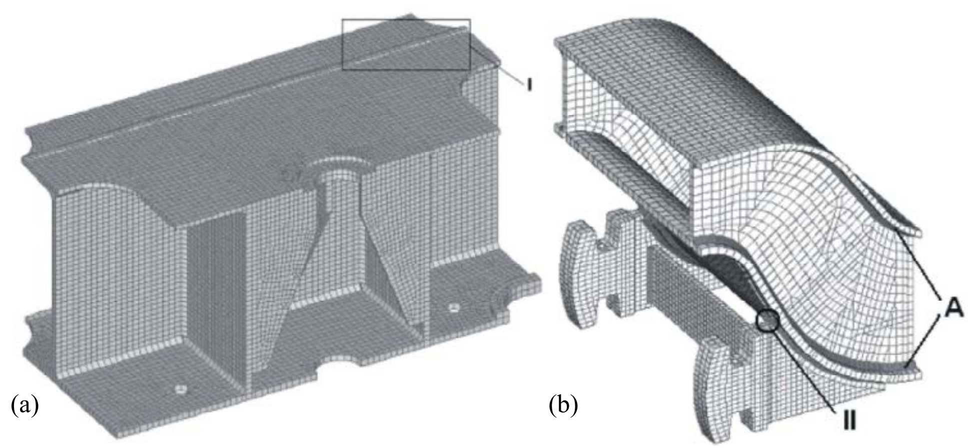

Fig. 2: Finite element model of the most loaded areas:
a – car body; b – truck frame

For structural elements, operating on compression, we further study the global and local stability loss possibility with the geometrical and physical nonlinearities.

The load-bearing structures safety on the strength criterion is carried out by comparing the levels of maximum stress obtained in static and dynamic setting, with allowable stress given by the regulations. From the stability point of view, safety is determined by comparing the stresses in compressible elements with critical compressive stresses and shear.

Passenger Cars Reliability and Durability Evaluation: Based on the dependence of stress change in the most loaded passenger cars bearing structures welded joints, we produced construction fatigue life and survivability assessment with the reliability parameters definition. Calculations of fatigue resistance are based on the model of high-cycle fatigue, which uses a fatigue damage summation linear hypothesis [12] for random loading.

In the calculations welding joints stress concentration coefficients are taken into account[13,14], as well as residual welding stresses and the joints surface hardening treatment possibility. In this case, as a damaging effects source we take dynamic equivalent stress spectra, according to Mises energy distortion hypothesis, produced in the construction elements on the proposed technique [15].

Welded structures survivability analysis is based on the synergetic concept of deformed metal damaging in the elastic-plastic deformation, developed by V.S. Ivanova [16] taking into account the real behavior of polycrystalline material with defects under cyclic dynamic loading. Within the adopted concept, construction loading is considered as a energizing of it, spending on deformation. Since as the energy dissipation transition criterion by plastic deformation to the dissipation caused by microdestructions, we take the maximum deformation energy, its critical value, which is the material constant, is regarded as the local strength energy criterion. The critical value of the maximum deformation energy controls the stable microcracks germs emergence that are capable of spontaneous growth.

The current value of the maximum deformation energy is the sum of two components, the first of which corresponds to the energy dissipation by distortion (shape change), the second - dilatation (volume change). Both components of the maximum deformation energy current values can be expressed by the normal and shear octahedral stresses in the elastic and elastic-plastic regions.

In case of construction cyclic loading, which leads to plastic deformation in a local pre-fracture zone, there is the maximum deformation energy accumulation to a critical value, above which is the destruction of the structural element.

Since the input energy, when construction is under loading, is distributed unevenly throughout its volume and in stress concentration areas maximum deformation energy is much higher, survivability assessment of the body bearing structure is held in a local volume of area with stress concentration at the tip of crack-like defects of the most loaded weld. In the crack growth modeling its discrete nature was considered, which is especially characterize the cyclic loading.

When analyzing welds survivability, crack-like defects are introduced in the weld undercut or cracks form. Regard to the abrupt stresses and strains concentration at the defect top was performed by top modeling using singular five-fold volume of quadratic elements with shifted to the defect top intermediate nodes of ¼- side length. The singular element size is taken into account with a polycrystalline steel grain size. Crack growth is modeled by successive replacement of structural elements with the maximum deformation energy level greater than the critical, by the two end elements with disconnected nodes, establishing cracks cradle and new crack tip formation at the next with the exception of the structural element. The calculation procedure is repeated until the cracks exit on the opposite side of the seam and turn it into a pass-through.

CONCLUSION

The above technique has been successfully used in applied research for the benefit of the Tver Carriage Works and Tver Institute of car building. In particular, using the technique we performed passenger car body bearing structures safety assessment for models 61-4440, 61-4447, 61-4458, 61-4179 and trucks cradle-less design model 68-4075 with the constructional speed of 200 km / h and 68-4095 model with a constructional speed of 160 km / h [17]. The use of this technique in the rolling stock units design allowed in 1.42 times to reduce the new generation cars construction cost for models 61-4440, 61-4447, compared with the car model design of 61-4179, 1.38 times lower the cost of designing the model truck 68-4095, compared with the previously created truck model 68-4075. Turnaround time for data structures have been reduced by 1.9 times, which ultimately led to a reduction in life-cycle costs by an average of 15-17% and higher competitiveness of the car-building enterprises of Russia.

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