Modeling the Dynamics of Russian Railroad Vehicles with MEDYNA

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For the use of MEDYNA program by Russian specialists in the field of railroad transport, its Russian version was created. In it there were implemented the main parameters of Russian railroads including 1520 mm rail gauge, standard wheel and rail profiles, normative track irregularities. In the first stage there was made an attempt to perform expertise of ride qualities of high-speed train SOKOL that was designed for the first specialized high-speed railroad between St. Petersburg and Moscow.

Modeling the dynamics of high-speed train SOKOL

1. Model development

In the frame of work to evaluate consumer qualities of high-speed train SOKOL the influence of its running gear and intercar connections parameters was investigated.

For simulation the calculation schemes of separate car and three-car section of the train that took main special features of SOKOL and MEDYNA modeling capabilities into account were developed.

For calculation of ride qualities the model consisting of absolutely rigid bodies and elastic-damping interconnections was used. The calculation scheme of one passenger car contained 11 rigid bodies and 32 interconnections.

The position of interconnections was assumed in the following way:

- Four spring-damper elements were installed between the car body and the bogie frame. Two corresponded to pneumatic springs and two — to special yaw dampers;
- Two spring-damper elements were installed between the bogie frame and the wheelset;
- Wheel-rail contact was considered as a separate interconnection and was modeled either linear or nonlinear, depending on the purpose of simulation;
- Each track element was connected with track bedding by two spring-damper elements.

To form the model the following connection element types were chosen from MEDYNA catalogue:

- Spring-damper elements between the car body and the bogie frame were modeled by compact linear element that provided stiffness and viscous damping in three translational and three rotational directions (No 61 from MEDYNA catalogue);
- Spring-damper elements representing yaw dampers were modeled by linear springs that provided longitudinal stiffness (No 41 from MEDYNA catalogue);
- Wheel-rail interconnection was represented by quasi-linear element for stability and ride qualities investigation (No 22 from MEDYNA catalogue) and by nonlinear element for investigation of quasi-stationary equilibrium position in curves (No 21 from MEDYNA catalogue).

Rigid bodies with five degrees of freedom (no longitudinal displacement) represented the car body and each of two bogie frames. Wheelsets were modeled by rigid bodies with all six degrees of freedom and the track elements positioned under each axes had three degrees of freedom each (vertical and lateral translation and roll angle).

RSPROF program was used to build the wheel and rail profiles that are used on Russian railroads. Besides new profiles the approximate types of worn profiles were developed and used for evaluation of wear influence on the stability and ride qualities of high-speed train SOKOL.

2. Investigation of stability and ride qualities

In the first stage of work the influence of suspension parameters on vehicle stability was investigated. This resulted in developing proposals into the technical project of the train concerning the optimization of its running gear parameters.

In the second stage of work considering the modified initial data, the investigation of motion stability and determination of ride qualities on tangent track were performed. Parameters of the track were different for the newly constructed special high-speed railroad between St. Petersburg and Moscow and for the existing railroads. Different possible types of wheel profile wear were taken into account. The forces in wheel-rail contact, accelerations of car bodies and ride indices were determined according to system frequency response to track irregularities represented by spectral density function.

The following main results were obtained:

1. For all types of cars the critical speed was equal to 760 kph with new wheel profile. Increasing the wheel wear led to elimination of 10 % reserve of construction speed. On the existing railroad where SOKOL is planned to operate at 250 kph the reserve was lost at 4 mm wheel tread wear (276 kph critical speed). On the newly constructed railroad where SOKOL is planned to operate at 350 kph the critical value of wheel tread wear was equal to 3 mm (378 kph critical speed).
2. The analysis of performed calculations showed that SOKOL ride qualities meet the domestic and international requirements. ORE ride index does not exceed 3.0 at 350 kph on newly constructed high-speed railroad, and it does not exceed 3.25 at 250 kph on the existing track.

3. Investigation of curving behavior

The simulation was performed using nonlinear wheel-rail interconnection element. The existing quasi-stationary equilibrium positions determined speed limits for the given curve radii. As a result it was found that SOKOL meets the Russian normative requirements. Recommendations were made for the newly constructed high-speed railroad between St. Petersburg and Moscow.

On the whole the results obtained with MEDYNA showed satisfactory correspondence with the earlier obtained results. Soon the calculations will be validated by comparison to ride trial results.

Development of Freight Car Models for Higher Operation Speeds

Based on satisfactory correspondence of the results when modeling the high-speed train dynamics in the next stage of work there was made an attempt to simulate the dynamics of freight car on 18-100 bogies by means of MEDYNA.

To solve the problem, at first the earlier developed in Russia linear models of freight cars on 18-100 bogies were systemized and repeated by means of MEDYNA. The use of different wheel-rail contact models implemented in MEDYNA made it possible to widen the application field of traditional models and to receive more accurate motion characteristics (critical speeds, maximum car body accelerations, allowable curve radii).

Main tendencies of freight car motion on tangent track were traditionally investigated using the model with following features:

- the bolster was considered massless, the car body rested on side frames straight through central suspension springs;
- the possibility of bogie “lozenging” (obtaining a parallelogram shape) was modeled by stiffness in joints that were positioned at axleboxes;
- the track was considered rigid or inertialess-elastic;
- the contact was modeled by linear element that took wheel conicity into account and used Carter model for creep forces calculation.

Due to implemented in MEDYNA possibilities this model was modified in the following way:

- track inertia and track bedding stiffness were taken into account;
- Kalker models were used for creep forces calculation (including spin creep) with more accurate values of creep coefficients.

The comparison of traditional model and MEDYNA model was performed with variation of initial parameters of the system according to critical speed values.

The analysis of system natural frequencies with initial parameters showed that the traditional model gives 24 m/s value of critical speed and MEDYNA model — 35 m/s critical speed. Experiments show that speeds of stability loss are scattered in the wide range between 20 and 40 m/s.

In operation the Russian freight bogies demonstrate essential wear of axlebox sittings and noticeable change in their angular stiffness. To evaluate bogie yaw stiffness (k_ψ) its value varied in a wide range. The results are presented in Fig. 1. Qualitative appearance of the given dependencies is alike, the maximum value of critical speed is obtained for $k_\psi = 10^7$ Nm/rad. Variation of central suspension vertical stiffness also gives the dependency of the critical speed (Fig. 2) with higher values in MEDYNA model.

A different result was obtained for variation of central suspension horizontal stiffness. The traditional model gave the values of critical speed that were noticeably larger than those obtained by MEDYNA model (Fig. 3). In simulations by traditional model there was also made a conclusion that installation of horizontal dampers did not influence the value of critical speed. Using MEDYNA model it was shown that this conclusion was true only for viscous friction coefficient value $< 10^4$ Ns/m. Fig. 4 demonstrates the dependency of critical speed for viscous friction coefficient up to the critical value ($2.68 \cdot 10^6$ Ns/m).

The linear model was also used to evaluate such parameters of freight car motion as dynamic coefficient and maximum car body acceleration over the pivots. The results obtained by traditional and MEDYNA models were practically the same.

Modification of MEDYNA model for use with nonlinear wheel-rail contact model allowed to use it for investigation of quasi-stationary equilibrium position in curves which was not possible within traditional model.

Further different variants of freight car model were created that took the inertia of the bolster and operation of the pivot into account.

Further we plan to modify bogie models according to technical solutions proposed for design competition of a bogie for higher operation speeds and to use the developed models for comparison and expertise of different projects.

References

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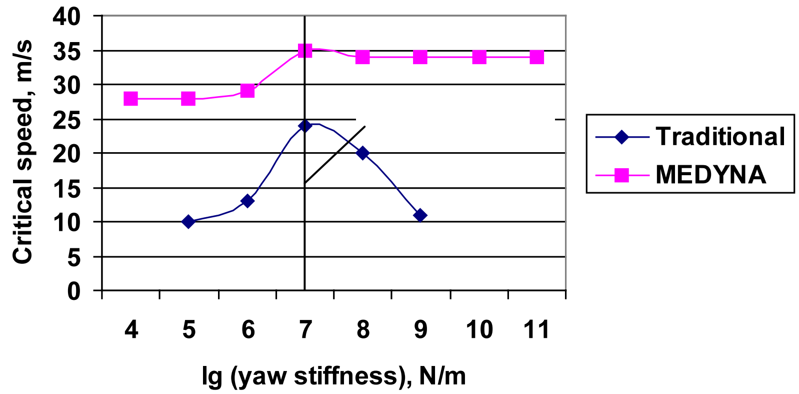

Fig. 1: The dependency of freight car critical speed on bogie stiffness in plane

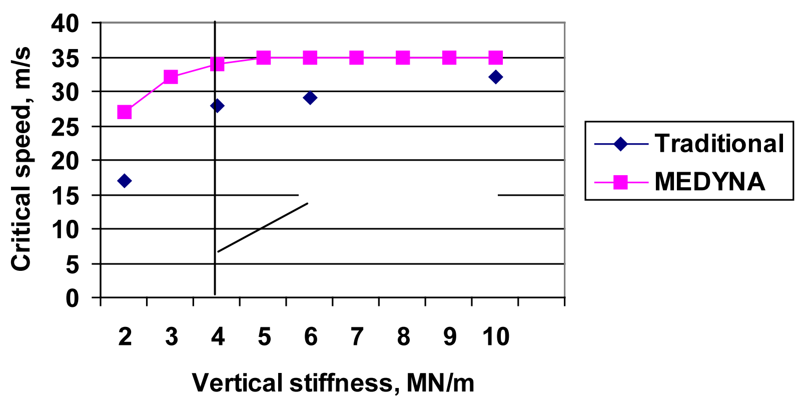

Fig. 2: The dependency of freight car critical speed on the vertical stiffness of central suspension

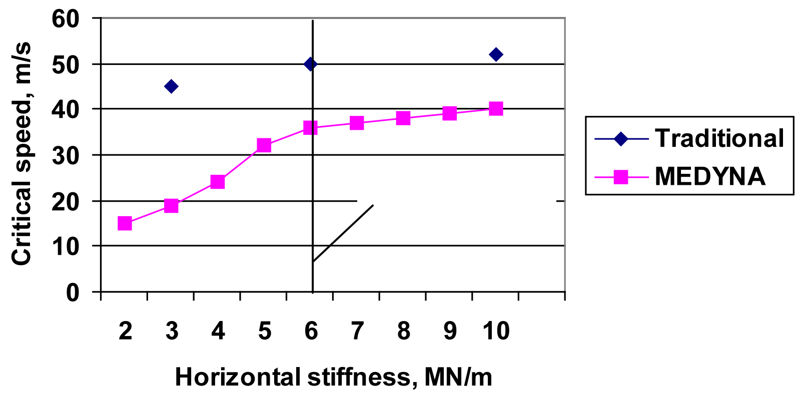

Fig. 3: The dependency of freight car critical speed on horizontal stiffness of central suspension

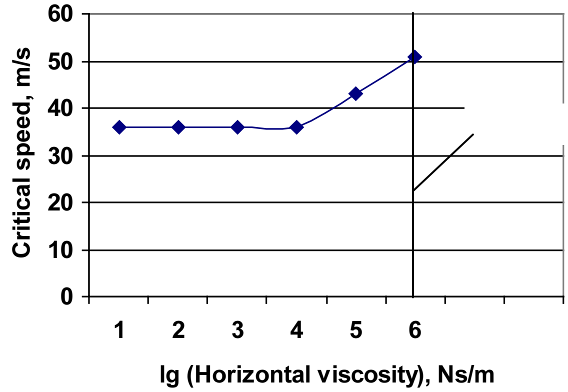

Fig. 4: The dependency of freight car critical speed on horizontal viscous friction coefficient in central suspension