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APPLICATION OF SENSITIVITY ANALYSIS IN DESIGN OF CHARACTERISTICS OF DAMPING JOINTS IN LOCOMOTIVE RUNNING GEAR

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Abstract: *Operation of railway vehicles at higher speeds is conditioned by assurance of a stable run of the vehicle in straight track with a high level of geometric parameters. This property is usually reached by retrofitting of a joint between the vehicle body and the bogies with an efficient damping with suitable characteristics. Because the relative motion between the vehicle body and the bogies in the straight track shows low amplitudes and high velocities, special longitudinal dampers – so-called yaw dampers – are used for these purposes. The aim of this paper is a theoretical analysis of the yaw damper characteristics on the stability limit of a locomotive performed by means of sensitivity analysis.*

Keywords: ***Sensitivity analysis, stability of vehicle run, critical speed, yaw dampers, simulations.***

1. Introduction

Nowadays, computer simulations of running and guiding behaviour create an integral part of development of new or modernized rail vehicles. The simulations are practically the only possible way for verification of dynamic properties of the vehicle in the design stage. It is possible to use them for optimization of suspension and damping parameters, as well.

Jan Perner Transport Faculty of the University of Pardubice co-operates with the company CZ LOKO, a.s. on solving of R&D project “TIP” of the Ministry of Industry and Trade of the Czech Republic; the aim of this project is manufacturing of a prototype of a locomotive Class 744.0 as well as preparation of a broad-gauged version of this locomotive according to the GOST standards. The computer simulations of dynamic behaviour of the new locomotive create one of the main parts at the project solving.

2. Locomotive Class 744.0 CZ LOKO

The locomotive Class 744.0 CZ LOKO (see fig. 1) is a four-axled diesel-electric locomotive with AC/AC or AC/DC power transmission which is intended for track as well as shunting service. The maximum speed is 120 km/h. The modular conception of the locomotive allows manufacturing of various versions with a maximum power of combustion engine of 800 up to 1500 kW. Traction drive is assured by means of four asynchronous or serial direct-current axle-mounted nose-suspended traction motors with roller bearing. Each of these motors belongs to one wheelset and has a maximum power of 360 kW.

The main frame of the locomotive is mounted on two two-axled bogies (see fig. 2 and Kopal, 2009) by means of flexi-coil springs. The longitudinal force transmission between the bogie and the locomotive body is performed with a central pivot. The wheelset guiding in the bogie frame is performed by means of connection rods; the primary suspension is created by two flexi-coil springs at each journal box. The vertical (primary as well as secondary) suspension is supplemented by hydraulic dampers; damping of lateral oscillations between the vehicle body and the bogies is performed by two lateral hydraulic dampers per bogie.

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Besides the locomotive for European track gauge 1435 mm, a broad-gauged version of the locomotive for eastern market is developed parallelly. This locomotive, which comes out from the standard-gauged locomotive to a maximum degree, is intended for the "Russian" track gauge 1520 mm and is designed according to the GOST standards. Besides indispensable modifications of the bogie frames and usage of new wheelsets it is necessary to perform a modification of parameters of the suspension (because of the intended total weight of the locomotive from the range of 80 up to 90 t) and to verify the influence of these modifications on the dynamic behaviour of the locomotive.

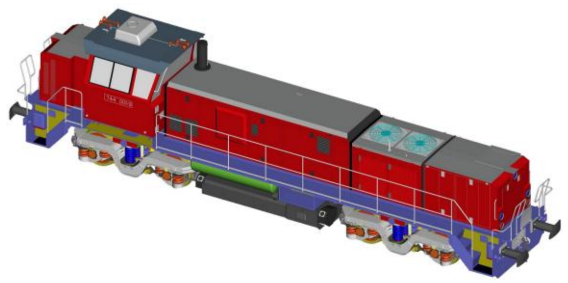

Fig. 1 Visualization of the Class 744.0.

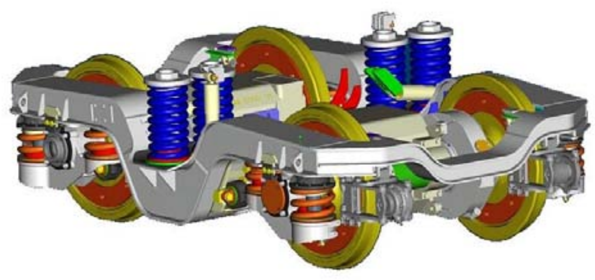

Fig. 2 A bogie of the Class 744.0.

3. Simulations of dynamic behaviour of the locomotive

The computer simulations of dynamic behaviour of the new locomotive are performed by means of an original multi-body simulation software (Zelenka, 2009). The first simulation results of the broad-gauged version of the locomotive Class 744.0 CZ LOKO are shown in paper (Zelenka & Michálek, 2011). On the basis of current documentation and measurement of real parameters of the locomotive suspension (Zelenka et al., 2011), simulation input data were specified. Investigation of the influence of change of relevant parameters, which is related with the modification of the locomotive for the broad track gauge, was also performed and its results are shown in paper (Kohout et al., 2011).

The main input parameters of the dynamic model of the locomotive (i.e. the mass and geometric parameters, characteristics of elastic and damping joints etc.) were determined with the project documentation and they are gradually specified during the development and subsequent manufacturing of the locomotive by the project manager. A substantial influence on the dynamic behaviour also has the characteristics of wheel/rail contact geometry which characterize the joint between the wheelset and the track. In this stage, simulations were performed for two different sets of characteristics of wheel/rail contact geometry – λ_{ekv} = 0.207 (theoretical wheel profiles and rail profiles 60E1/1:40) and λ_{ekv} = 0.403 (operationally worn wheel and rail profiles). In fig. 3, there are shown curves of delta-*r* function and equivalent conicity. In the next, the relevant wheel/rail contact geometry will always be named by means of value of the equivalent conicity for the wheelset amplitude y_0 = 3 mm.

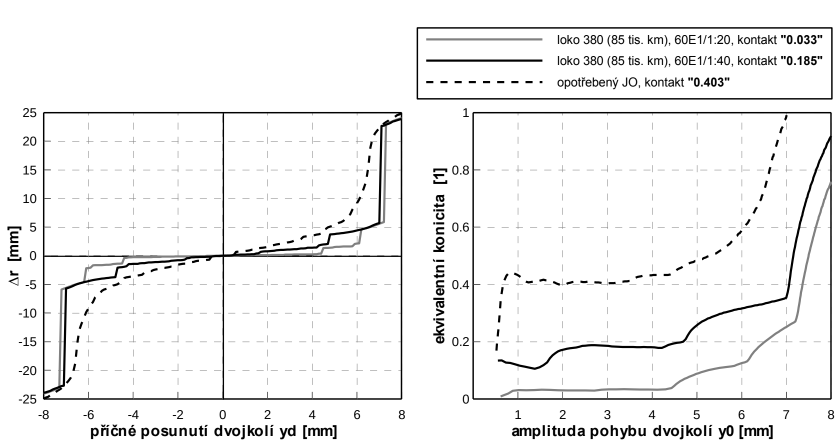

Fig. 3 Characteristics of wheel/rail contact geometry.

From the point of view of the vehicle dynamics, the locomotive comprises complicated non-linear dynamic system. Therefore, for purposes of determination of influence of different input parameters on dynamic behaviour of the whole locomotive a sensitivity analysis can be used. The sensitivity analysis allows acquisition of an image describing a qualitative behaviour of such complicated system (locomotive) with respect to variable input parameters. One of the most important parameter of the rail vehicle is its critical speed. The critical speed represents the maximum speed at which the rail vehicle shows so-called stable run, i.e. running behaviour without lateral oscillations of wheelsets, bogies and the vehicle body. Value of the critical speed is influenced by many parameters and exceeding of this speed can lead to exceeding of the safety limits of the vehicle run (see the EN 14363) and degradation of the ride comfort. For purposes of sensitivity analysis of the locomotive Class 744.0, four weight variants (with a total weight of 80, 84, 86 and 90 t) were considered. Besides to that, influence of some other parameters was observed, above all the equivalent conicity (i.e. the wheel/rail contact geometry), friction coefficient in the wheel/rail contact and the influence of yaw dampers.

4. Assessment of stability of run of the locomotive

For purposes of assessment of the stability of vehicle run (i.e. determination of the critical speed of the vehicle), several methods are usually used – see paper (Polách, 2010), for example. In case of the locomotive Class 744.0, the sensitivity analysis was performed by means of non-linear method on theoretical straight track; the excitation of the dynamic model of the locomotive was carried out with isolated lateral track unevenness. For purposes of the stability assessment, lateral motion of the wheelsets (lateral oscillations) was observed at the decreasing vehicle speed.

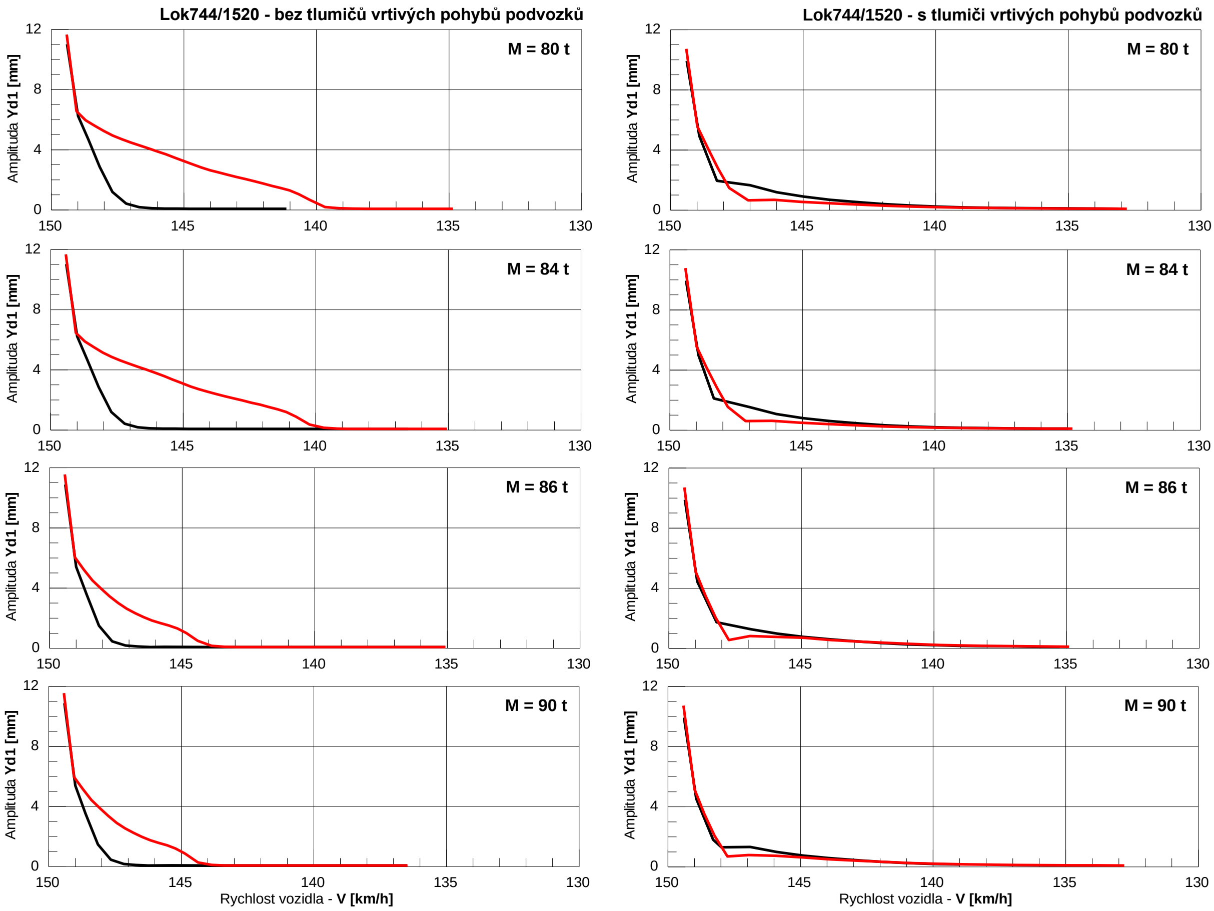

Fig. 4 Amplitude of the lateral motion of the 1st wheelset after the excitation on the ideal straight track for various total weight of locomotive and various contact conditions (decreasing speed; value of a friction coefficient in the wheel/rail contact: 0.40; red – λ_{ekv} = 0.403, black – λ_{ekv} = 0.207).

In the graphs in fig. 4 there are shown curves of the amplitudes of lateral motion of the 1st wheelset of the broad-gauged version of the locomotive. These curves were obtained by means of simulations of response of the locomotive on lateral unevenness at the speed 150 km/h. Four weight variants (with a total weight of 80, 84, 86 and 90 t), two different conditions of the wheel/rail contact geometry (red lines – λ_{ekv} = 0.403, black lines – λ_{ekv} = 0.207) and a value of friction coefficient in the wheel/rail contact of 0.4 were considered here. On the left side there are shown the results of the locomotive without yaw dampers, the results on the right side represent the locomotive equipped with yaw dampers (two pieces per bogie). As it is evident from the graphs in fig. 4, the critical speed is higher than ca. 140 km/h in all considered cases. Especially in case of locomotive with yaw dampers, the wheelset oscillations disappear immediately after the excitation. From this reason, analogous assessment of the stability was performed at higher initial speed (200 km/h); relevant results for locomotives with total weight 80 and 90 t are shown in fig. 5. It is apparent that the yaw dampers can shift the critical speed to higher values; however, the wheel/rail contact geometry influences the stability very significantly, as well.

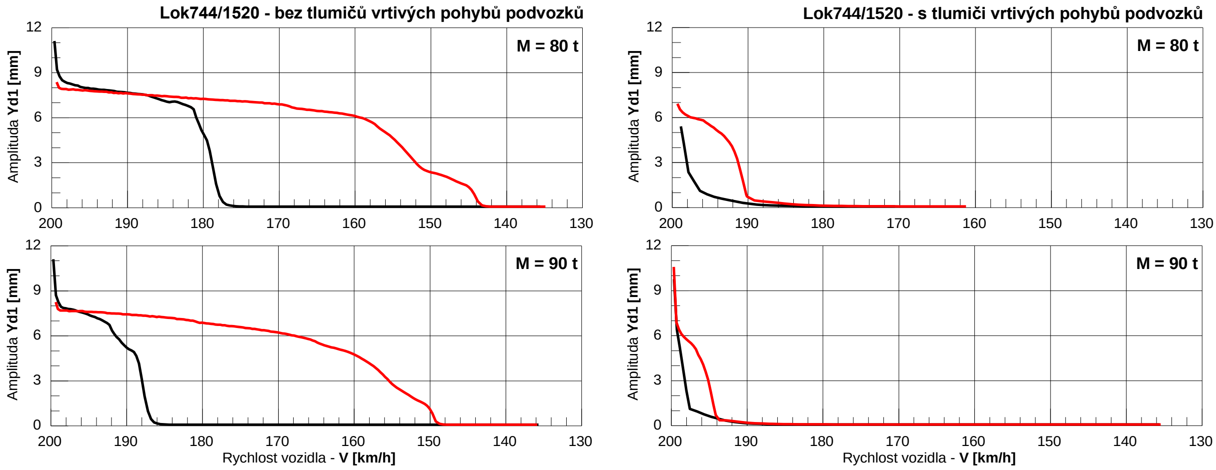

Fig. 5 Amplitude of the lateral motion of the 1st wheelset after the excitation on the ideal straight track for various total weight of locomotive and various contact conditions (decreasing speed; value of a friction coefficient in the wheel/rail contact: 0.35; red – λ_{ekv} = 0.403, black – λ_{ekv} = 0.207).

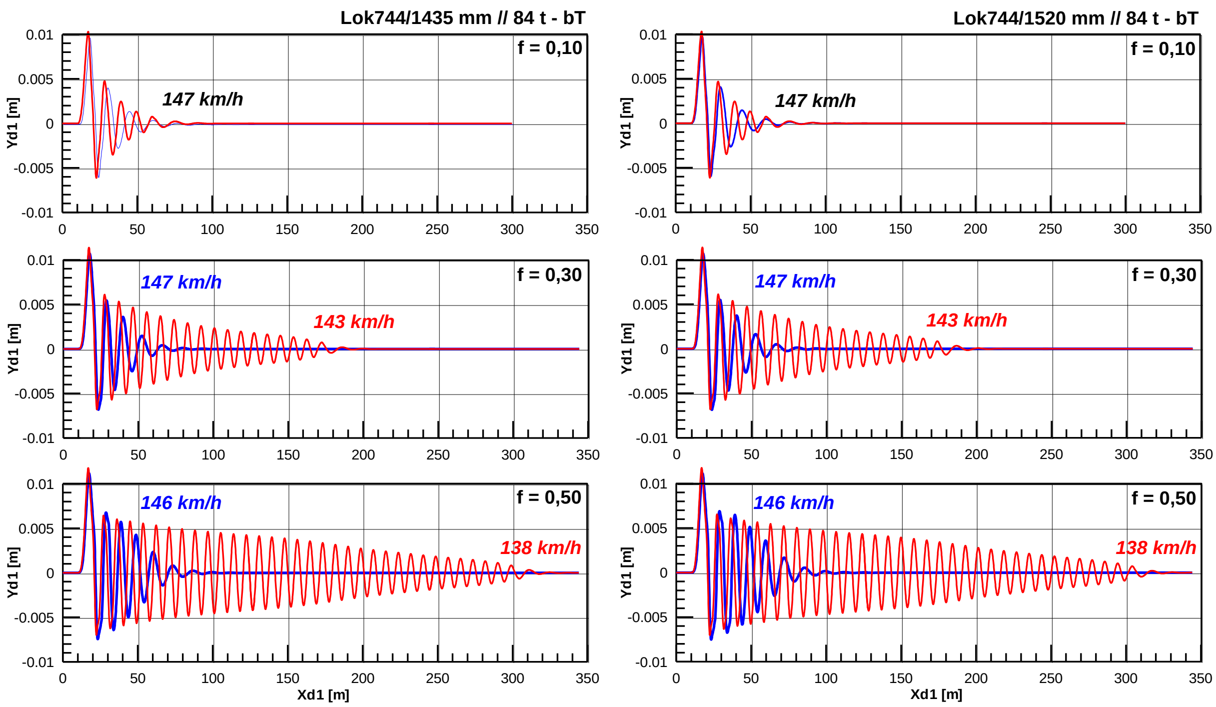

Fig. 6 Lateral motion of the 1st wheelset after the excitation on the ideal straight track for the standard- (left) as well as broad-gauged (right) version of the locomotive with total weight 84 t without yaw dampers, for various friction coefficient and various contact conditions (decreasing speed; red – λ_{ekv} = 0.403, blue – λ_{ekv} = 0.207).

In the graphs in fig. 6 there is demonstrated influence of the friction coefficient in wheel/rail contact on the critical speed. The simulations were performed in the same way as in case of results in fig. 4. However, the broad-gauged version as well as the standard gauged version of the locomotive with a total weight of 84 and without the yaw dampers was considered in this case. The friction coefficient in wheel/rail contact ranged from 0.10 up to 0.50. It is apparent that increasing value of the friction coefficient in wheel/rail contact shifts the critical speed to lower values. The graphs in fig. 6 also show that a difference between the standard-gauged and broad-gauged version of the locomotive is negligible from the point of view of the stability of run.

The second way, how to investigate the stability of run of a rail vehicle, is usage of simulations of the run on the ideal straight track at constant speed; see (Polách, 2010 or Zelenka & Kohout, 2011), for example. After the excitation of the vehicle by means of isolated lateral track unevenness, the lateral wheelset motion stabilizes in a steady state which is characterized with its amplitude. Then, the qualitative change of the dynamic behaviour at the parameter change can be presented by means of bifurcation diagrams. In case of stability assessment, the bifurcation diagrams usually represent dependency of the amplitude of lateral wheelset motion on the vehicle speed. For better clearness, this method is demonstrated on example of an electric locomotive – see also the paper (Zelenka & Kohout, 2011). In fig. 7 there are shown the simulation results (i.e. histories of lateral motion of the 1st and 3rd wheelset of the locomotive) at different speeds for concrete conditions given by wheel/rail contact geometry (λ_{ekv} = 0.033) and characteristics of yaw dampers (named as "Os4", in this case).

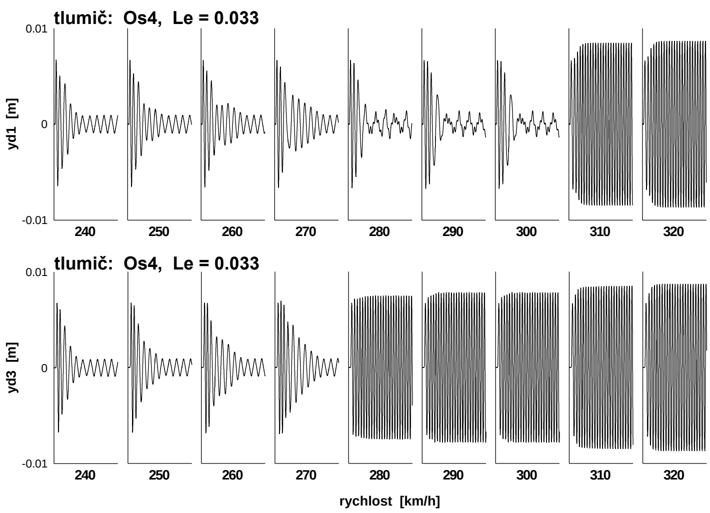

Fig. 7 Lateral motion of the 1st (top) and 3rd (bottom) wheelset of investigated locomotive for concrete conditions given by wheel/rail contact geometry and characteristics of yaw dampers at various speeds.

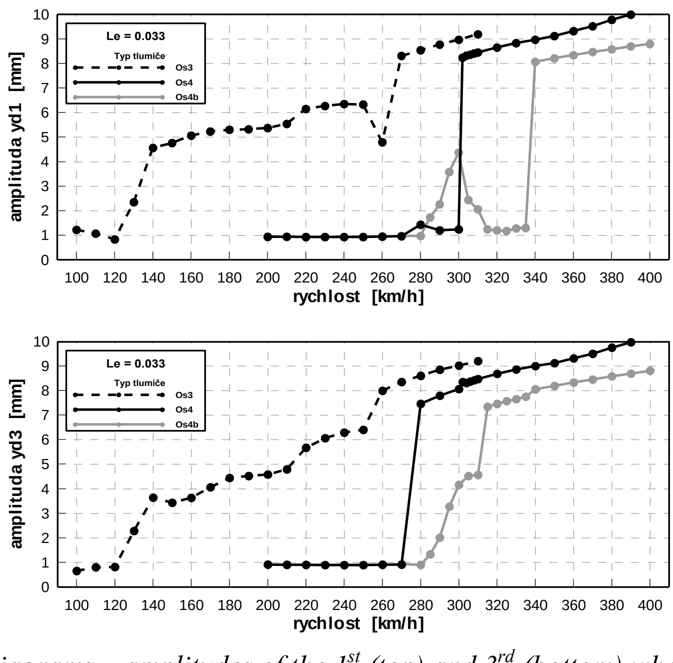

Fig. 8 Bifurcation diagrams – amplitudes of the 1st (top) and 3rd (bottom) wheelset of investigated locomotive for concrete wheel/rail contact geometry and various characteristics of yaw dampers.

In fig. 8 there are presented relevant bifurcation diagrams (i.e. dependencies of amplitudes of the lateral motion of the 1st and 3rd wheelset on the vehicle speed) for the concrete wheel/rail contact geometry (λ_{ekv} = 0.033) and for various characteristics of yaw dampers. It is evident that the characteristics of the yaw dampers can influence dynamic behaviour of the whole locomotive very significantly; even it can change the type of Hopf's bifurcation. Besides yaw dampers, characteristics of the wheel/rail contact geometry can influence the stability of the run very significantly, as well. In fig. 9 there are shown examples of bifurcation diagrams of the lateral motion of the 1st wheelset of the electric locomotive for various condition of the wheel/rail contact geometry (left – λ_{ekv} = 0.185, right – λ_{ekv} = 0.403; see also fig. 3) and for various characteristics of used yaw dampers.

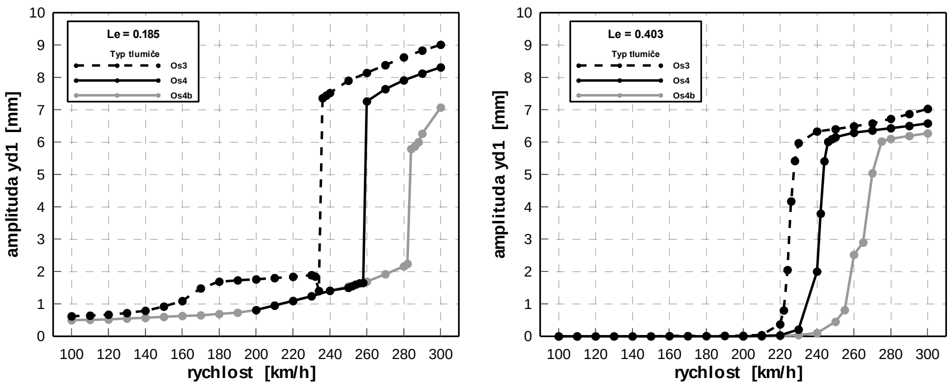

Fig. 9 Bifurcation diagrams – amplitudes of the 1st wheelset of investigated locomotive for various conditions of wheel/rail contact geometry and various characteristics of yaw dampers.

The results of this method are more exact and allow more detailed assessment of the dynamic behaviour of the rail vehicle at the stability limit, but they are equivalent to the usage of the above described method of the stability assessment using the decreasing vehicle speed at the simulations (see fig. 4 and 5), practically. Especially in case of the locomotive Class 744.0 CZ LOKO without the yaw dampers (see fig. 5), the wheel/rail contact geometry also has a significant influence on the dynamic behaviour of the whole locomotive. The contact with equivalent conicity λ_{ekv} = 0.207 seems to lead to the subcritical Hopf's bifurcation; the other one (λ_{ekv} = 0.403) leads to the supercritical Hopf's bifurcation evidently. Application of the considered yaw dampers shifts the critical speed to higher values in both cases. More detailed description of methods of determination of the bifurcation diagrams is presented in the paper (Polách, 2010).

5. Conclusions

This paper deals with application of sensitivity analysis at the assessment of dynamic behaviour of railway vehicles by means of computer simulations. By means of the sensitivity analysis, many different parameters and above all an influence of their changes on the dynamic behaviour of the vehicles can be observed in the design stage of these vehicles. In this way, the computer simulations of running and guiding behaviour allow the optimization of design and properties of some important constructional parts of newly developed vehicles.

In chapter 4, an analysis of stability of the run of the new diesel-electric locomotive Class 744.0 CZ LOKO for the "Russian" track gauge 1520 mm is performed. By means of sensitivity analysis, influences of the total weight of locomotive (from the range of 80 up to 90 t), application of the yaw dampers into the running gear, various conditions of the wheel/rail contact geometry and various values of the friction coefficient in the wheel/rail contact on the critical speed were observed. In all cases the critical speed seems to be higher than the intended maximum speed of this locomotive. At this assessment, the stability analysis performed on an ideal straight track with isolated lateral unevenness at decreasing vehicle speed was used.

Besides to this, another method of the stability analysis, which serves for determination of so-called bifurcation diagrams is described and presented on example of en electric locomotive in chapter 4, as well. This method is used for purposes of assessment of influence of characteristics of yaw dampers and wheel/rail contact geometry on dynamic behaviour of the vehicle at the stability limit.

In the next stage, authors will deal with analysis of influence of other simulation input parameters on dynamic behaviour of the new locomotive. Areas of sudden increase of amplitudes of lateral oscillations of the wheelsets in bifurcation diagrams – i.e. the dynamic behaviour of the vehicle at the stability limit – will be observed for purposes of acquisition of a more detailed image of dynamic properties of the whole non-linear dynamic system of the rail vehicle. Knowledge, which will be obtained in this way, will be used for verification of dynamic behaviour of other types of rail vehicles, subsequently.

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