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TEST STAND MECHANICAL SYSTEM DYNAMICS ANALYSIS

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Abstract: The paper deals with the computer analysis of the railway wheelset/rails interaction on the roller rig. The analysis is badly needed for prediction of the dynamic behaviour of the wheelset on the actual roller rig. The basic computation models as well as examined quantities, computing requirements and input conditions are presented.
Keywords: test stand, wheelset /rail interaction, dynamics analysis

1. INTRODUCTION

Experimental investigation of interaction rotating rails and a wheelset is a complex interaction of test stand construct design and test sample, which is represented by a wheelset and a collection of computer controlled loading conditions for the realization of tests. Test stand is a part of the laboratory, affecting with results of its running and also current state of the environment affects the running of test stand and test results.

To assess the behavior of the test bench in operation at the specified boundary conditions, it is often necessary, sometimes indispensable to do simulating calculations taking into account all important parameters future experimental work. The test bench is equipped with measurement technology with characteristic sensor ranges. For ensuring the best use of the range and accuracy of the sensors, as well as the entire measurement chain is the specification of the anticipated values of the measured magnitudes significant contribution. Computer simulation of the movement of the wheelset, pressed against the rotating rails is another important contribution in analysis of the its interaction, when loading forces affect. They can be derived from measured values of forces in analysis or forces obtained by computer simulation in movement of goods wagon running on railway track. We must discern, when analyzing the interaction of the wheelset and rotating rails, what driving style of vehicle is proceeding. We suppose quasi-static position when the wheelset is running in track curve. When running in a straight line, we expect that wheelset performs sinuous periodic motion. In both cases, the aim is to apply the loading of wheelset analogous to real loading in operation. In the specification of load is necessary to answer the question: „Which vehicle can be considered as representative and what axle load should be based on?“ Our considerations are based on the fact that the aim of the simulation is to obtain the results of computer simulations analogous to real running of goods wagon with Y25 bogies, which is loaded by vertical forces corresponding to the axle load of 22.5 t. In simulation calculations we can take into account the influence of braking. As a reference ways of braking, we will consider downhill braking (at constant braking performance with braking speed control). In a simulated braking we eliminate the influence of changes in the friction coefficient, that´s why we apply a constant braking torque. With analysis of the consequences of full braking we verify the accuracy of the performed calculations. For standard loading conditions, simulating a real operation will be created a set of endurance modes. It´s application will cause a wear of the wheel (change in geometry of wheel profiles). Properly analyzed the working load with specification of endurance modes in simulation calculations is an important milestone and a base for creating a control and loading computer program for the realization of tests on real test bench. This program involves a change in angle of attack of wheelset in motion, which rebound in the increase of the tangential component of the resultant force. The focus of investigation is aimed to the occurred creeps. Similarly, it is interesting to analyze the position of the contact point of the wheelset with regard to a transversal movement of the wheelset and angle of attack. When you move the position of the contact point in direction of axis „x“, then come about a deflection angle of the normal producing additional force. We will look for an analogy of magnitude of the measured active forces which will respond forces acting on the wheelset. If the operation of the bench in a laboratory can achieve relevance of wheelset displacement in direction of „y“ with values obtained by simulation calculations, then it will be obvious that the simulated load is adequate with loading in real.

2. RUNNING IN A TRACK CURVE

Running in track curve can be quasi-static or dynamic, and dynamic component has in small and big radii aperiodic – stochastic character. Running test bench can achieve the quasi-static behaviour of wheelset by setting wheelset angle of attack, applying transversal frame force and vertical frame forces. Dynamic component can be achieved by the introduction of appropriate inputs with random runs.

3. A STRAIGHT LINE RUNNING

To simulate running in a straight line at the braking bench, it is necessary to excite wheelset so that the reaction responded dynamic behavior of real wheelset on the track. Dynamics of real wheelset in a straight track may have stochastic nature, or may have an expressive periodic progress, which corresponds to a boundary cycle of movement.

4. COMPUTER ANALYSIS OF DYNAMIC BEHAVIOR OF THE WHEELSET ON THE TEST STAND

Provisional performed analysis by computer simulation should indicate to what extent can the braking bench achieved quasi-static behaviour of the wheelset in curve and movement of the real wheelset in border cycle in a straight line.

4.1. MATHEMATICAL MODELS DATA AND INPUT DATA FOR THE CALCULATION

Wheelset and rail disks:

- nominal wheel diameter 920 mm
- wheelset weight 1.4 t
- axle load 18 t, 22.5 t
- wheel profile DIN 5537 E 1425 (ORE S1002)
- nominal disk diameter 1250 mm
- disk profile
    - UIC 60 E1 track gauge 1435 mm
    - real rail profile, taper 0.192 at an amplitude of 3 mm in combination with wheel profile DIN 5537 E 1425 (ORE S1002) and 1435 mm track gauge
- friction coefficient 0.4
- Kalker´s coefficients reduced by a factor 0.66

All calculations were performed in program „Mi-Rail“ by method of time integration. Intra pre-processing were data of contact geometry examined by means of program Kontakt_DB_Minden.

4.2. MATHEMATICAL MODEL OF THE REFERENCE VEHICLE FOR LOADING FORCES OF TEST STAND DETERMINATION

As a reference vehicle was chosen loaded freight goods wagon with four-wheel bogies type Y25

In order to achieve results that correspond to actual parameters on track were performed simulation calculations of freight goods wagon with Y25 bogies in a straight line and also in a curve.

In the straight line was chosen the velocity V= 92 km/h and 18 t axle load, for which was as real indicator test at test stand in the laboratory of the Department of transport and handling machines, Faculty of Mechanical Engineering, University of Žilina.

In simulation calculations run vehicle through the curve of radius R= 250 m and outside rail raise of 150 mm at a speed responsive the balanced and unbalanced acceleration a_q= 0.8 m.s^{-2}. To simulate running in curves was used a mathematical model of a goods wagon with standard Y25 bogies.

To achieve unstable operation (boundary cycle) while running in a straight line of a freight wagon, there were modified parameters of the primary suspension in longitudinal and transversal directions, and moment of inertia of the vehicle body around a vertical axis so that the movement of the wheelset responded boundary cycle with high values of transverse frame force.

By way of comparison computationally simulated quasi-static and dynamic behavior of the goods wagon wheelset with results of simulation calculation on the braking bench were performed calculations both for the vehicle on the track and for the wheelset on the braking bench in three variants:

- running without braking,
- running to stop,
- downhill running with permanent braking at a constant speed.

For the presentation of selected results of simulation calculations, entering as loading conditions the simulation calculations of the analysis of forced movements of the wheelset on the bench and compare the results of simulation calculations of this bench, we selected the relevant case, which is running in a straight line in the boundary cycle.

4.3. SIMULATION RESULTS OF THE GOODS RUNNING IN A STRAIGHT LINE AND OF THE WHEELSET ON THE TEST STAND MOVEMENT

The dynamic behaviour of the second wheelset of the goods wagon with modified Y25 bogies is shown in Fig. 1 (variant without braking).

The dynamic behaviour of the wheelset on the test stand harmonically excited in a transversal direction and in rotation around longitudinal and vertical axe shows Fig. 2 (variant without braking).

Fig. 3 represents the dynamic behaviour of the wheelset on the braking bench excited by the frame force H and torque Mz taken from simulation calculations of goods wagon (variant without braking).

Fig. 1 to Fig. 3 contain a set of seven or eight graphs that show the following:

Graph 1a.: transversal frame force H and torque of longitudinal frame forces Mz about a vertical axis,

Graph 2a.: angle of attack ψ and shift of the wheelset in the transversal direction y,

Graph 3a.: the sum of the guiding forces SY

Graph 4a.: tangential forces Tx of left and right wheel,

Graph 5a.: Delta r function: wheelset wheels roll radii difference,

Graph 6a.: guiding forces Y of left and right wheel,

Graph 7a.: wheel forces Q of left and right wheel, Graph 8a. (Fig. 2): phase shift of longitudinal frame forces torque Mz around the vertical axis to the transversal frame force H

The first results of the calculations for the simulation of the border cycle on the test stand showed that:

- harmonically excited wheelset in the transversal direction and rotation about the longitudinal and vertical axis does not show quantitative and qualitative movement of the wheelset examined in the goods wagon and even the forces between wheel and rail,
- consistency with the results of the vehicle has not been achieved neither by variation of phase shift between the transversal frame force H and excitation torque of longitudinal frame (bearing) forces around the vertical axis M as shown in Fig. 1 and Fig. 2,
- satisfactory consistency between the dynamic behavior of the wheelset in modified Y25 bogie was achieved on the braking bench by excitation of frame forces H and torque Mz taken from simulation calculations of goods wagon (Fig. 1 and Fig. 3). The character of parameters H and Mz substantially differs from the harmonic shape in the case of longitudinal frame forces. In Dynamics of these forces is clearly reflected nonlinear shape of Delta-r-function.

Goods wagon with bogies (mod Y25)
Running in a straight line without disturbing deviations of the rails position

The dynamic behaviour of the 2. wheelset, velocity V= 92km/h without braking axle loading 18t, wheel profile: DIN5537E1425 (ORES1002)rail profile: UIC60E1 track gauge: 1435 mm

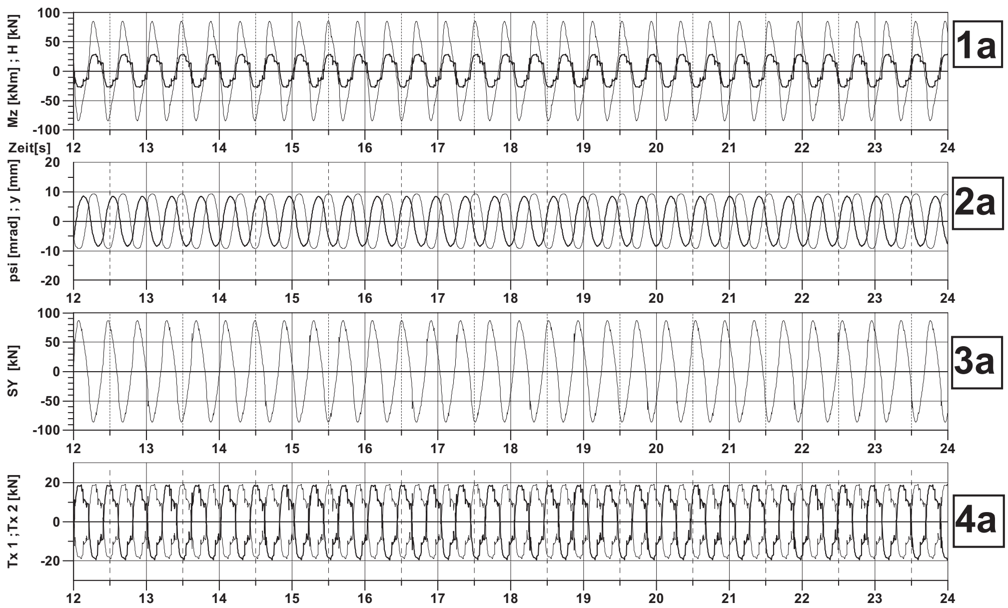
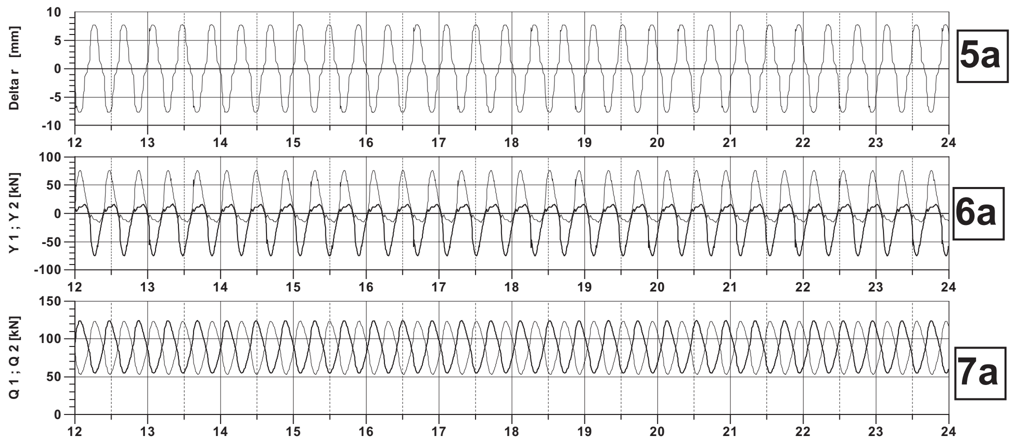


Fig. 1. Freight car – 2. wheelset – simulation of the dynamical behaviour



cont. Fig. 1. Freight car – 2. wheelset – simulation of the dynamical behaviour

Braking test bench
Forced dynamic behavior of the wheelset

Dynamic behavior of harmonically excited wheelset with phase displacement of angle of attack vis-s-vis transversal movement with step 0.02 sec in interval of 4 sec, velocity V= 92km/h without braking axle loading 18t
wheel profile: DIN5537E1425 (ORES1002)rail profile: UIC60E1
track gauge: 1435 mm

Amplitudes: H-Kraft: 80kNMz-Torque: 30kNm Mx-Torque: 15kNm

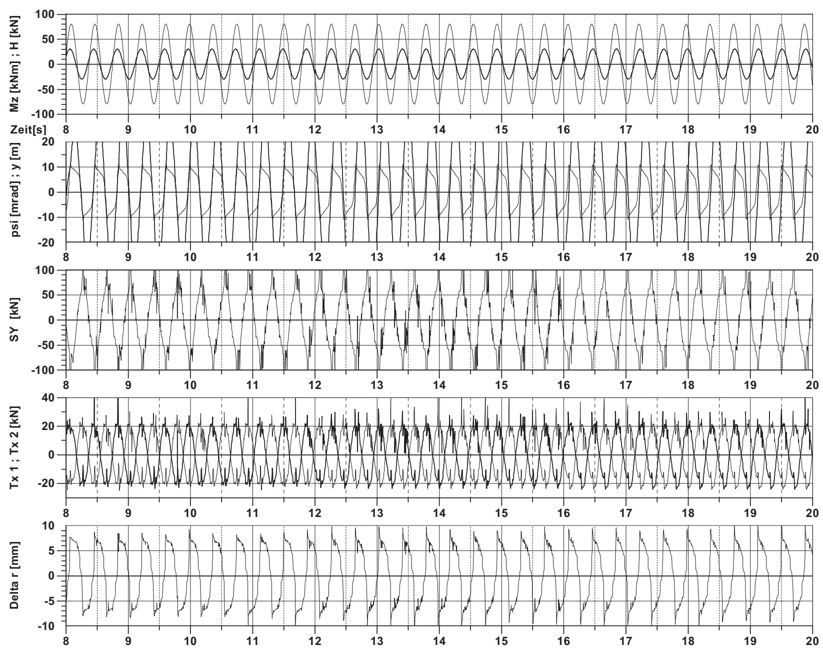
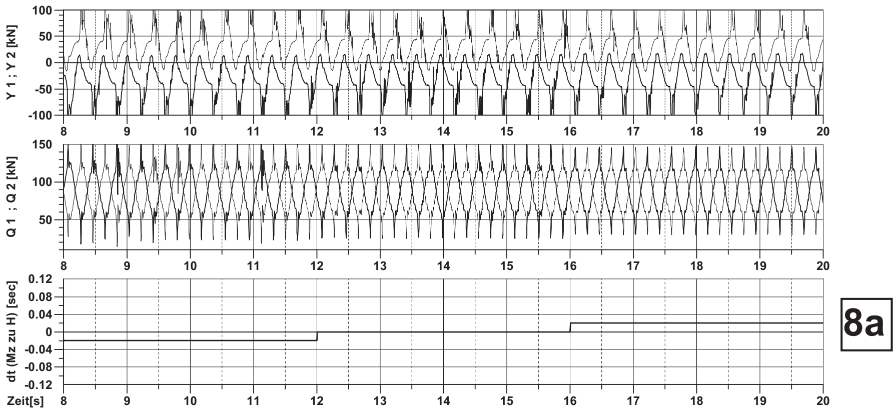


Fig. 2. Braking roller rig – simulated dynamical behaviour of harmonically excited wheelset



cont. Fig. 2. Braking roller rig – simulated dynamical behaviour of harmonically excited wheelset

Calculation results of the simulation analysis on test stand model, when results of the analysis calculated for 2. axle of first bogie from analysis of modified Y25 enter as loading conditions of calculation:

Braking test bench
Forced dynamic behavior of the wheelset
Dynamic behavior of the wheelset excited by the frame force H and torque Mz of goods wagon.
velocity V= 92km/h without braking axle loading 18t
wheel profile: DIN5537E1425 (ORES1002)rail profile: UIC60E1 track gauge: 1435 mm, Amplitudes: H-Kraft: 80kN Mz-Torque: 30kNm

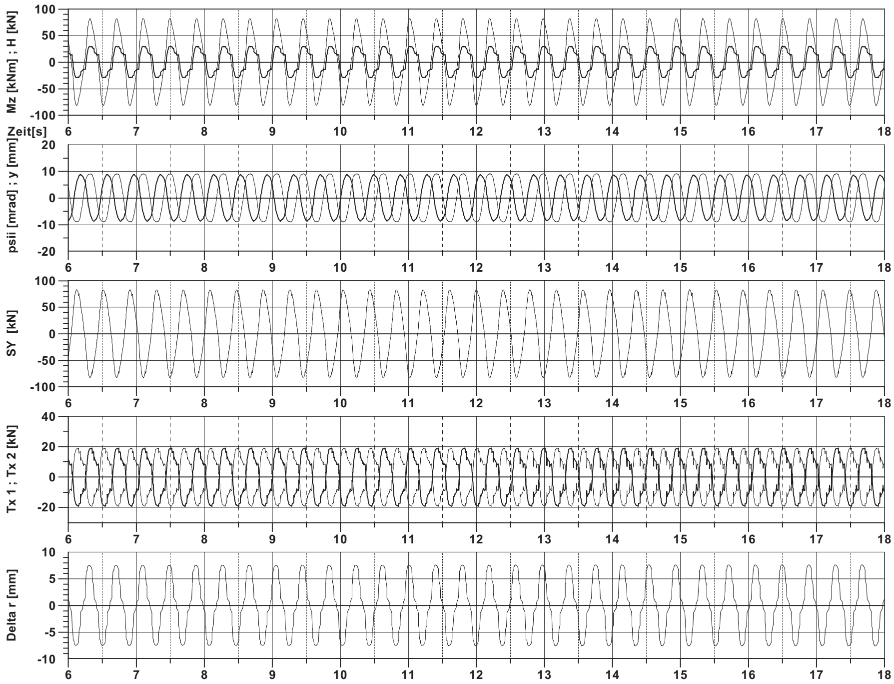
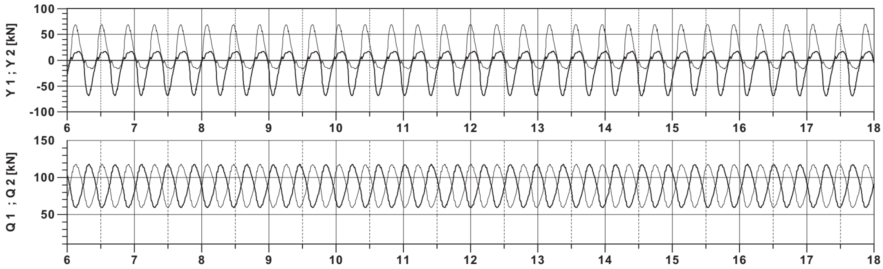


Fig. 3. Braking roller rig – simulated dynamical behaviour of wheelset excited by H-force and Mz-moment of freight car wheelset



cont. Fig. 3. Braking roller rig – simulated dynamical behaviour of wheelset excited by H-force and Mz-moment of freight car wheelset

Two-dimensional graphs of functional relations of running values enable a comparison of the dynamic behavior of goods wagon wheelset on straight track and excited wheelset on braking bench.

In Fig. 4 to Fig. 7 are displayed functional relations of running values:

DR = F(yo) Delta-r-function (dependency of size of the subtraction of immediate wheels rolling radii of the wheelset and transversal displacement of the wheelset yo),

Mz_Tx = F(y) dependency of size of the torque Mz and transversal displacement of the wheelset,

psi RS1 = F(y) dependency of size of the angle of attack ψ and transversal displacement of the wheelset,

SY = F(y) dependency of size of the guiding forces of the first wheelset and a transversal displacement of the first wheelset,

SY = F(psi) dependency of size of the guiding forces of the wheelset and angle of attack ψ,

Mz_Tx = F(psi) dependency of torque Mz and angle of attack ψ of the wheelset, for two running variants:

1. without braking (Fig. 4 and Fig. 5),
2. downhill braking at a constant speed (Fig. 6 and Fig. 7)

Larger deviations in the 2nd variant are due to the large longitudinal creep due to the action of braking forces and also different creep ratios.

Figures 4 to 7 are indicated on the following pages.

Goods wagon with bogies (mod Y25)
Running in a straight line without disturbing deviations of the rails position
2nd wheelset – functional relations

Delta r = F(yo) Mz_Tx = F(y) psi = F(y) SY = F(y) SY = F(psi) Mz_Tx = F(psi)
velocity V= 92km/h without braking axle loading 18t
wheel profile: DIN5537E1425 (ORES1002)rail profile: UIC60E1
track gauge: 1435 mm

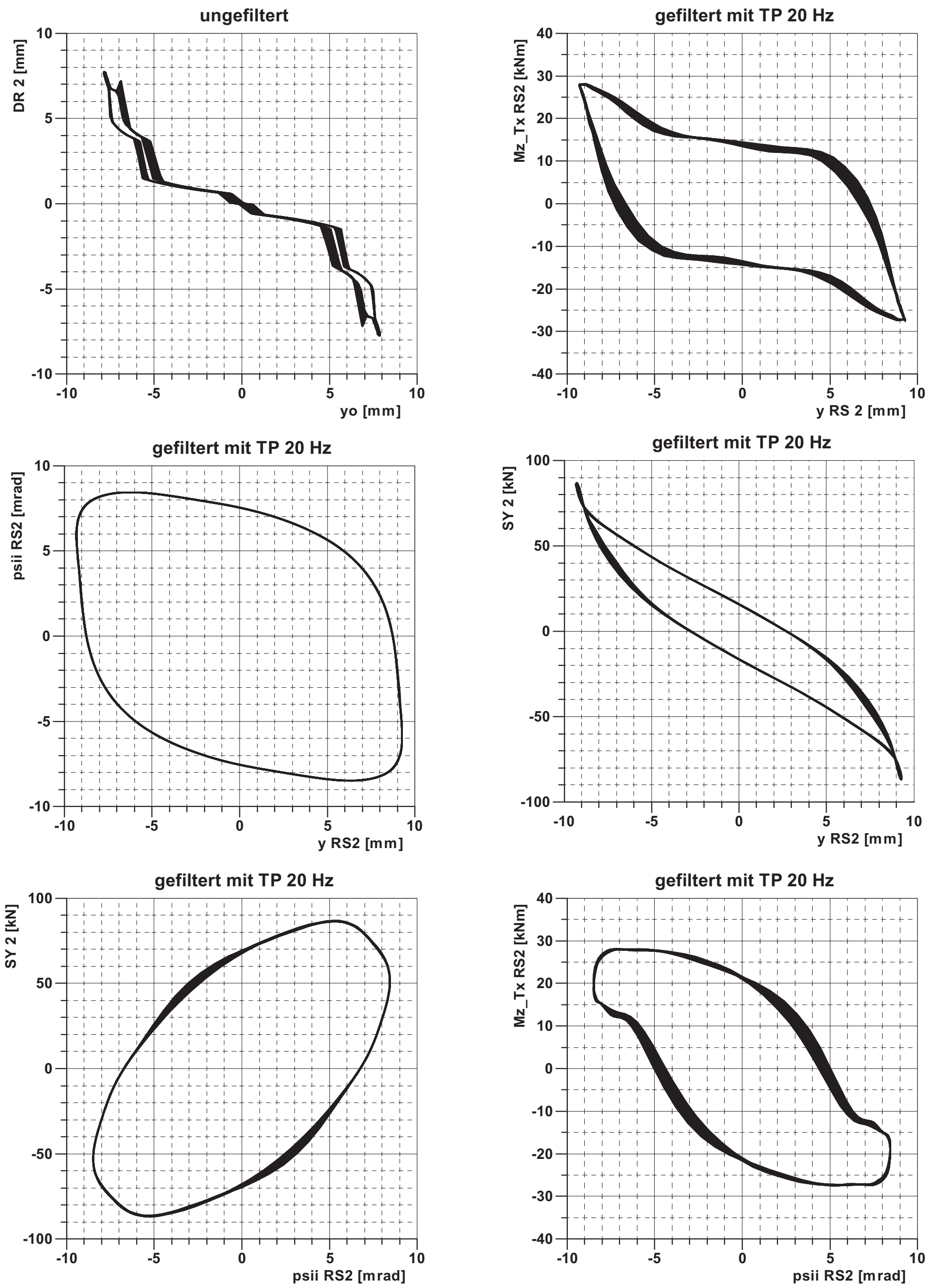


Fig. 4. Functional relations of running quantities of the 2. freight car wheelset – Version: no braking

Variant: without braking / Braking test bench
Forced dynamic behavior of the wheelset

Functional relations:
Delta r = F(yo) Mz_Tx = F(y) psi = F(y) SY = F(y) SY = F(psi) Mz_Tx = F(psi)
velocity V= 92km/h without braking axle loading 18t
wheel profile: DIN5537E1425 (ORES1002)rail profile: UIC60E1 track gauge: 1435 mm

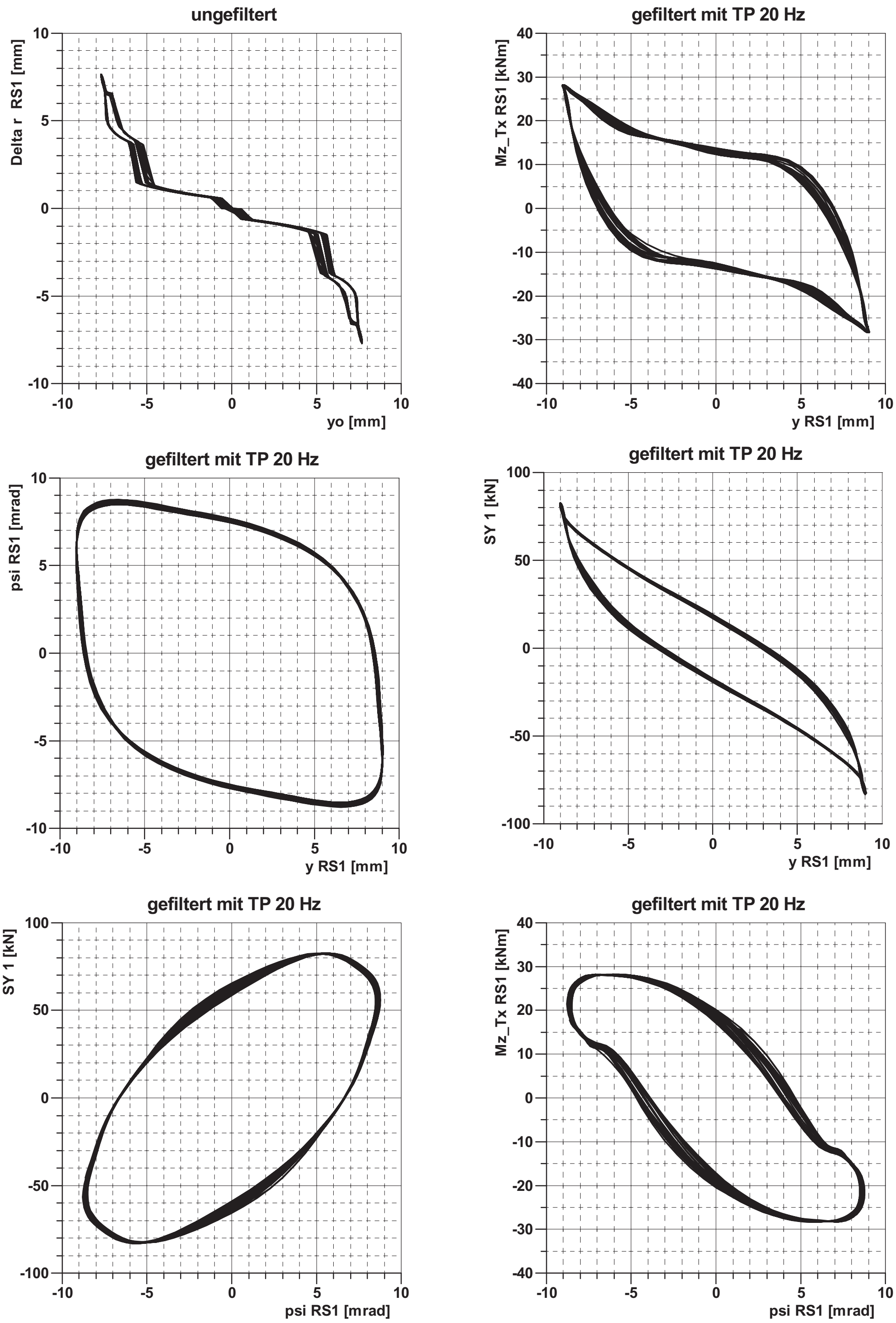


Fig. 5. Functional relations of running quantities of the wheelset on roller rig
Version: no braking

Goods wagon with bogies (mod Y25)
Running in a straight line without disturbing deviations of the rails position
2nd wheelset – functional relations
Delta r = F(yo) Mz_Tx = F(y) psi = F(y) SY = F(y) SY = F(psi) Mz_Tx = F(psi)

velocity V= 92km/h downhill braking axle loading 18t, wheel profile: DIN5537E1425 (ORES1002)rail profile: UIC60E1, track gauge: 1435 mm

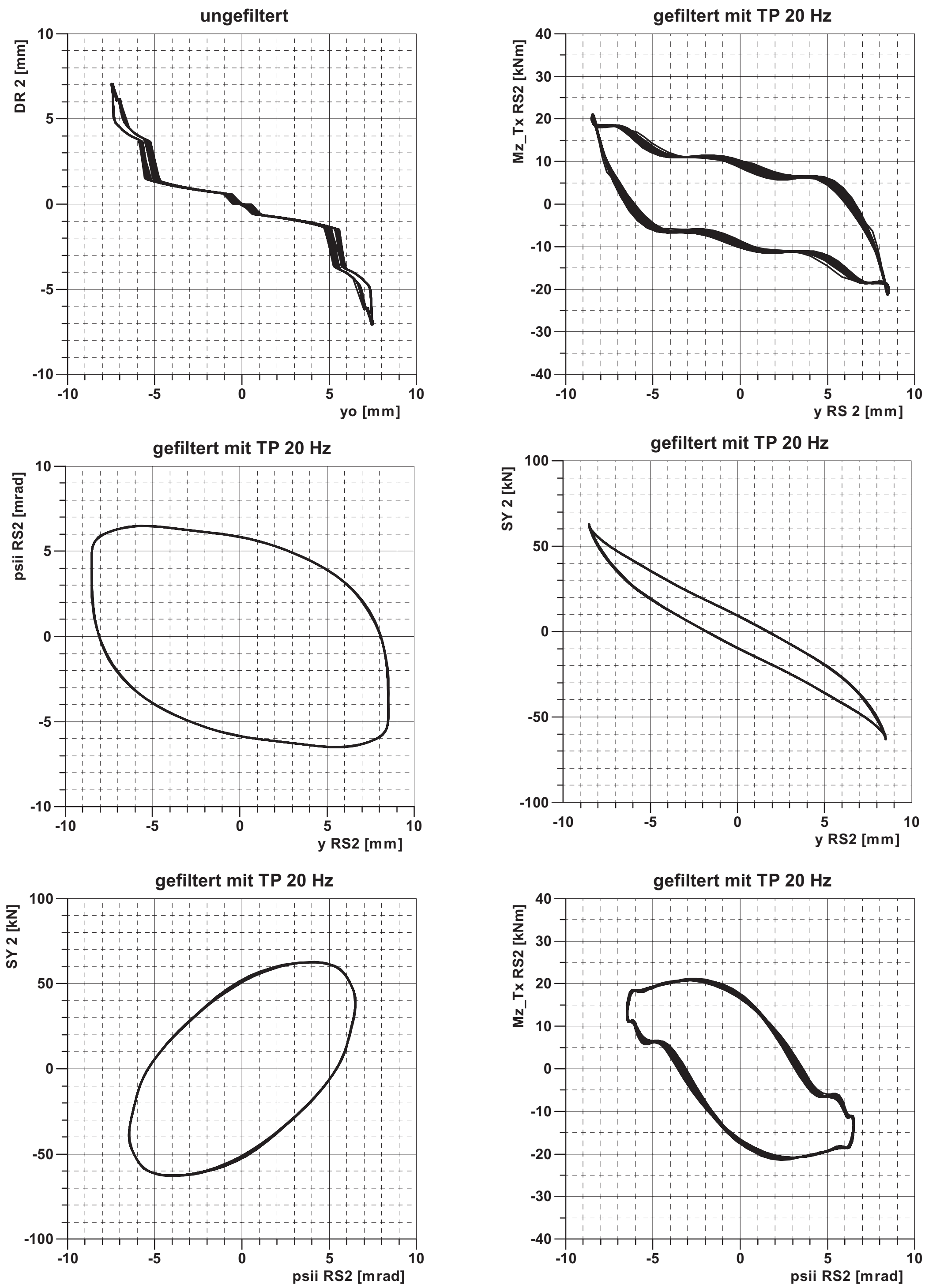


Fig. 6. Functional relations of running quantities of the 2. freight car wheelset
Version: downhill braking

Variant: downhill braking
Braking test bench / Forced dynamic behavior of the wheelset
Functional relations:
Delta r = F(yo) Mz_Tx = F(y) psi = F(y) SY = F(y) SY = F(psi) Mz_Tx = F(psi)
velocity V= 92km/h downhill braking axle loading 18t, wheel profile: DIN5537E1425 (ORES1002)rail profile: UIC60E1 track gauge: 1435 mm

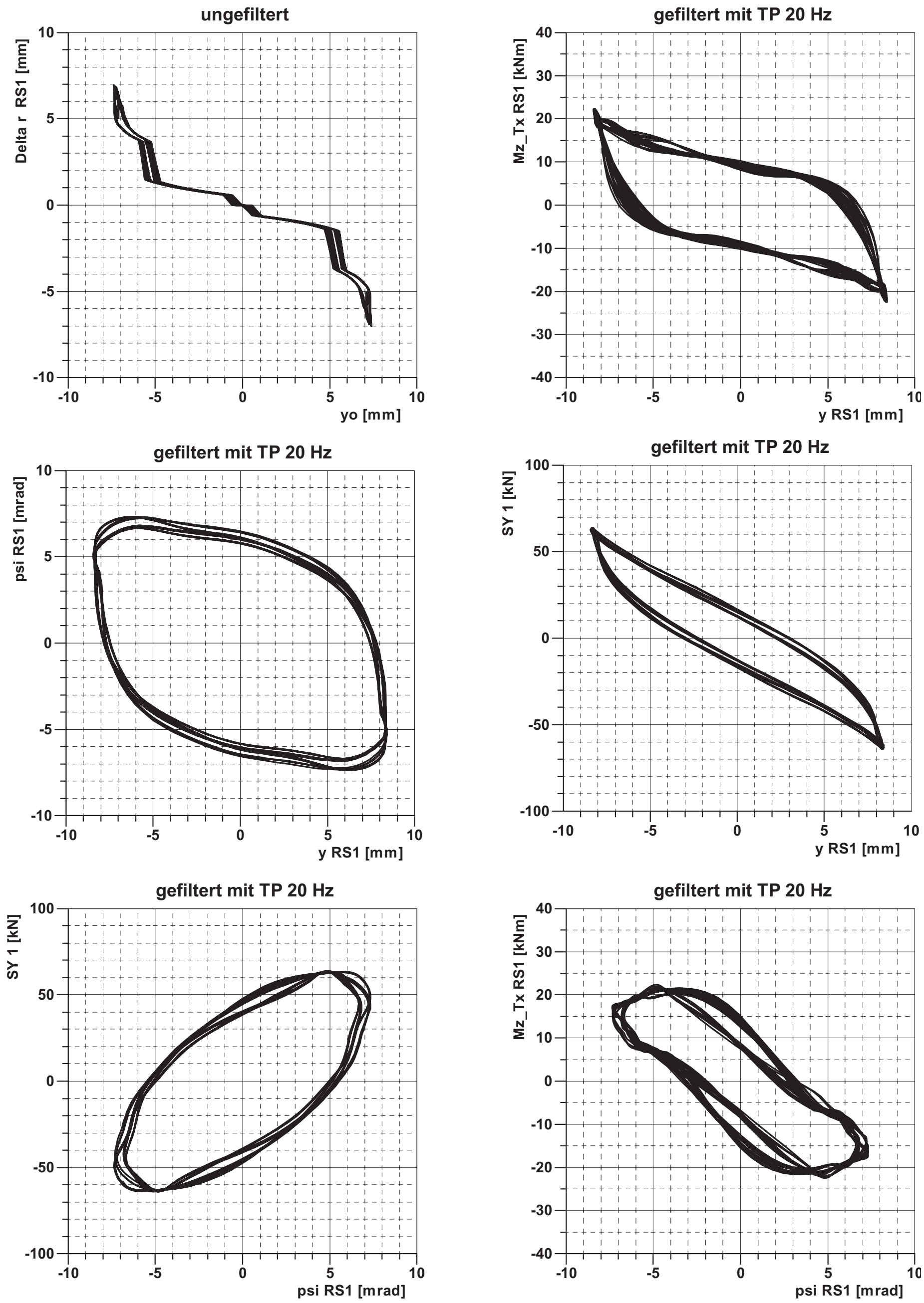


Fig. 7. Functional relations of running quantities of the wheelset on roller rig
Version: downhill braking

5. CONCLUSION

The aim of the project „RAILBCOT – test bench of brake components of rail vehicle“, ITMS code 26220220011 supported by the operational program Science and Research financed by the European Regional Development Fund, is to built the original tester [1], which in laboratory conditions allows the prediction of the wear rate of wheel profiles of railway wheelset in accordance with specified operating conditions on the real track.

Whereas in laboratory conditions can not be guaranteed fully realistic test conditions, we are looking for an analogy of laboratory loading conditions to the operating loading, which caused the same (ideal) or most probable effect on the body of wheelset. Analysis of the interaction of the wheelset and rotating rails on test bench using computer simulation is an important tool for prediction of the consequences under specified laboratory loading, which also allows to manage the structural changes of test bench to achieve the desired results before the test bench is manufactured and actuated. Based on the obtained computationally simulated results should be considered, that when it´s going about simulation of running in a straight line with movement in the border cycle on the braking bench and with excitation of the wheelset with harmonic transversal movement and angle of attack, then it´s necessary to compare results of the braking bench and results of validated measurements of real track ratios very carefully. With a variation of these parameters we will be able to find the optimal affinity with the results of the real dynamic behavior of the wheelset in a straight line.

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Research-Educational Center of Rail Vehicles (VVCKV)

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ANALIZA DYNAMIKI MECHANICZNEGO SYSTEMU Z UŻYCIEM STANOWISKA BADAWCZEGO

Streszczenie: W artykule przedstawiono zagadnienie badania dynamiki układu zestaw kołowy/szyna, metodami symulacji komputerowej, z wykorzystaniem stanowiska specjalnego badawczego. Badania tego typu są istotne mając na uwadze określenie dynamicznych własności układu zestaw kołowy – stanowisko badawcze. W artykule przedstawiono model obliczeniowy oraz dane wejściowe I wyniki końcowe otrzymane z badań.
Słowa kluczowe: stanowisko badawcze, oddziaływanie zestaw kołowy/tor, analiza dynamiki zestawu kołowego