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MULTIBODY SIMULATION OF A SLOW FRONT IMPACT OF THE ŠKODA 14 TR M TROLLEYBUS AGAINST A CONCRETE WALL

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***Summary**: A front impact against a concrete wall at the driving speed of 5 km/h is one of the tests which are used for the verification of properties of public transport vehicles required by their keepers. In practice a slow front impact may occur e.g. during arrival in the bus depot. In that impact a permanent deformation of the vehicle structure should not occur. Simulation of a slow front impact of the ŠKODA 14 Tr M trolleybus was performed with a simple one-purpose multibody model using **alaska** program. Results of the mentioned simulation were used as input data for the COSMOS/M FEM program, which was applied in the calculation of the deformation of the trolleybus structure.*

Key words: computer simulations, multibody model, dynamics, vehicle, front impact

1 Introduction

ŠKODA OSTROV s.r.o. company is the most prominent manufacturer of road vehicles of municipal public transport (i.e. trolleybuses and buses) in the Czech Republic. ŠKODA VÝZKUM s.r.o. (ŠKODA RESEARCH Ltd.) has been participating significantly in developing and improving these means of transport for several decades.

Fig. 1. The ŠKODA 14 Tr M trolleybus

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A front impact against a concrete wall at the driving speed of 5 km/h is one of the tests which are used for the verification of properties of public transport vehicles required by their keepers. In practice a slow front impact may occur e.g. during arrival in the bus depot. In that impact a permanent deformation of the vehicle structure should not occur. The fulfilment of this requirement was verified at the present standard serial design of the ŠKODA 14 Tr M trolleybus.

Computer simulation keeps being of a greater importance for solving concrete problems of the technical practice. Software products intended for investigating kinematic and dynamic properties of systems of bodies are an important instrument for developing and improving properties of vehicles (using multibody simulations is of an irreplaceable importance especially if it is not possible to carry out experimental measurements on a real structure). In ŠKODA VÝZKUM s.r.o. **alaska** (**a**dvanced **la**grangian **s**olver in **k**inetic **a**nalysis) mechatronics software [10] is used for creating multibody models and investigating dynamic behaviour of trolleybuses and buses.

The **alaska** program was developed in *Institut für Mechatronik*, Chemnitz, Germany. In addition to rigid bodies it is also possible to use a special element, so-called "superelement", which approximates a dynamic behaviour of an elastic beam. The program includes the modules, which enable to model a tyre (*Tire Module*) and a wheel-rail contact (*Wheel-Rail Module*). In simulating movement with multibody models in the **alaska** program non-linear equations of motion are made out by means of Lagrange's method. The equations are solved by means of a numerical time integration (results given in this report were obtained using Shampine-Gordon integration algorithm - in [10] reference to [11]).

Simulation of a slow front impact of the ŠKODA 14 Tr M trolleybus was carried out with a simple one-purpose multibody model using the **alaska** program. Results of the mentioned simulation were used as input data for the COSMOS/M FEM program, which was applied in the calculation of the deformation of the trolleybus structure.

2 Multibody models of the ŠKODA trolleybuses and buses

At present multibody models of vehicles included in the basic production program of ŠKODA OSTROV s.r.o. company are created (i.e. the ŠKODA 14 Tr M [1] trolleybus, the ŠKODA 15 Tr articulated trolleybus [1], the ŠKODA 21 Tr low-level deck trolleybus, the ŠKODA 22 Tr low-level deck articulated trolleybus [2] and the ŠKODA 21 Ab low-level deck bus [3]) and that of the ŠKODA 22 Ab low-level deck articulated bus [4] as well.

Generally it is possible to carry out following simulations with multibody models of the ŠKODA trolleybuses and buses:

1. simulations of driving operations (braking, "slalom", overtaking, driving into a curve and acceleration in a curve) - results inform on driving properties of the vehicle (on the basis of the results of the simulation of braking it is possible to evaluate the suitability of the applied braking system; results of simulations of other driving operations can be used e.g. for evaluating the vehicle driving stability),
2. simulation of driving over an artificial obstacle - outputs of time histories of dynamic forces at suspension elements (i.e. air springs and shock absorbers) are input data for the calculation of the bodywork stresses by means of FEM programs; time histories of relative displacements of the air springs and relative velocities at the shock absorbers inform on the suitability of the used suspension elements,

3. simulation of a slow front impact against a concrete wall - outputs are input data for the evaluation of the deformations of the vehicle bodywork using the FEM programs,
4. simulation of driving along an uneven road surface - results can be used in the field of fatigue life assessment of dynamically loaded structures.

Multibody models of the ŠKODA buses and trolleybuses are created and improved step by step according to the requirements of the manufacturer - ŠKODA OSTROV s.r.o. company - on the basis of provided numerical data and structural drawings. That is why some models are only one-purpose and all the mentioned simulations cannot be carried out with them (see Tab.1).

Vehicle Type	**Simulation**			
	Driving operations	Driving over an artificial obstacle	Slow front impact	Driving along an uneven road surface
ŠKODA 14 Tr M trolleybus	No	No	Yes	No
ŠKODA 15 Tr trolleybus	No	No	Yes	No
ŠKODA 21 Tr trolleybus	No	Yes	No	No
ŠKODA 22 Tr trolleybus	Yes	Yes	Yes	Yes
ŠKODA 21 Ab bus	Yes	Yes, verified with an experiment	Yes	Yes, verified with an experiment
ŠKODA 22 Ab bus	Yes	Yes	Yes	Yes

Tab. 1. Survey of multibody models of the ŠKODA vehicles and possible simulations

As stated in Tab. 1, results of some simulations were verified with those of the experimental measurement, on the basis of which virtual multibody models were specified more precisely.

In the nearest future an all-purpose model of the ŠKODA 21 Tr low-level deck trolleybus is supposed to be created and verification of its behaviour during simulations of driving over an artificial obstacle and driving along an uneven road surface with the planned experiment is supposed to be done.

3 One-purpose multibody model of the ŠKODA 14 Tr M trolleybus

Due to the limited amount of input data it was not possible to create a detailed all-purpose multibody model of the ŠKODA 14 Tr M trolleybus. The front impact against a concrete wall at driving speed of 5 km/h was simulated with a simple one-purpose multibody model suitable only for the simulation of this state of operation. A simple multibody model of the ŠKODA 14 Tr M trolleybus (see Fig. 2) is formed by 8 rigid bodies (corresponding with bodywork, wheels and bumper), which are mutually coupled with 8 kinematic joints with 13 degrees of freedom. Air springs, shock absorbers and silentblocks are not considered in the multibody model. This one-purpose multibody model was used for the simulation on the basis of comparison of verifying simulations of the slow front impact against a concrete wall with the all-purpose detailed [9] and the simplified one-purpose multibody model of the ŠKODA 21 Ab bus [1].

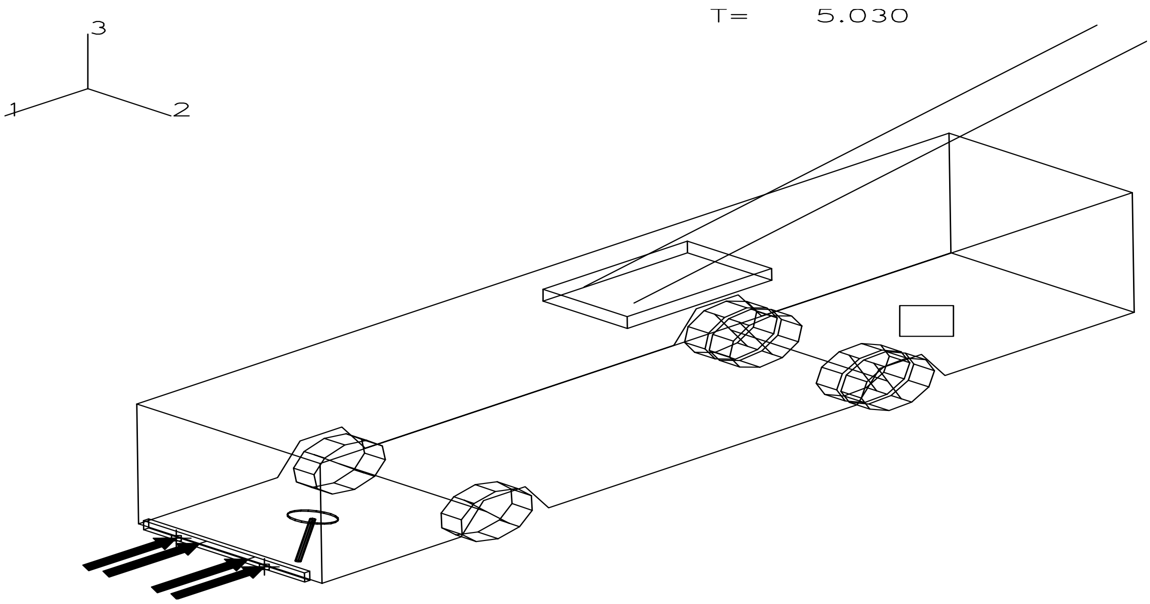

Fig. 2. One-purpose multibody model of the ŠKODA 14 Tr M trolleybus at impact simulation

4 Verifying simulations of a slow front impact

A detailed multibody model of the ŠKODA 21 Ab bus is formed by 24 rigid bodies, which are mutually coupled with 31 kinematic joints with 93 degrees of freedom. The simplified model was created applying the same approach as the simple one-purpose multibody model of the ŠKODA 14 Tr M trolleybus. It is composed of 7 rigid bodies corresponding with bodywork and wheels mutually coupled with 7 kinematic joints with 12 degrees of freedom. Air springs, shock absorbers and silentblocks are not considered.

Simulation of the slow front impact was carried out in the same way as in [9], i.e. by placing one spring element (*sdforce* function of the **alaska** program) between the front wall of the bodywork and the base (concrete wall), whose characteristic is the experimentally measured loading characteristic of the **whole** bumper from the ROMEO RIM American producer [8]. Results of the impact simulation with the simplified multibody model [1] were compared with those of the simulation with the detailed multibody model [5].

EXTREME VALUES	Detailed model	Simplified model
Total force transferred to the front wall of the bodywork [N]	-262358	-253977 (deflection by 3.19 %)
Deformation of the bumper [m]	-0.095	-0.0942 (deflection by 0.32 %)
Acceleration at the front wall of the bodywork (in driving direction) [m/s^2]	-26.77	-24.89 (deflection by 7.02 %)
Acceleration on the floor above the front axle (in driving direction) [m/s^2]	-26.97	-24.82 (deflection by 7.97 %)

Tab. 2. Extreme values of the monitored quantities

Extreme values read from time histories of the monitored quantities during the impact simulation with the simplified multibody model differ within permitted limits in percentage from the extreme values during the simulation with the detailed multibody model (most in the acceleration on the floor above the front axle of the ŠKODA 21 Ab bus - by 7.97 %) - see Tab. 2. Time histories of the monitored quantities are of the same character till the moment of the finishing of unloading the spring element, which models the elastic properties of the bumper. After this time more significant local extremes appear in the time histories of acceleration during the simulation with the simplified multibody model. This phenomenon is the result of the higher stiffness of the simplified multibody model.

Verifying calculations confirmed keeping the satisfactory precision of the results during the simulation of the slow front impact with the simplified multibody model of the ŠKODA 21 Ab bus. Thus it can be supposed that the same conclusion is true for the simple model of the ŠKODA 14 Tr M trolleybus.

5 A bumper model

In the multibody model of the ŠKODA 14 Tr M trolleybus a bumper produced in ŠKODA OSTROV s.r.o. company and used normally in this type of a trolleybus is considered. The bumper consists of a steel part and two identical rubber elements. The steel part is firmly fixed to the bodywork frame and both rubber elements are symmetrically attached to it. During the front impact the rubber elements are the first to come in contact with the concrete wall.

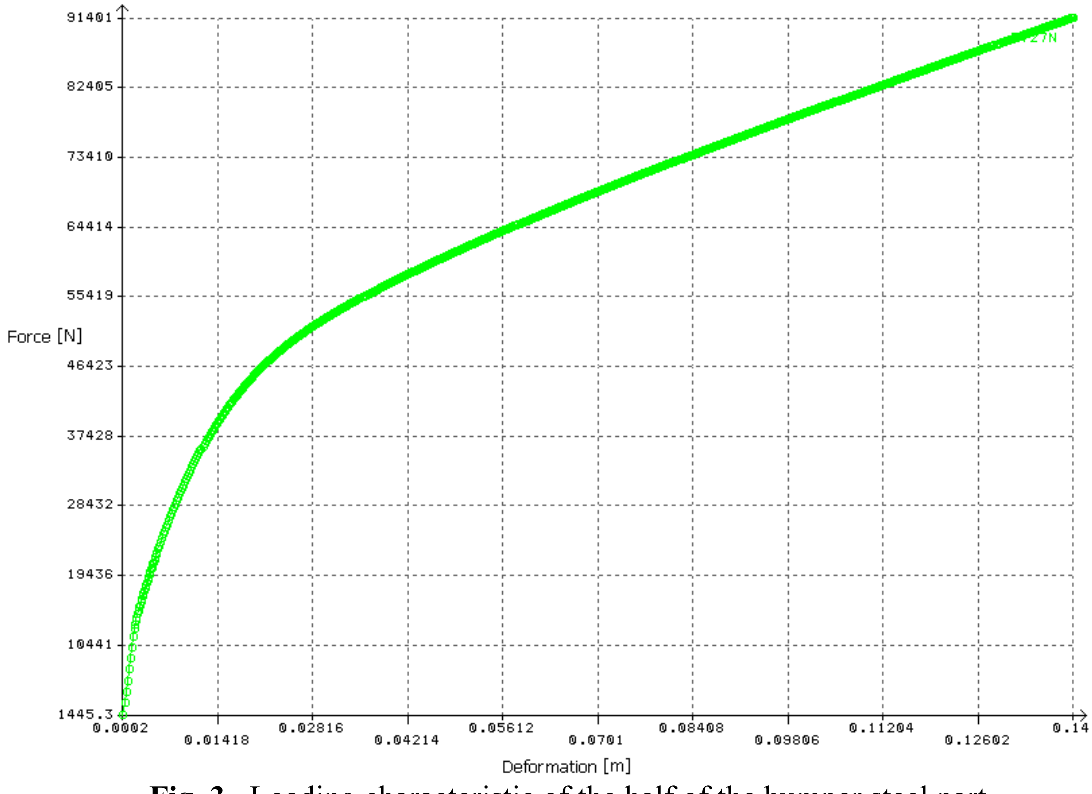

Fig. 3. Loading characteristic of the half of the bumper steel part

Static loading characteristic of the half of the bumper steel part was calculated using the FEM COSMOS/M program during the acting of a loading force in the place of the rubber element fixing, namely for the cases of both central front impact (considering symmetric conditions – see Fig. 3) and an impact to only one rubber element [7]. Characteristic of the half of the bumper steel part for the case of the central front impact applied in the **alaska** program is in Fig. 4.

Static loading characteristics of two rubber elements were experimentally measured in the Accredited Dynamic Testing Laboratory of ŠKODA VÝZKUM s.r.o. on the SCHENCK 400 kN hydraulic loading device [6]. Measured loading characteristics are shown in Fig. 5.

Due to the fact that the loading characteristic of the whole bumper, which is used in the ŠKODA 14 Tr M trolleybus, is not known, but separately that of its steel part and separately that of its rubber elements, it was possible to use the well-tried type of the bumper model from [9] only partly.

Following model proved to be suitable for the simulation of the slow central front impact of the ŠKODA 14 Tr M trolleybus against a concrete wall: the bumper is considered to be a rigid body, elastic properties of two rubber elements are represented by placing two spring elements (*sdforce*) between the bumper and the base (concrete wall) and elastic properties of the bumper steel part by placing two spring elements between the front wall of the bodywork and the bumper.

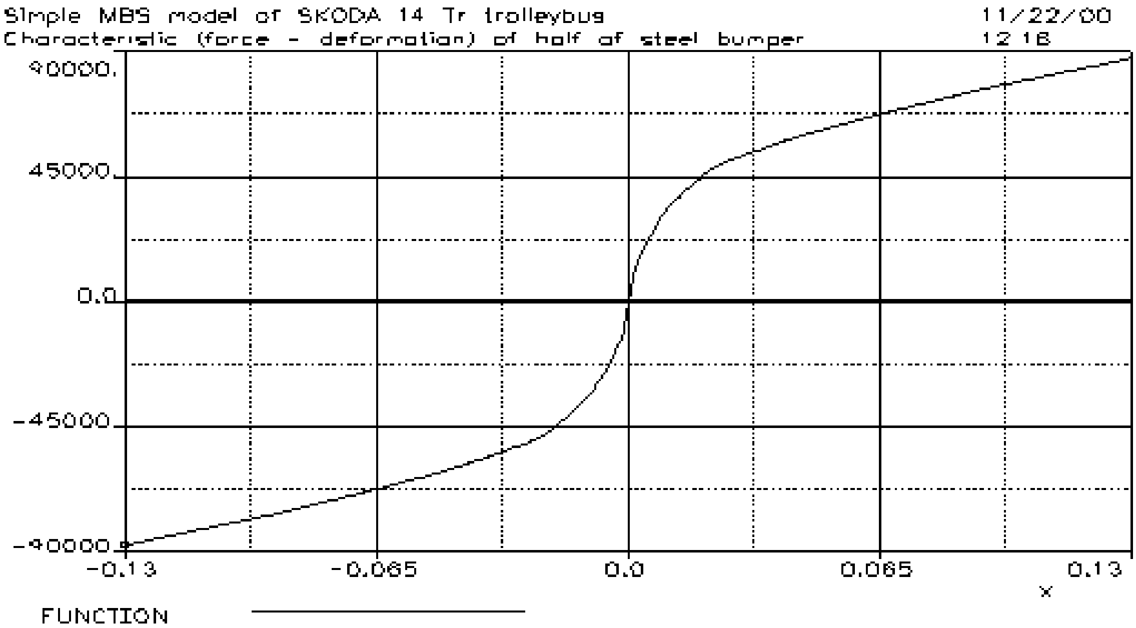

Fig. 4. Characteristic of the spring element modelling one half of the bumper steel part

The bumper and the bodywork are coupled with the prismatic kinematic joint (with the degree of freedom in the direction of the multibody model driving, i.e. in direction of axis "**1**" – see Fig. 2). Characteristic of the spring elements in the place of the bumper fixing to the front wall of the bodywork is in Fig. 4.

Loading characteristics shown in Fig. 5 are the characteristics of two spring elements between the bumper and the base (concrete wall) which model the elastic properties of the bumper rubber parts (for the deformations of the bumper rubber parts larger than 0.024 m courses of the characteristics are considered to be linear). These spring elements start to be active 5 seconds after the beginning of the simulation of the trolleybus multibody model driving. This time is sufficient for the fading out of dynamic processes during the multibody model transition from the initial position (it is not identical with the equilibrium position, it is given by the initial "setting" of kinematic joints in multibody models) into the steady state before the beginning of the impact simulation itself.

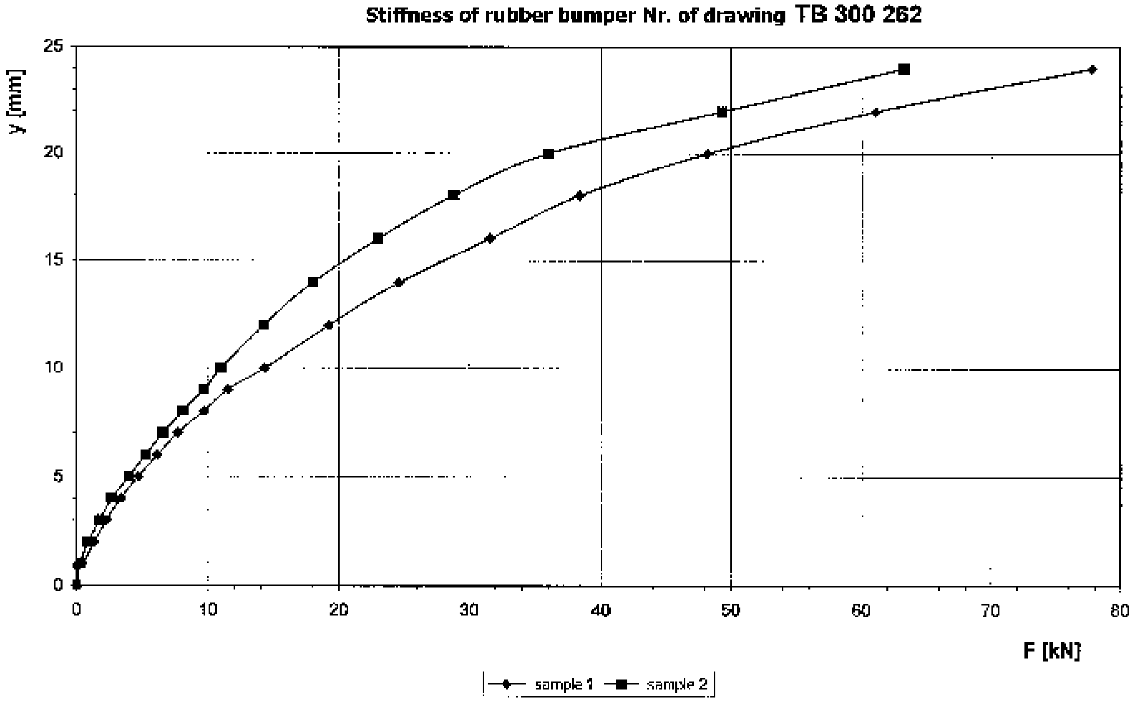

Fig. 5. Measured loading characteristics of the bumper rubber elements

6 Simulation of a slow front impact of the ŠKODA 14 Tr M trolleybus

The impact simulation occurs on assumption that the unloading of the spring elements modelling the bumper elastic properties runs according to the same curves as their loading.

Extreme values read from the time histories of the monitored quantities are given in Tab. 3. Due to simulating the central front impact extreme values of the time histories of the monitored quantities are given only for the right side of the bumper (they are the same for the bumper left side).

EXTREME VALUES	For the bumper rubber element designated as:	
	Sample I	Sample II
Force transferred to the front wall of the bodywork with the bumper right support [N]	-74 488	-74 549
Total force transferred to the front wall of the bodywork [N]	-148 977	-149 098
Force acting between a concrete wall and the bumper right rubber element [N]	-77 575	-75 412
Total force between a concrete wall and the bumper [N]	-155 151	-150 824
Deformation of the bumper right steel part [m]	-0.0856	-0.0858
Deformation of the bumper right rubber element [m]	-0.024	-0.0257
Total deformation of the bumper [m]	-0.1091	-0.1112
Acceleration at the front wall of the bodywork (in drive direction) [m/s^2]	-14.56	-14.54
Acceleration on the floor above the front axle (in drive direction) [m/s^2]	-14.68	-14.65

Tab. 3. Extreme values of the monitored quantities

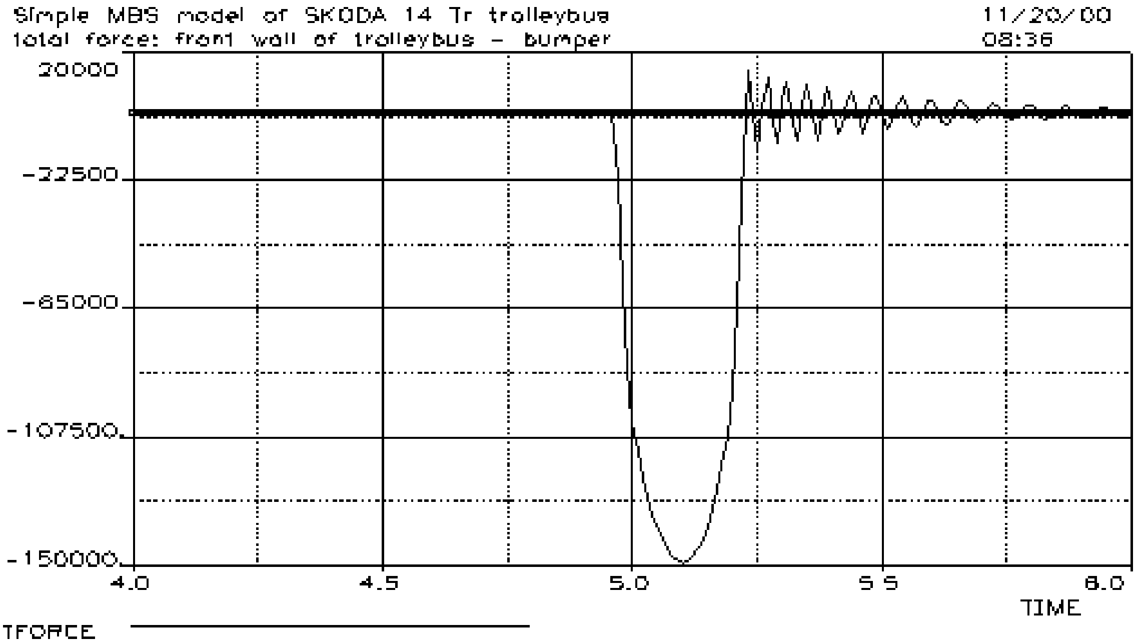

Fig. 6. Total force transferred to the front wall of the bodywork [N] - Sample I

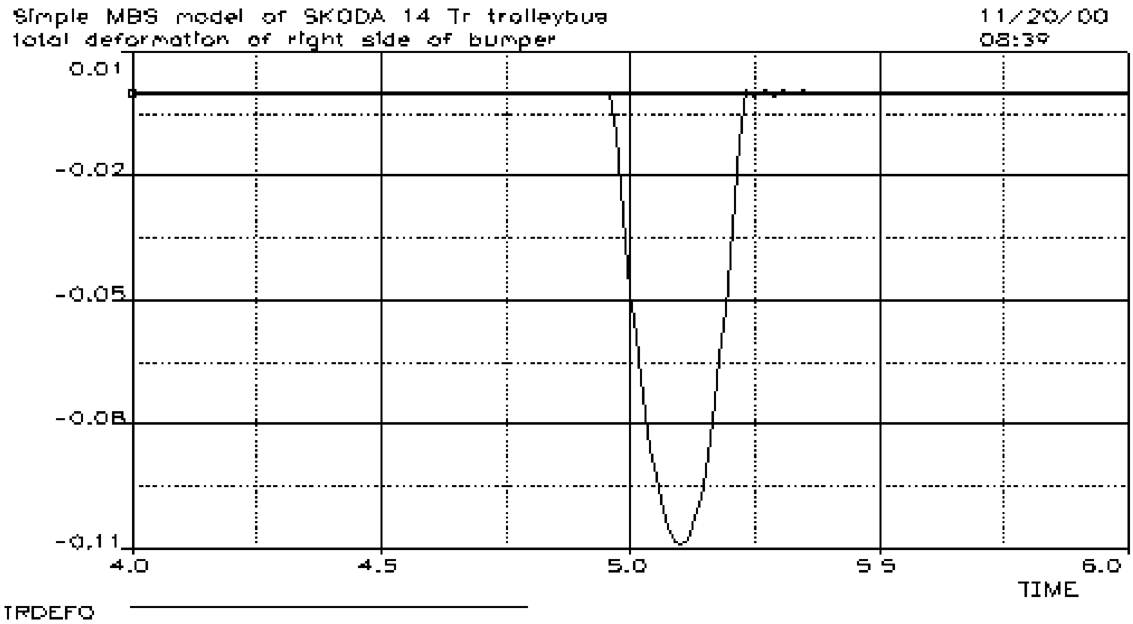

Fig. 7. Total deformation of the bumper [m] – Sample I

It is necessary to point out possible causes of results inaccuracy:

1. loading characteristic of the bumper steel part (Fig. 3) does not bring the possibility of increasing in the bumper stiffness by "fitting on" to the front wall of the bodywork (in the impact the deformation of the steel part of the bumper almost 0.09 m was calculated),
2. characteristics of the spring elements (*sdforce*) applied for the model of elastic properties of the bumper were determined during static loading, not at speed of 5 km/h,

3. during the impact simulation deformations of the bumper rubber elements larger than 0.024 m were calculated, i.e. larger deformations than those, for which the loading characteristic of rubber element designated as Sample II were measured (during the simulation linear course of characteristics was considered for this field of deformations),
4. the unloading of the spring elements (*sdforce*), which model the bumper, was running according to the same curves as their loading (if this condition were not valid, the obtained time histories of the monitored quantities would not correspond from the moment of declining from the extreme achieved value with the reality - Figs. 6, 7 and 8).

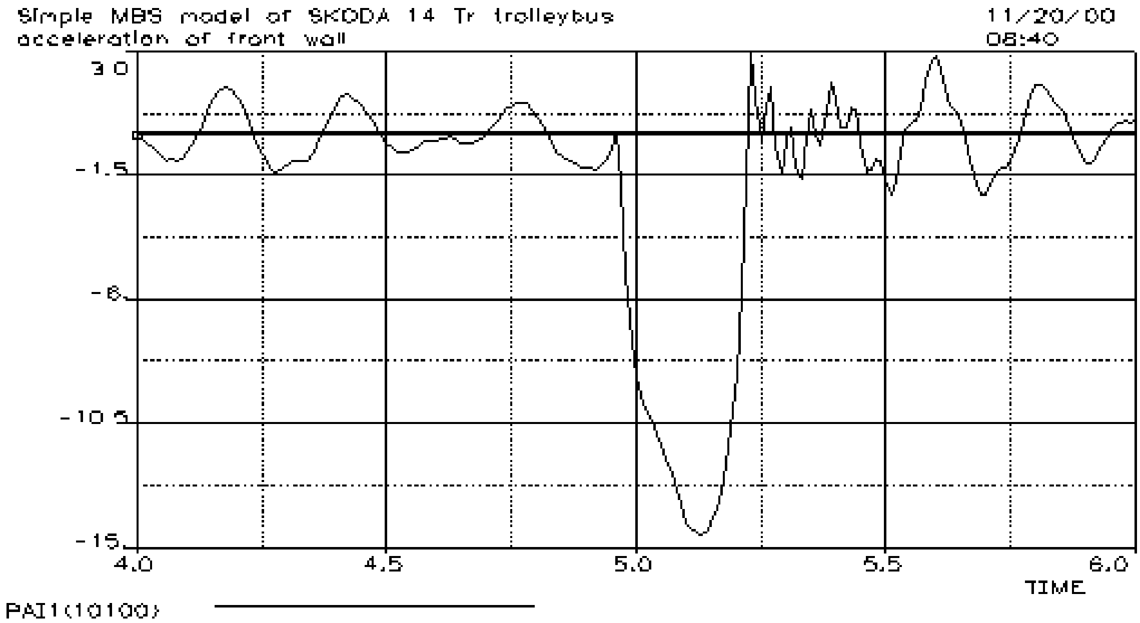

Fig. 8. Acceleration at the front wall of the bodywork [m/s^2] – Sample I

Since the applied loading characteristic of the bumper steel part (Fig. 3) does not bring the possibility of increasing in the bumper stiffness by "fitting on" to the front wall of the bodywork, it would be suitable to assess the real loading characteristic of the bumper and time histories of the monitored quantities experimentally during the slow front impact of the real vehicle. Results of the experiment would serve for the verification of existing results assessed by calculations and they would be a useful basis for the designs of optimum vehicle bumpers using computer simulations.

The present simple multibody model of the ŠKODA 14 Tr M trolleybus suitable only for the simulation of the central front impact could be adapted for the simulation of a non-central front impact as well.

7 Conclusion

Computer programs used for investigating kinematic and dynamic properties of the systems of bodies become more and more frequent in solving concrete problems of technical practice. But it is necessary to realize that results of simulations describe behaviour only of a created virtual mechatronic model and not of a real system. That is why it is necessary to take this fact into account if we evaluate the results of simulations. If a real prototype exists as well, it is suitable to verify the multibody model with the results of measurements. Utilization of multibody simulations is of a great importance especially from the point of view of saving costs for the realization of experiments on a real system and during the investigation and improvements of kinematic, dynamic and mechatronic properties of a structure even in the stage of a structural design.

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