



MATLAB/SIMULINK PACKAGE AS A ENVIRONMENT FOR RAIL VEHICLE SIMULATION STUDY

A. Chudzikiewicz

Keywords: simulation package, Matlab/Simulink, rail vehicle

1. Introduction

During the last decade, a number of simulation devices have been created, e.g. from analogue computers, hybrid computers as well as a special simulation software for a digital computer. From simulation languages such as CSMP or ACSL through simulation environments for example MATLAB - type, like SIMULINK, to the MBS programs the multitude of the simulation software is surprising. Taking into account our interest it should be remarked that a number of MBS programs originally had the intent to set up general multibody system equations (without special regard to requirements for specific vehicle-rail vehicle). Only few, from the number of MBS - codes, can be used in the process of rail vehicle simulation dynamics analysis.

Some of them are [Grubel 1992]: MEDYNA, NUCARS, VOCO, VAMIRE, SIDIVE, A'GEM, AUTODYNROBOTRON and SIMPACK. But it should be pointed out that each of the codes has its own, specific assumptions and that the range of the applications is limited. In Poland, the research on a computer package for rail vehicle dynamics analysis have been started in the middle of 70's. The first study in the problem was done by Osmólski [Osmólski 1978] who published the conception and realisation of a package for digital simulation of dynamic systems.

The work was devoted to the problem of applying simulative investigations to research on rail vehicles but it was too poor and incomplete. A general concept of the full investigation in the track rail vehicle was presented by Kisilowski [Kisilowski 1978].

Basing on the works, Chudzikiewicz [Chudzikiewicz 1987] published the concept, algorithm and description of the RVSD software package for simulation research of the track-rail vehicle behaviour. The continuation of the works is the package WAGON [Chudzikiewicz at all 1995], a simulation's tool which was prepared in MATLAB environments.

The paper describes the general conception of the track-rail vehicle research, which was the base of the RVSD and WAGON simulation's tool.

2. The conception of simulation package

The problem of investigation of dynamic phenomenon which occurs in the rail vehicle is thematically extensive. The study of the rail vehicle without taking into account the subsystem, contact area, track and its structure, power system which are connected with the vehicle, are incomplete and can not give us full information about the subject of the matter. The algorithm of the investigation dynamics of the track-rail vehicle system was presented in 1987. It should be remarked that it include almost all problems which should be investigated in the track- rail vehicle system. It was the base for future works on the software simulation package for railway vehicles.

The RVSD computer program was closely related to this algorithm. The hardware realisation of the

software tool RVSD was on the computer ODRA 1300 series and in this connection the pre- and postprocessing were too simple and poor. And it should be stressed that the modes of analysis the tool and computational methods which were engaged in the computing process, were broad (kinematics analysis, dynamic analysis, linear system analysis) and sophisticated (e.g. Gear method's, QR - algorithm). A sudden development of the computer technology (hardware and software) in the 80's created new possibilities for researchers working on computer simulation tools, in particular on pre- and postprocessing solutions.

A simulation model, in case of railway vehicles, should have include: vehicle model, wheel-rail interaction contact model and track model. All three models and their simplifications play important role in the investigation process. The analysis of a mechanical system, rail vehicle in particular, can be performed in various ways. The most popular is time-integration of the equation of motion, so called dynamic analysis.

Besides, the vehicle analyses are frequently, especially in the last time, concerned with other methods of analysis, such as: quasistatic, modal, inverse and assembly. The majority of MBS-codes which can be used in rail vehicle investigations area have only two or three the possibilities. It was assumed that the package will realise: dynamic, modal, and kinematics analysis. Also the problem of formalism for establishing the equation of motion has started to be important. There are two categories: a numeric and a symbolic one. Almost all multibody computer codes, which have rail vehicle-oriented pre-processors, are working under numeric formalism. The reason is that in the 80's, when the software was formed, there were not any good simulation environments, e.g. MATLAB-SIMULINK type, for using symbolic formalism. Now, the situation is changing.

2.1 Assumptions and package's task

WAGON is a software package which enables the simulation and analysis of railway vehicles type passenger car with MD bogies structural data. The algorithm of the package is shown on Fig.1. The package consists of three parts, an interactive pre-processor, the analysis programs and an interactive postprocessor. Each part of the package is menu driven allowing the use of programs without detailed knowledge of the computer system being used. Considerable emphasis has been placed on simplification of input and output systems, to provide a user-friendly package. It would be obtained because of engaged MATLAB environments. MATLAB is a highly interactive general matrix analysis package, which provides a rich set of matrix manipulation and computation facilities based on reliable numerical linear algebra routines. It also provides good graphics and organising capabilities. It was used in the process of organising the package. The equations of motion are formulated in terms of Cartesian co-ordinates and we used here numeric formalism.

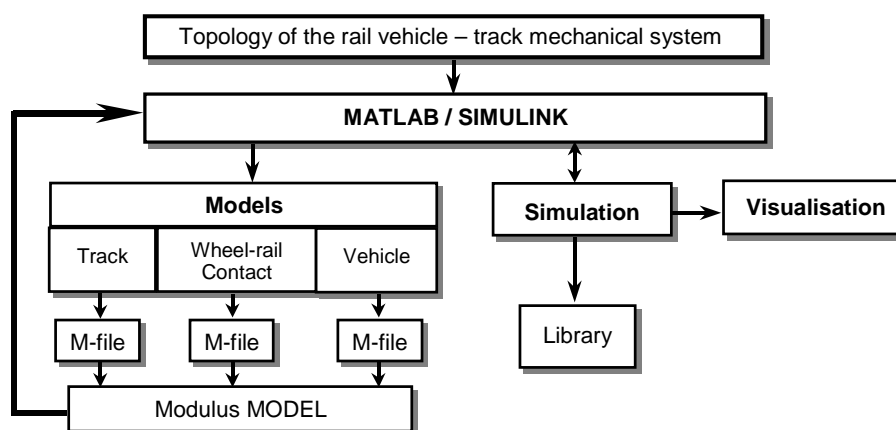


Figure 1. Algorithm of the package

A vehicle in turn is made of a series of rigid bodies. Formally each of these has 6 degrees of freedom, but some of the motions are neglect because at physical constrains.

The wheel-rail interactions are modelled by a full non-linear model allowing for a wheel and rail geometry and a creep force - creepage a relationship based on on-line calculations by the non-linear

programs with FASTSIM routine [Kalker 1990]. The track is modelled as rigid but with four types geometrical irregularities. They are kinematics excitations.

The possibility of using the WAGON package only for research a passenger car with MD bogies is a limitation but the attention was paid on the pre- and postprocessing.

Several pre-processing programs are included in the package. These can be used for model simulation input and checking, and for plotting of track (wheel-rail profiles, geometrical irregularities) and general forcing inputs. The software is supplied with input libraries containing measured wheel-rail and track inputs. Figure 2 shows the main functional options in the user's menu. Each of them include suboptions.

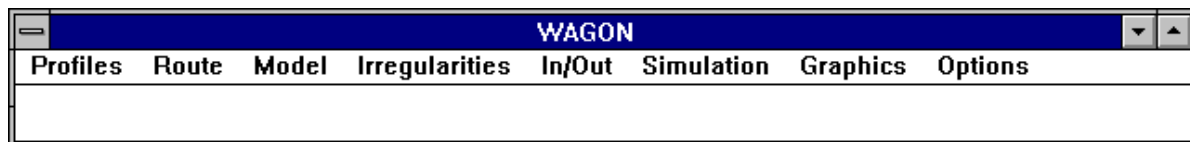


Figure 2. View of the user menu

The user's menu contain: *Profiles*: wheel (left, right; standard or measured), rail (left, right; standard or measured), *Route*: straight track, curved track, special sections or their combinations, *Model*: single wheelset, single truck, vehicle, *Irregularities (defined or from experiments)*: cant, level, gauge, alignment *Input/Output*: files data inputs, files data outputs, *Simulation*: method of integration (Gear, Adams, Runge-Kutta), boundary conditions, boundary conditions, *Graphics*: variation of results with vehicle speed in time and frequency domain, wheel-rail parameters.

The package was used in process of investigation dynamical behaviour of the tram CITADIS 116.

3. Description of the model and example of results

The discrete model was built to create a mathematical model which could be used in computer simulations in order to obtain basic information concerning dynamic behaviour of the train under investigation in the motion induced by excitations of low frequencies, below 50 Hz. During the analysis of the tram moving along the track, which is a complex dynamic system, three connected subsystems were distinguished. During the modelling process these were presented as: a track model, a contact model, a vehicle model.

For the purpose of modelling, a model of a rigid track was assumed, whose mathematical description is based on its geometrical shape [Drozdziel 1995]. The geometry of the track consists of nominal geometry which results from designing assumptions (a straight track, curves and junctions) and geometrical irregularities of a track which are a consequence of deviations from nominal dimensions which result from construction and operation processes. If we assume a perfect shape of a track as far as its nominal parameters are concerned, geometrical irregularities, obtained through geometrical measurements of the track, are the basic group of kinematic disturbances acting on wheel sets of a tram during its move on the real track. In practice, geometrical irregularities of a track are described by four parameters: vertical irregularity of the centre line of the track - z_t , lateral irregularity of the centre line of the track - y_b , local inclination - θ_t (or h_t), variable width of the track - s_t . In equations for a rail vehicle motion it is convenient to describe the co-operation between wheel sets and an irregular track (especially, if we take into account changeable width of the track) by the introduction of irregularities in the form of: vertical irregularities of the centre line of the track - z_t , local inclination - θ_t (or h_t); lateral irregularities of the right and left rail treads - y_l and y_r .

It is easy to notice the equivalence between the first and the second group of parameters. The function of the changeable width of the track s_t was obtained from the measurements of the tram track in Warsaw [Uhl 2001] (Bemowo track is presented in Fig. 3). The contact model refers to two basic issues, namely geometrical determination of contact functions and calculating wheel - rail contact forces, using as input data geometrically calculated contact functions.

The distribution of contact tangential stresses at the point where wheels contact the track and of contact forces was determined by a contact model based on non-linear, simplified Kalker theory and its numerical implementation: the FASTSIM procedure.

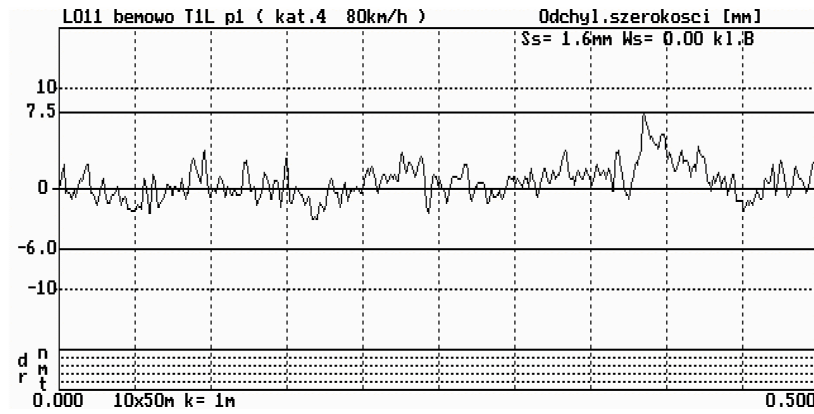


Figure 3. Fluctuation of tram track width measured in Warsaw

A nominal model of a tram obtained as a result of the analysis of its structure is a mechanical system consisting of rigid solids [Uhl 2000]. Those are 6 wheel sets and 3 bogies (2 motor bogies, 1 middle trailer bogie) and 3 tram bodies. The motor bogies are equipped with equaliser beams. Wheel sets are connected to the bogie frame by primary suspension, whereas, bogie frames are connected to the body by king-pins. There are secondary suspension between bogie frame and bolster. Single elements of the tram body are connected by rigid couplings which are placed in the basic floor plane and additional over-roof plane. The coupling between segments C1 and C2 is a cylindrical coupling allowing for $\pm 16, 5^\circ$ reciprocal lateral deflection of these fragments of the body, on the other hand, the coupling between segments C2 and C3 is a ball coupling allowing for reciprocal vertical deflection of these fragments of the body. The overall structure of the nominal model of the tram is presented in Fig. 4.

The equation describing the vibration of the dynamic model of the tram was derived from the Lagrange equations of the type II:

$$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = Q_i$$

where $i = 1, \dots, n$, $q = [q_1, \dots, q_n]$ - the vector of generalised co-ordinates,
 $Q = [Q_1, \dots, Q_n]$ - the vector of generalised forces, L - Lagrange function.

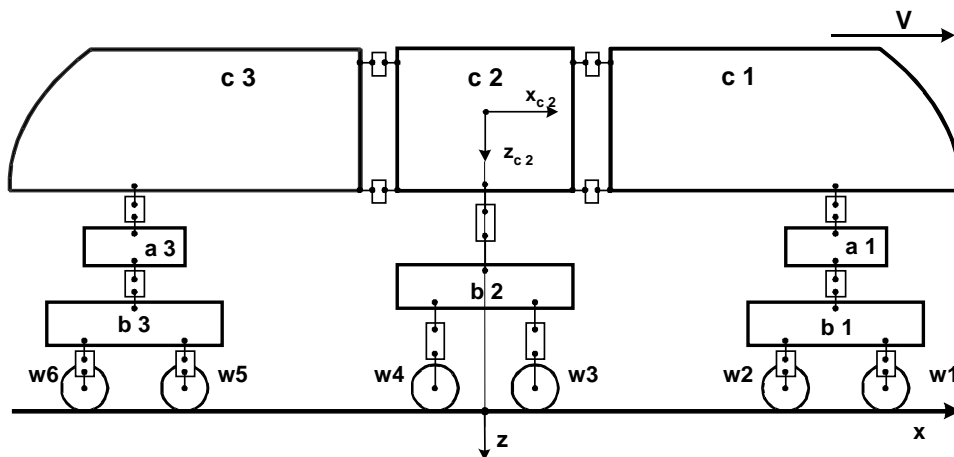


Figure 4. Nominal model of tram (CITADIS 116)

The tram model developed was combined with the track and contact models, thus, creating the model of the tram-track system. Then, MATLAB-Simulink environment was used to create the software package. It was used to carry out simulation examination of the dynamics behaviour of CITADIS 116 tram in operating conditions, with real geometrical irregularities of the track taken into account. The software package algorithm is presented in Fig. 1. It was used to carry out simulation examination of the dynamics behaviour of CITADIS 116 tram in operating conditions, with real geometrical irregularities of the track taken into account.

Speed and force variations at the selected points of the nominal model of the tram were determined on the basis of simulation analyses. The changes in the position of the wheel set mass centre at the tram speed $V = 20$ m/s and kinematic disturbances induced by geometrical irregularities of the track were obtained from the measurement of the track in Warsaw presented in Fig. 5.

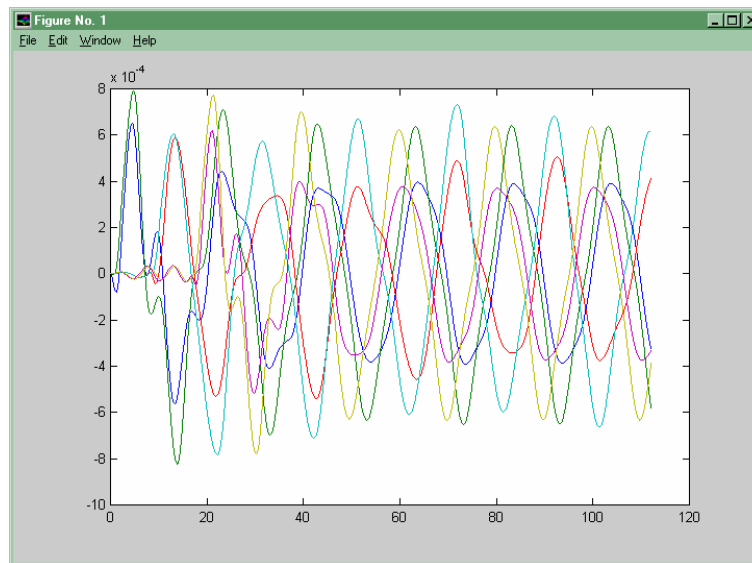


Figure 5. Displacement of wheelset (wheelsets W1, W2, W3, W4) center during driving on real track in [m] as a function of distance in [m]

Reaction (dynamic and static) forces have been computed for all structure elements, given track conditions, and given vehicle speed using WAGON software. For considered tram structure 213 different reaction forces have been taken into account.

Based on obtained discrete model simulation results, in the form of time history of operation forces in chosen structure elements, the stress distribution has been calculated. The tram bolster has been considered. The bolster geometry and finite element mesh is presented on fig. 6, and example a spatial distribution of external and reaction forces is presented.

Eleven significant forces and torques loaded tram bolster has been located. The computation was done with time interval 0.001 sec for 10 sec of tram driving on a good track with speed 14 m/s.

4. Conclusions

The WAGON package has been used to solve real railway problems which occur during exploitation of a city tram the CITADIS 116. The procedure applied in this research work makes it possible to design and modify rail vehicle structures taking into account numerous quality criteria. What is important, the procedure allows to optimise dynamic properties of a vehicle, such as its dynamic features, stability of a ride, concentration of the vibration energy in elements of the structure, its fatigue life and acoustic radiation. The application of models which were verified experimentally should shorten time necessary to modify an existing structure, at the same time enabled the analysis of various structural options.

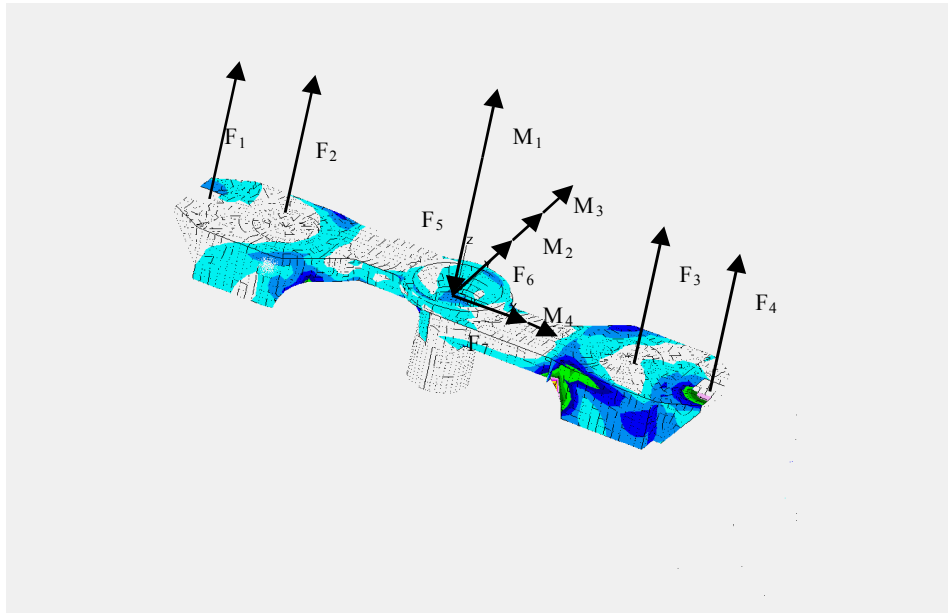


Figure 6. Spatial force distribution scheme for the tram bolster

References

- Chudzikiewicz, A., "System badania zjawisk dynamicznych w układzie mechanicznym tor-pojazd szynowy", Wyd. Politechniki Warszawskiej, Warszawa, 1988.
- Chudzikiewicz, A., Drożdźiel, J., Sowiński, B., "Wykorzystanie MATLAB-a do symulacji dynamiki pojazdu szynowego", II Warsztaty Naukowe Symulacja w Badaniach i Rozwoju, PTSK IPPT PAN, Warszawa, 1995.
- Chudzikiewicz, A., Drożdźiel J., Sowiński, B., "Dynamic interaction between railway car and track during the steady state motion. Measurements and simulations", X International Conference Problems In Mechanics of Railway Transport, Dnepropetrovsk, Ukraina, 2000, pp 211-212
- Drożdźiel J., Sowiński B., "The Effect of Harmonic Track Alignment and Rail Wear Ratio on the Railway Vehicle Dynamics", Machine Dynamics Problems, 11, Warsaw, 1995.
- Grubel G., Kortum, W., "Towards a Coherent Technology for Computational Vehicle System Dynamics", Proceedings of AVEC'92, International Symposium on Advanced Vehicle Control, Yokohama, Japan 1992.
- Kalker J.J., "Three-Dimensional Elastic Bodies in Rolling Contact", Kluwer Academic Publishers, Dordrecht, 1990.
- Kisilowski J., "Dynamika układu tor-pojazd", Wyd. Pol. Warszawskiej, Warszawa, 1978
- Osmólski W., "Symulacja cyfrowa układów dynamicznych pojazdów szynowych", Wyd. Politechniki Poznańskiej, Poznań 1974.
- Uhl, T., Chudzikiewicz, A., "Analytical and Experimental Investigation of Low Floor Tram Dynamics", 17th IAVSD Symposium Lyngby, Denmark, 2001.
- Uhl, T., Chudzikiewicz, A., "Noise, vibration and durability problems in rail vehicle design", Proceedings of ISMA25, Vol. II, 2000, Katholieke Universiteit Leuven, pp 771-776.

Andrzej Chudzikiewicz, Professor
 Warsaw University of Technology, Faculty of Transport
 00-662 Warsaw, Koszykowa str. 75, Poland
 Tel/Fax: +48-22- 6215687
 Email: ach@it.pw.edu.pl