IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Study of the dynamic behavior of rolling stock using a computer experiment

To cite this article: A Kuzyshyn *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **985** 012002

Study of the dynamic behavior of rolling stock using a computer experiment

A Kuzyshyn[1,2,4], A Batig[2], S Kostritsa[3], J Sobolevska[1], S Dovhaniuk[3] and V Dzhus[1]

[1]Lviv branch of Dnipro National University of Railway Transport named after Academician V. Lazaryan, 79052 Lviv, Ukraine
[2]Lviv Research Institute of Forensic Expertise, 79000 Lviv, Ukraine
[3]Dnipro National University of Railway Transport named after Academician V. Lazaryan, 49000 Dnieper, Ukraine

[4]kuzyshyn1993@gmail.com

Abstract. The authors of the article analyzed existing software systems that are used to study the dynamic behavior of rolling stock, and also emphasized the importance of using a computer experiment to implement this task. An improved spatial mathematical model of the dynamic behavior of a freight wagon when it interacts with a rail track is considered, and it is proposed to study it using an object-oriented approach using the Maple software package. To accomplish this task by writing procedures, separate modules (subprograms) were created that included differential equations of motion for the individual components of the object under study. Based on existing procedures, the main module was created, which reflected the sequence of performing certain functions (calling up the necessary information, especially the use of logic, methods for solving the problem, as well as visualizing the results). Using the created modules in the Maple software package, a computer experiment was used to study the dynamic behavior of a freight car when it interacted with a rail, and also showed the possibility of taking into account the influence of individual parameters of its technical condition on its dynamic behavior.

1. Introduction

The railway is an area of high danger, so the transportation of passengers and goods, the safety of traffic during the rolling stock operation are under special consideration.

One of the criteria of traffic safety during the design and operation of the rolling stock is the allowable level of its main dynamic indicators. The determination of such indicators consists in the study of dynamic processes in the system “vehicle-track” [1-3].

The study of dynamic processes in the mechanical systems boils down to generation and analysis of differential equations that describe these processes. Analytical methods, electronic modelling methods and approximate numerical integration are used to solve and analyse differential equations. The choice of the method for solving these equations depends on the ultimate goal of the study, the type and structure of differential equations of the system. They often use qualitative analytical methods that allow to determine natural frequencies and oscillation patterns for the vehicle.

In the study of the dynamic interaction of the system “vehicle-track”, given complex system is usually simplified, and the idealized mathematical model is obtained that has basic dynamic properties of a given system. Then the parameters and characteristics of the elements of the calculation scheme are specified; differential equations are made up in such quantity that their number corresponds to the number of system freedom degrees. The most widely used method is D'Alembert method, which consists in the direct addition of equilibrium equations of the system, taking into account the forces of mass inertia. For the selected calculation scheme and the accepted coordinate system, differential equations of oscillations according to D'Alembert method are recommended to be made according to the geometric-physical-static rule (Popov A.A. rule).

Usually, the "vehicle-track" calculation scheme, even after simplification, has 10 to 40 degrees of freedom, and with complex connecting characteristics, the differential equation system is non-linear. Therefore, the integration of such complex systems is only possible through a computer experiment, which will reduce errors likelihood, greatly automate the process of mathematical model research and solve complex problems in a few actions.

2. Literature analysis and problem statement

At present, a considerable number of software products and complexes have been created for computer experiments related to the study of the dynamics of the rolling stock, which make it possible to simulate realistically the behaviour of the railway transport vehicles when driving along the track.

Examples of such software systems are: ADAMS / Rail, Medyna, Nucars, Simpack, Vampire, and Universal Mechanism (UM).

The ADAMS / Rail software package allows to create virtual prototypes of rail vehicles and to analyse them with the help of the same approaches that are used for real objects analysis [4]. The suspension system of a railway vehicle is divided into a primary and secondary suspension systems. These subsystems can be built by the user with the help of templates of creation or predefined templates. An illustrative example of a created bogie prototype in ADAMS / Rail is shown in Figure 1.

One of the best-performing complexes is MEDYNA software complex developed by a number of German manufacturers and scientific organizations. One of the significant advantages of this software complex is the simulation of interaction in the wheel-rail contact, as well as the successful experience application [5].

In order to describe the wheel-rail contact, MEDYNA software complex offers a choice of elements from kinematic connection to elastic multi-point contact, from a contact spot description as an ellipse to formation of a real interaction surface, from linear formulation of creep forces to nonlinear one. It is also possible not only to simulate wheel rolling on a rail, but also wheel rolling on a roller that allows to model the conditions of a bench experiment.

To simulate the dynamics of the rolling stock in the mode of traction and run, NUCARS software complex is used, which allows to apply different types of connections of individual elements of the studied object: vibration dampers, series and parallel springs, dampers (Figure 2) [6].

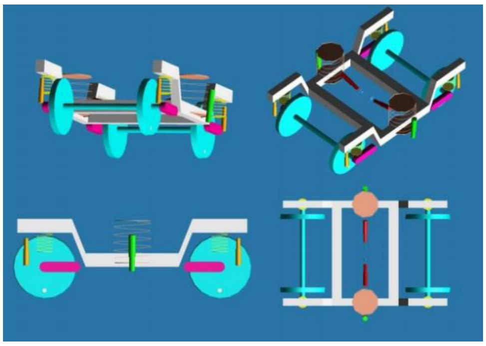


Figure 1. Model of a bogie in ADAMS/Rail.

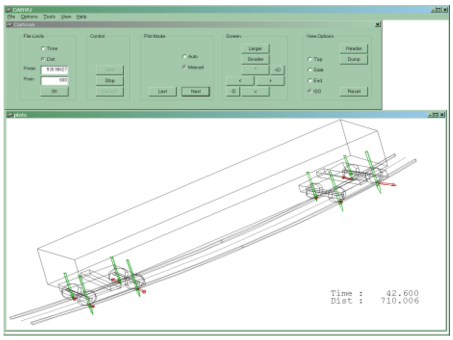


Figure 2. Modeling of the object under study in NUCARS software complex.

VAMPIRE software complex is a development of the British Railways Research Division, with the help of which a significant number of passenger vehicles have been investigated (Figure 3). However, VAMPIRE does not have the ability to simulate the processes occurring in wedge dampers, which does not allow to investigate widespread three-element bogies in the USA, Australia, South Africa and Ukraine.

The main features of SIMPACK Rail software include the possibility of track modeling – both rigid and elastic, the database availability of typical profiles of rails and wheels, with the ability to import profiles from in-situ measurements or regulatory documents (Figure 4) [7].

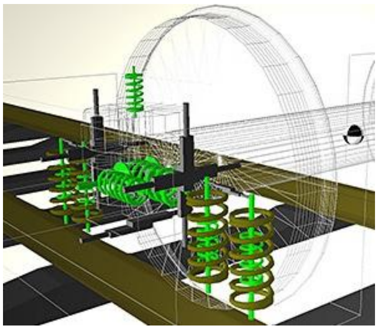


Figure 3. Suspension System Modeling in the VAMPIRE software complex.

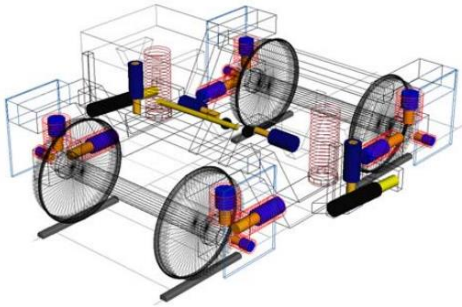


Figure 4. Model of a bogie in SIMPACK Rail software.

«Universal Mechanism» (UM) software complex is designed to simulate the dynamics and kinematics of planar and spatial mechanical systems that can be represented by a system of completely rigid or elastic bodies interconnected by kinematic and force elements. Systems of this type include: locomotives, wagons, various machines and mechanisms [8].

Whereas, in recent years, the number of applications for railway expertise implementation for the cases related to the rolling stock derailment to Lviv Research Institute of Forensic Expertise is significant and, given the current state of domestic rolling stock, with an upward trend, then the use of the above software packages to investigate derailment causes is a prerequisite. The peculiarity of such expertise is the need for its rapid execution, with the possibility of determining the appropriate causes of rolling stock derailment depending on its dynamic behaviour, which cannot be done by above software complexes in full measure.

Also, given the strategic partnership between the EU and Ukraine, which is a prerequisite for the successful integration of Ukraine into the European railway area, the issue of harmonization and formation of common approaches to the implementation of safe operation of railway vehicles is important. This peculiarity necessitates the development of a software complex with the ability to implement and compare different approaches to determine possible causes of rolling stock derailment.

Therefore, given the above, the development of a universal software system for modeling the rolling stock dynamics is an urgent task and needs further investigation.

3. The purpose and objectives of the study

The purpose of this work is to develop a software module to study the dynamic behaviour of a freight wagon in Maple computer environment and to conduct a computer experiment on the mathematical model.

Research objectives:

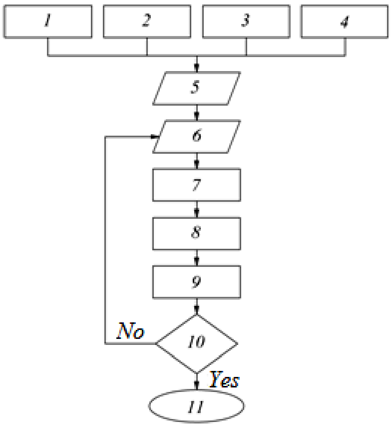
- to analyse necessary functions in Maple for software modules creation;
- to develop the basic software module of dynamic behaviour of a freight wagon in its interaction with the track;
- to carry out a computer experiment on a mathematical model of a freight wagon in the created main program module.

4. The basic program module of dynamic behaviour of a freight wagon

In this work, Maple software package was taken as the basis for creation of software modules of a freight wagon dynamic behaviour in its interaction with the track.

To display the algorithm for solving this problem in Maple software package, the authors of the article constructed a block diagram, which is presented in Figure 5 [9].

Blocks of differential equations of a body, bogie bolsters, lateral frames and wheel-sets are described by the procedure [10]. The procedure is called a separate module program (subroutine), which has an independent value and performs one or more operations, usually quite complex and different from the operations performed by built-in operators and functions.



1 – block differential equations of the body of the rolling stock;
2 – block differential equations of the bolster;
3 – block differential equations of the side frames;
4 – block differential equations of wheelsets;
5 – unchanged input data;
6 – variable input data;
7 – a system of differential equations;
8 – solution of differential equations;
9 – obtaining results;
10 – verification of the fulfillment of certain conditions;
11 – output and visualization of the results

Figure 5. Flowchart of the algorithm.

The sequence of a procedure call is as follows (Figure 6).

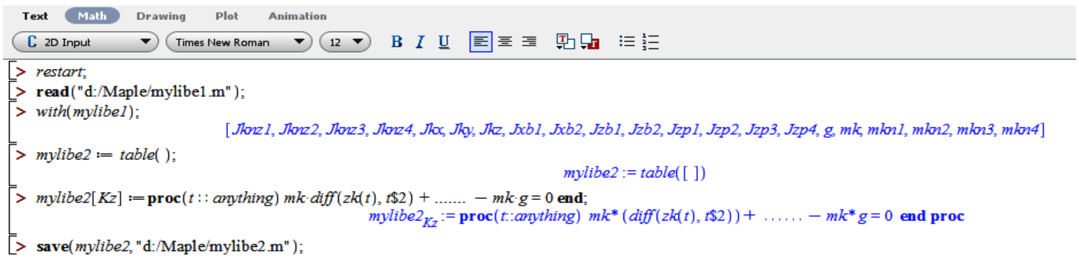


Figure 6. The sequence of a procedure call.

The input data are set by a separate block through the operator *table* (*F*), where *F* – is a table or an array (Figure 7).

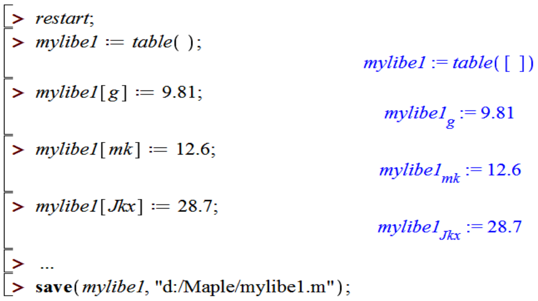


Figure 7. An array of input data.

For analytic and numerical solution of differential equations, Maple uses *dsolve* command, the format of which is:

$$dsolve(\mathrm{eqns}, \mathrm{vars}, \mathrm{option}) \tag{1}$$

where eqns – is the system of equations with respect to undefined functions vars;

option – are additional conditions that allow you to specify the method for solving the problem.

The mathematical model was calculated using 4-5 order numerical Runge-Kutta method (Figure 8).

```
> dsol1 := dsolve((AB_AB(0, 0, 0, 0, 0, 0, 0, 0)), numeric, maxfun = 0);
                    dsol1 := proc(x_rkf45_dae) ... end proc
> dsol1(0)
[t = 0., θb1(t) = 0., d/dt θb1(t) = 0., θb2(t) = 0., d/dt θb2(t) = 0., θk(t) = 0., ...... ]
```

Figure 8. Numerical solutions of differential equations.

When modeling freight wagon dynamics, the gaps closure takes place in the side bearers, axle-boxes, between the flange and the rail head, and therefore, in order to take into account the forces that arise in such cases, you can use the operator *if* whose format is (Figure 9).

```
> for cikl from 0 to 5 by 0.1 do
  dsol1 := dsolve((AB_AB(S[1], S[2], S[3], S[4], S[5], S[6], S[7], S[8])), numeric, maxfun = 0);
  print(cikl, dsol1(cikl));
  A1 := op(2, op(18, dsol1(cikl)));
  A2 := op(2, op(19, dsol1(cikl)));
  A3 := op(2, op(20, dsol1(cikl)));
  A4 := op(2, op(21, dsol1(cikl)));


  if A1 > 0 then S[1] := 0 else S[1] := 1 end if;
  if A2 > 0 then S[2] := 0 else S[2] := 1 end if;
  if A3 > 0 then S[3] := 0 else S[3] := 1 end if;
  if A4 > 0 then S[4] := 0 else S[4] := 1 end if;
  if A1 > 0 then S[5] := 0 else S[5] := 1 end if;
  if A2 > 0 then S[6] := 0 else S[6] := 1 end if;
  if A3 > 0 then S[7] := 0 else S[7] := 1 end if;
  if A4 > 0 then S[8] := 0 else S[8] := 1 end if;
```

Figure 9. Operator format *if* .

Computer graphics was used to visualize the results. The main command is *plot* which is in the standard library and does not require a preliminary call (Figure 10).

The structural appearance of the command *plot* is as follows:

$$plot\left(\{\text{func1, func2...}\},\ x=\text{a...b},\ y=\text{c...d, option}\right) \tag{2}$$

where func1, func2 – analytical expressions;

$x = \text{a}\dots\text{b}$ – is a change interval of the variable x (segment along x - coordinate);

$y = \text{c}\dots\text{d}$ – is the interval along y - coordinate.

```
> p1 := plot([qwe[i], ert1[i], i = 1 ..kk - 1]) :
> with(plots) :
> display({p1})
```

Figure 10. The sequence of the command call *plot* .

5. Computer experiment of a spatial mathematical model of a freight wagon

The computer experiment is an experiment on a mathematical model of an object of study on a computer, that is, according to one parameter of the model, its other parameters are calculated and, on this basis, the properties of the object described by the mathematical model are derived. This type of experiment can only conditionally be attributed to the experiment, because it does not reflect natural phenomena, but is only a numerical implementation of a human-created mathematical model. Indeed, if the mathematical model is incorrect, its numerical solution can be strictly divergent from the physical experiment.

To accomplish this task, the authors of the article use an advanced spatial mathematical model of a freight wagon consisting of 30 second order differential equations. With the help of a computer experiment, we demonstrate the ability to study the dynamic behaviour of a freight wagon using Maple software package. For example, we study the dynamic behaviour of a body at different combinations of gaps in the side bearers and forces that result from their closure (Figure 11-14).

Based on the requirements of the regulatory documents, we study the dynamic behaviour of a freight wagon body using two different combinations of gaps in the side bearers: I – all four gaps have a nominal value of 10 mm (Figure 11), II – in the first two side bearers, the total gap is 3 mm, which is not in accordance with the requirements of Instruction TSV-0043 (Figure 12).

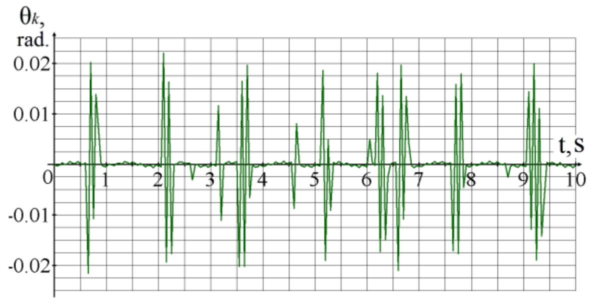


Figure 11. Lateral body oscillation at the first combination of gaps in the side bearers.

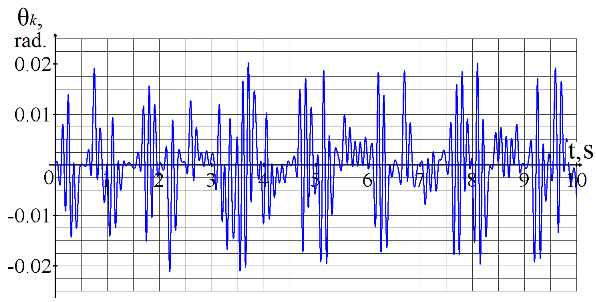


Figure 12. Lateral body oscillation at the second combination of gaps in the side bearers.

Analysing the above drawings, it is observed that the dynamic behaviour of a body is largely determined by the gaps in the side bearers, which non-normative value can lead to amplitude increase of lateral body oscillations, which is especially dangerous for curved track areas where tipping of a wagon can occur.

Having shown the possibility of studying the dynamic oscillations of a body at different combinations of gaps in the side bearers, it is appropriate to establish forces arising from these gaps closure (Figure 13).

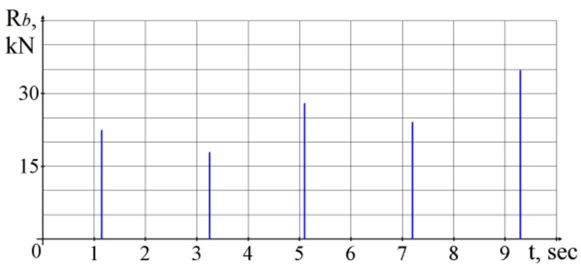


Figure 13. Forces resulting from gaps closure in the contact side bearers.

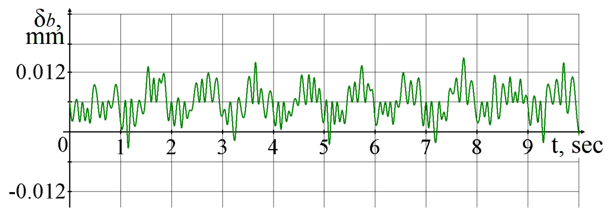


Figure 14. Dynamic change in the gap in the first contact side bearer.

After calculating the mathematical model, we obtained graphs of the dynamic change of the gaps in the contact side bearers (see Figure 14 for the first side bearer). In this case, the vertical unevenness of the track and the nominal size of the gap in the contact side bearer were adopted so that it was possible to close the gap and determine the reaction that occurs at the time of its closure. The analyses of Figure 14 shows that at certain points of time the gap in the side bearer takes on negative values, which indicates its closure, and at that moment, as it is observed in Figure 13, the reaction occurs immediately.

The authors want to point out that in this article the priority task is to test the possibility of Maple software package use in the study of dynamic processes of the rolling stock in its interaction with the track. Also, it is equally important to test the possibility of creating separate modules (subroutines) that would allow simulating any type of the rolling stock, including the rolling stock on pneumatic suspension.

To check the adequacy of the calculations performed, the forces arising in the side bearers of constant contact were analyzed. According to GOST 34387-2018 the static pressing force in the side bearers height does not exceed 27.1 kN. The work considered the movement of a wagon with small vertical irregularities of the railway track, for which it can be considered that the influence of dynamic processes

IOP Conf. Series: Materials Science and Engineering **985** (2020) 012002 doi:10.1088/1757-899X/985/1/012002

is insignificant. The design forces in the side bearers were 32 kN, which exceeds the static value by 15%.

Therefore, having analysed the main functions of Maple software package and conducted the study of the dynamic behaviour of a fright wagon body, the authors of the article came to the conclusion that Maple software package could be used in the study of the rolling stock dynamics, which in the future will allow to determine the causes of the rolling stock derailment using the dynamic model of the wheel-rail interaction.

6. Conclusions

Having analysed the existing software complexes, it was emphasized the importance of their use in the study of the dynamic behaviour of the rolling stock. Due to the peculiarities of forensic railway expertise, it was decided to use Maple as an alternative.

Using «$\mathbf{proc}(t::anything)$» procedure, separate modules (subroutines) were created, with the help of which the basic module for the study of the dynamic behaviour of a freight wagon was constructed.

Having conducted a computer experiment on a mathematical model in the main module, the dynamic behaviour of a freight wagon, namely the body, was investigated at various combinations of gaps in the side bearers and the forces that result from their closure.

It has been established that the Maple software package can be used to simulate any type of rolling stock and study its dynamic behavior. Also using this software environment and a dynamic model of wheel-rail interaction, it will be possible to proceed to establish the causes of the rolling stock derailment.

References

[1] Kuzyshyn A, Batig A, Kostritsa S, Sobolevska J, Kovalchuk V, Dovhanyuk S and Voznyak O 2018 Research of safety indicators of diesel train movement with two-stage spring suspension *BulTrans 2018: 10th Intern. Sci. Conf. on Aeronautics, Automotive and Railway Engineering and Technologies* **234**-1–**234**-6

[2] Kovalchuk V, Kuzyshyn A, Kostritsa S, Sobolevska Y, Batig A and Dovganyuk S 2018 Improving a methodology of theoretical determination of the frame and directing forces in modern diesel trains *Eastern-European Journal of Enterprise Technologies* **6/7 (96)** pp 19-25

[3] Kuzyshyn A, Kostritsa S, Ursulyak L, Batig A, Sobolevska J and Voznyak O 2019 Research of the impact of geometric unevenness of the railway track on the dynamic parameters of the railway rolling stock with two-stage spring suspension *IOP Conference Series: Materials Science and Engineering* **664**-1–**664**-10

[4] Azhar I, Mohd Azman A and Khisbullah H 2013 Multibody Dynamics Models of Railway Vehicle Using Adams/Rail *Applied Mechanics and Materials* **393** pp 644–648

[5] Kortum W 1990 Analysis of railway vehicle system dynamics with the multibody program MEDYNA *DLR German Aerospace Research Establishment Institute for Flight Systems Dynamics*

[6] Wilson N, Shu X and Gonzales K 2015 *TTCI's Scientific Software Suite and NUCARS* p 34

[7] Seyed Milad Mousavi Bideleh 2016 Multiobjective Optimization and Active Control of Bogie Suspension *Department of Applied Mechanics Chalmers University of Technology Gothenburg* p 50

[8] Kovenkin D A and Karpov I G 2016 Modeling the interaction of the railway crew and the track in the Universal Mechanism software package *Laboratory workshop in the discipline Software for calculating the construction of railway tracks* p 100

[9] Kuzyshyn A, Batig A, Sobolevska J, Kostritsa S, Ursulyak L and Dovhaniuk S 2019 Determining the causes of rolling stock derailment from the track using modern research methods *2 and International Scientific and Practical Conference "Energy-Optimal Technologies, Logistic and Safety on Transport" (EOT-2019) MATEC Web of Conferences* **294**-1–**294**-8

[10] Dyakonov V P 2006 *Maple 9.5/10 in mathematics, physics and education* p 720