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GENERATION OF VIRTUAL TRACK PROFILES USING EXPERIMENTS AND COMPUTER SIMULATIONS

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An advantage of computer simulations of structures is the prediction of dynamic properties, loading, strength, fatigue life stability, etc. A new goal of computer simulations is the fatigue life analysis of vehicle structures or that parts. A "virtual track profile" (mathematical description of the track profile) can solve the problem of proper excitation. The paper describes one possible approach of virtual track profile generation. Experimental data and computer simulations are used for the profile generation.

Key words: track profile, fatigue analysis, rainflow method

1. Introduction

An advantage of computer simulations is the prediction of strength, loading dynamic properties, stability, etc. A new goal of computer simulations is the fatigue life assessment of structures or their parts. The problem of such an analysis is a definition of kinematic excitation of numerical models. It can be realized by the "virtual track profile". The virtual track profile means a mathematical description of a track surface. The virtual track can serve for the comparison of the aggressiveness of different operational tracks, see e.g. Hejman and Lukeš (2005) or Hejman (2005). This paper deals with the virtual track profile generation. The tracks vompound of the described method can be utilized for the strength assessment of structural parts close to the suspension. This restriction is due to the applied criterion of the track generation. The criterion is based on the agreement of the rainflow histogram of relative displacements and velocities between the structure and the axles of vehicles. The virtual track can by used in computer simulations or experimental tests.

2. Basic principles

The primary cause of fatigue damage D_i of a vehicle structure is the kinematic excitation of a springing. The excitation is transferred by the springing to the structure. Stress responses depend on the character of excitation and properties of the structure (modal shapes, frequencies, damping ratio, etc.) in places of the fatigue life assessment. Stress time-history courses are evaluated using the standard rainflow counting method (RF). The fatigue life assessment is performed by the application of the damage accumulation rule according to Miner. The process is described in Fig. 1, where n_i is the number of cycles on the ith level and N_i is the number of cycles to failure on the ith level according to the given S-N curve.

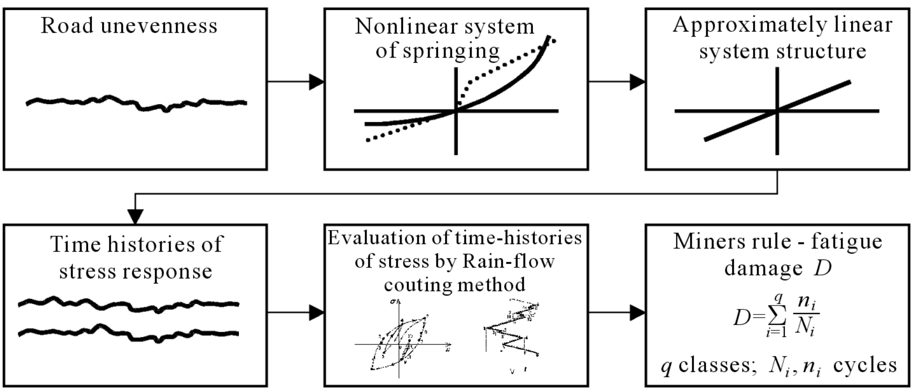


Fig. 1. A scheme of the inductive process of the vehicle fatigue damage

3. Classification of road surfaces

The proper path to the track profile generation is the measurement of a real track profile. But this approach is very complicated and for the purpose of multibody and finite element numerical simulations also unsuitable. There are several reasons why to generate track profiles in some other way.

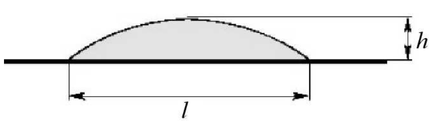
There are no appropriate mathematical models implemented in the MBS software considering full three-dimensional contact of a tire with road unevennesses. There are problems with numerical simulations and also with real measurements in three dimensions.

The examined vehicle drives along the same road in different tracks and it does not hit the unevennesses in the same way. Every exact method of the track profile measurement includes some inaccuracy. For the elimination of this inaccuracy it would be necessary to include many passages of the track.

Relative displacements of the axles and bodywork do not include "real information" of the track, because the relative displacements are the results of kinematic excitations and dynamic properties of the vehicle. But this quantity is suitable for our purpose because it includes the effects of the variable speed and weight of the vehicle.

4. Virtual track generation

The method based on the combination of predefined artificial unevennesses is used for the generation of a virtual track profile. It is necessary to make a set of artificial obstacles with different lengths and heights, see Fig. 2. The set must be large enough to be able to generate a sufficient virtual track profile. If it is necessary, other shapes of the obstacles can be proposed.



l [m] \ h [mm]	10	20	30	40	50	60
5.56			X			
2.78			X			
1.35			X			
1.11		X	X	X		
0.79	X	X	X	X		
0.62	X	X	X	X	X	
0.51	X	X	X	X	X	X
0.43	X	X	X	X	X	
0.37	X	X	X	X		

Fig. 2. The shape and size of the artificial obstacles

Numerical MBS simulations were performed for running over all these obstacles. The parameters of the used multibody model were identified from the experimental data (Polach and Hajžman, 2005). The responses, i.e. the relative axle displacements, are identified and then processed by using the rainflow method into one-dimensional histogram. The histogram for each obstacle represents a "basis function" in the track generation process. The least square method is used to find such a combination and number of the artificial obstacles that the resulting histogram of the artificial track approximates the histogram of the experimental measurement.

It is necessary to find such a vector of parameters $\boldsymbol{a}$ that the sum

$$\sum_{i=1}^{N} r_i^2 w_i$$

is minimized, where the residuum vector $\boldsymbol{r}$ is defined as

$$\boldsymbol{r} = \begin{bmatrix} D_m^d \\ D_m^v \end{bmatrix} - \begin{bmatrix} D_{p1}^d & D_{p2}^d & \cdots & D_{pN}^d \\ D_{p1}^v & D_{p2}^v & \cdots & D_{pN}^v \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_N \end{bmatrix}$$

The vector $\boldsymbol{w}$ represents the weight vector, $\boldsymbol{D}_p^p$ and $\boldsymbol{D}_p^v$ are the histogram vectors of relative displacements and their first time derivatives for each artificial obstacle, and D_m^p and D_m^v are the histograms of the experimental data.

The shape of the artificial obstacle is shown in Fig. 2 and the set of the obstacles is evident from the table. The table is not full, because some obstacles in the table corners have improper rations of length and height, and do not represent the existing characteristic obstacles.

A program in the Matlab system was created to generate virtual track profiles, see Fig. 3.

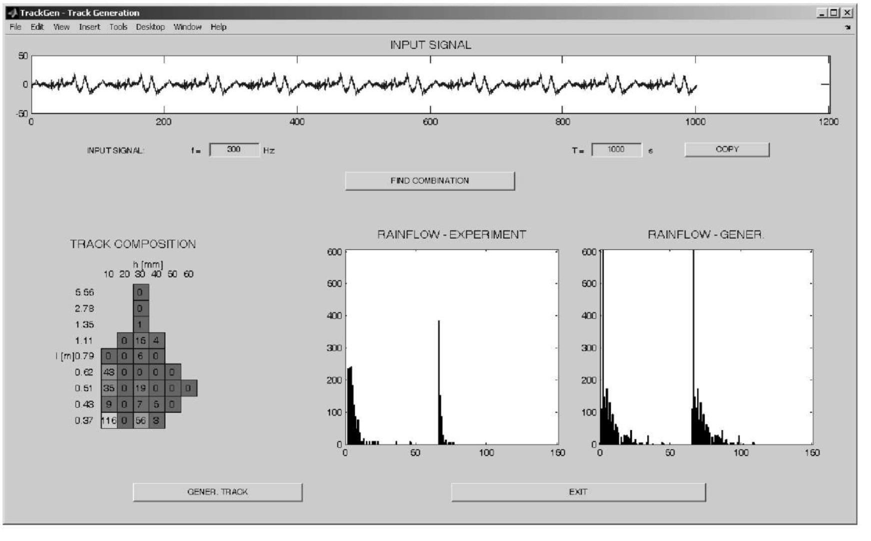


Fig. 3. The program for virtual track profile generation

The approach of the track generation is used taking into account the fact that the rainflow histograms of the selected segments can not be simply added.

The RF histogram, which is the sum of the RF histograms of the separated segments, is not necessary as well as the histogram of the whole signal. It is the consequence of the RF method principles (ASTM E 1049-85, 1999). As a result of the signal segmentation, some cycles are not closed or are closed at different class of the RF histogram.

The dynamic response of the springing depends on the obstacle characteristics and on the initial state of the system. To avoid interaction between the responses of different obstacles, the distance between two obstacles must be sufficient. The stress responses in the elements of the suspension or the parts close to the suspension are dependent on both spring forces and forces in shock absorbers. It is the reason why the RF histograms of relative displacements are used together with the RF histograms of velocities.

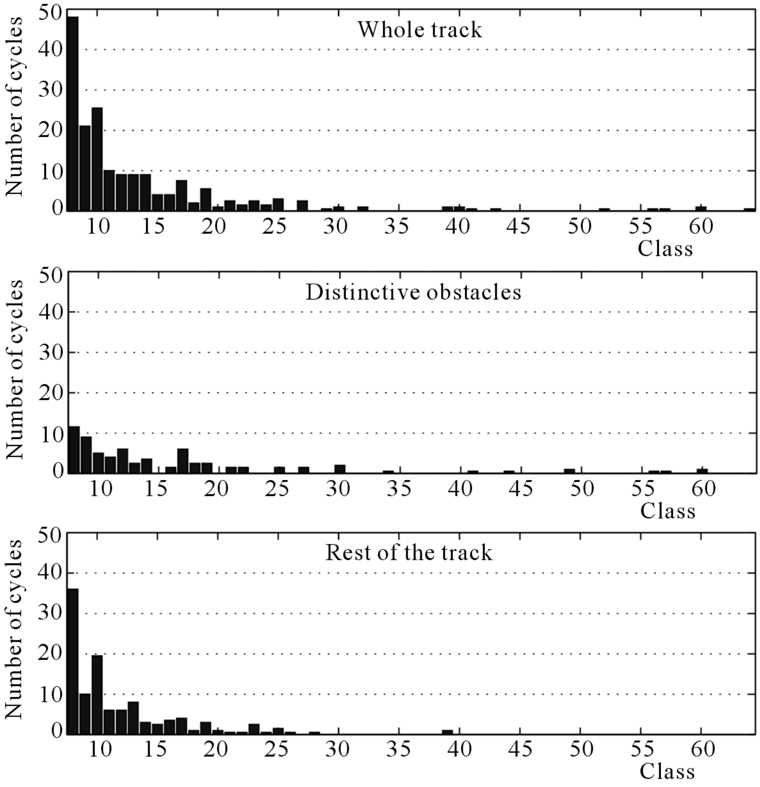


Fig. 4. Histograms of the stress history

The roadways are generally made of materials of different types and composition. Generally, it is possible to divide road surfaces into two groups. The first group involves homogeneous parts of the roadway. The second group in-

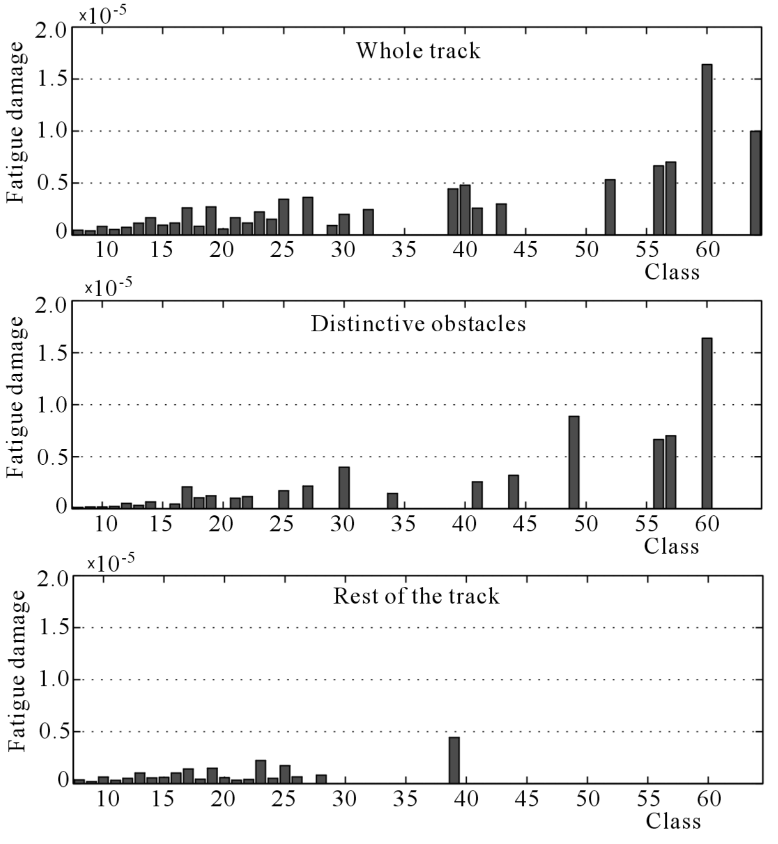


Fig. 5. Resulting fatigue damage

volves significant unevennesses of individual shapes like drains, retarders, pot holes, railway crossing, etc. This simple classification is proposed on the basis of the analysis of stress history obtained from the experimental measurements on a real track. In Fig. 4 and Fig. 5 some results of the rainflow processing and fatigue damage calculation for one stress history are illustrated. From the signal of stress history, segments corresponding to the significant unevenness were extracted and processed by the RF method and the damage algorithm. This also was done for the signal of the whole track and for the signal without the significant unevenness. It is evident from the graphs that the significant unevenness contributes to the RF histogram with a small number of cycles but with higher amplitudes and, therefore, the corresponding fatigue damage is bigger than the fatigue damage of the rest of the track. The segmentation of the experimental data and processing by the RF method is influenced by the same error as it was mentioned in the previous Section.

In the set of the artificial obstacles, there must be some obstacles with the characteristic response corresponding to distinctive obstacles in a real track. One possible way to include these obstacles is to identify their profile. An optical method was developed for this purpose. The optical method is based on taking pictures of the measured unevenness. A sizing rod is placed above the unevenness and the unevenness is marked by a bright adhesive tape, see Fig. 6. The acquired pictures are processed in own Matlab program. As a result, data sets describing the profile in the measured line are obtained. The accuracy of this method is not too high, but it is sufficient for the purpose of the numerical simulations. Advantages of the method are the simplicity and efficiency.

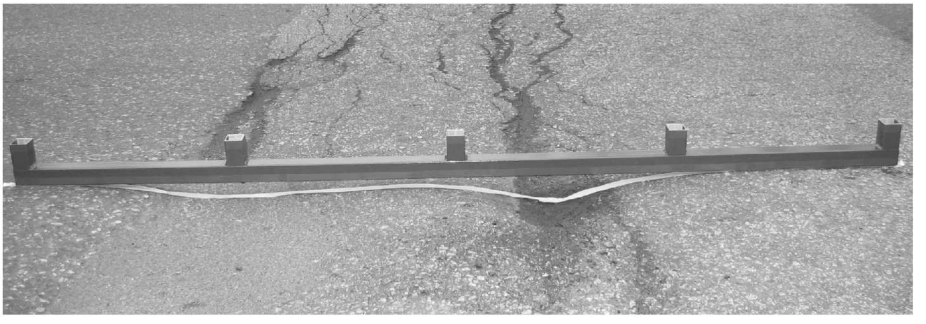


Fig. 6. The optical method for the measurement of significant unevenness

5. Conclusions

The method of the generation of the virtual track profile was presented in this paper. Virtual tracks are used in the multibody numerical simulations and can also be used for the fatigue tests. The virtual track profile is compared of a number of obstacles of different shapes. The selection of artificial obstacles and their number is determined by the least square method. The final rainflow histogram obtained from the computer simulations performed on the virtual track approximates the experimental data. This approach will be further improved to eliminate the effect of fragmentation of the rainflow procedure. This task can be solved by using some optimization methods.

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Generowanie wirtualnego profilu drogi na podstawie symulacji komputerowych i danych eksperymentalnych

Streszczenie

Jedną z korzyści płynących z symulacji komputerowych jest możliwość przewidywania właściwości dynamicznych, obciążeń, wytrzymałości, stabilności zmęczeniowej itp. różnych konstrukcji. W pracy przedstawiono nowy cel analizy wspomaganej komputerowo – badania wytrzymałości zmęczeniowej pojazdów i ich podzespołów. Zaprezentowano metodę „wirtualnego profilu drogi" (matematycznego opisu profilu drogi) do rozwiązania problemu wymuszenia kinematycznego pochodzącego od nierówności jezdni. W pracy zawarto opis jednego z możliwych sposobów generowania wirtualnego profilu drogi. W rozważaniach zastosowano symulacje komputerowe oraz oparto się na pomiarach doświadczalnych.

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