A model of a cabin simulator for assessing vibrations in an electronic locomotive
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Abstract

The goal of the paper is to present the conception and the process of building the model of the simulator of the cabin of electric locomotive. The study is being done for PKP (Polish Rail State) and it will be finished by the real construction of the simulator, which the PKP will use in the training process of electric locomotive operator. Because of that, the simulator should realize the function which occur in the real electric locomotive and a user should feel the vibration and others phenomena which occur while the locomotive is following the train in the real conditions. Also the conception and realisation of the control process of vertical and lateral vibration of simulator using the model is presented.

1. Introduction

The investigation of dynamical phenomena appearing in moving rail vehicle can be carried on in many ways. The development, in which a real object is moving in usual service conditions, give us the possibility of obtaining the most reliable results. But on the other hand, such development is relatively expensive, considering the necessity of using measurement train and it leeds to the temporary closing of railway traffic during the experiment. Moreover, for the reasons mentioned above, it is hard to make the investigation for many variants of essentially different conditions of vehicle movement.

Computer aided simulation investigations based on mathematical models create completely different, more wide possibilities, but they include an error connected with the mathematical model assumed.
Thanks to fast development of computer aided methods we can carry out many simulations of railway vehicle movement for different conditions using modules and systems which already exist [1, 2].

Time necessary to execute such investigations and the expenses borne are much lower than during field experiment made in real conditions on a real object. However, the obtained results are only an approximation of reality because of the simplifications made during building the mathematical model of a vehicle. Besides, despite so advanced methods of investigations, modelling of reality for railway vehicle, track mechanical system, is still difficult and complicated due to non-linearities existing in it.

In the face conditions limiting the possibility of making field experiments as well as computer simulations using mathematical models, the third method was developed which connect both methods mentioned above. This method consists in a simulation of movement of real railway vehicle in laboratory conditions. For this purpose, special investigation stands are built on which a railway vehicle is situated and its movement are excited by using servo-motors to simulate its real behaviour on track. We can also imagine such solution that only a part of a real object is represented together with all instruments and equipment existing in it. Such solution was realized in this case, which means that only a part of the electric locomotive with a cabin, in which the locomotive driver works, was built on the investigation stand.

The simulator of locomotive driver’s cabin built according to such assumptions can be used for the investigation of conditions which exist in that part of locomotive during its movement. This seems to be an important problem, taking into account their influence on a human body and our opinion about the quality of construction. Moreover, the simulator can be used for complex training of electric locomotive drivers.

The aim of this paper is to present a model of simulator cabin and a model of excitations which is a source of simulator movements.

2. A simulator of a locomotive cabin - general solution

To begin with it was assumed that in the future the simulator should fulfil the following conditions [3]:
- to enable the investigations in the domain of valuation of vibrations in the locomotive cabin during its running in different travel conditions,
- to enable the valuation of functionality of a locomotive driver’s work-stand from a technical and organisational point of view.

According to what was mentioned above, a simulator should functionally imitate the operation of all the equipment of the locomotive and its behaviour in different service conditions, and for different levels of track maintenance.
To fix the attentions it was assumed, that the simulator would represent the electric locomotive of the type ET09, which is used on Polish State Railways to service passenger traffic. It was also assumed that the simulation of freight traffic would be done by special computer program simulating the behaviour of the locomotive of the type ET09. This locomotive is used on Polish State Railways to service freight trains.

The main part of the simulator is a cabin of locomotive, provided with the visualisation system. This cabin is situated on a movable platform standing on a system of 6 hydraulic servo-motors. Thanks to them, the movement of the cabin can be observed, particularly, its behaviour during start-up, constant velocity run and braking process. The cabin together with the platform and the system of servo-motors is shown on figures 1a, 1b.

The inside of the cabin is a true copy of a real cabin of locomotive of the type EP09. A visualisation system, showing the figure of route which can be seen by a driver, is situated in front of the windscreen. The system simulating acoustic phenomena is installed inside the cabin. This system is to simulate all the sounds which exist during the run of locomotive in real conditions. Such solution secures stimuli and feeling which influence driver’s senses, in order to simulate the real environment of locomotive driver. The main source of simulator steering is the instructor’s stand. It is so equipped that the instructor can fully program the simulating strip and also inspect simulator’s work e.g. it is provided with the computer of the control system of simulator and other computers servicing control of hydraulic and electrical system of simulator. General block diagram of simulator is shown on figure 2.

3. Model of excitation of simulator cabin movement

In the beginning of the process of creating the model describing the form of excitation of the cabin, it was assumed, that the vibrations of the point of connection between driver’s seat and floor in the cabin of simulator and in the real locomotive should be compatible. In sense of compatibility we understand quality of linear spectra and angular accelerations in the range of essential accelerations. To obtain information about the form of vibrations existing in the cabin of locomotive during its run, the field experiment was made. The aim of the experiment was to record the variation of accelerations in several chosen points of locomotive EP09 during its run, with certain velocities chosen before and on track sections with different quality of maintenance. The experiment was made taking into account the following assumptions:
- measurements were made only for one locomotive with assumption that it was representative for all locomotives of this type,
- measurements were made on five track sections with different limitations of velocity and different qualities of maintenance,
movements, can be done in several different ways. Signals recorded during the experiment can be used directly to drive servo-motors, or it is also possible, to build a functional model of excitation using frequencies obtained from spectral analysis of recorded signals, as well as forms of vibrations.

It was decided to use the second solution. A model consisting of polyharmonic functions was build to excite the servo-motors presented on figure 1. General form of such function can be presented as:

\[ F(t) = f_0 + \sum_{n=1}^{M} (f(n)\cos(n\omega t + \varphi_n)) \]  

(1)

where: \( f_0 \) - constant, \( f(n) \) - amplitude of \( n \)-th harmonic, \( \omega \) - ground frequency, \( \varphi_n \) - phase shift of \( n \)-th harmonic, \( t \) - time.

Formula (1) results from the expansion (finite) of any function \( F(t) \) in trigonometric Fourier's series.

It should be noticed that \( f(n) \), \( n \), \( \omega \) and \( M \) can be obtained from spectral analysis of any stationary and ergodic signal and the limitation of formula (1) to \( M \) terms results from the limitation of frequency range of real signal analysis.

Formula (1) was modified, taking into consideration the influence of run velocity \( v \) and track class on the form of functions exciting vibrations of the cabin of simulator.

Denoting \( f(n) = f_n \), \( n\omega = \omega_n \) and digitising time \( t = i\cdot dt \), we will obtain:

\[ F(v, k, i) = f_0(v, k) + \sum_{n=1}^{M} (f_n(v, k)\cdot\cos(i\omega_n dt + \varphi_n)) \]  

(2)

where: \( k \in \{A, B, C\} \).

The next step has in view including the influence of different sectors of track (straight track, curve turnout, crossing, bridge and others) on function \( F \).

First the track sectors should be derived into 3 groups: \( et1 \), \( et2 \), \( et3 \). The first (ground) group will consist of straight track sector, second - a curve, and the third - all other elements of the run. Taking into account this classification, we will obtain:

\[ F(v, k, i) = f_0 \cdot et2(i) + \sum_{i=1}^{M} ((f_{no}(v, k) + \\
+ df_n(v, k)\cdot et3(i))\cdot\cos(i\omega_n dt + \varphi_n)) \]  

(3)

where: \( f_{no}(v, k) \) - amplitude of \( n \)-th harmonic, \( df_n(v, k) \) - an increase of amplitude due to the run on turnout, crossing, bridge and other elements of the run, \( f_0(v, k) \) - a component including run on curve.

Functions \( et2(i) \) and \( et3(i) \) are Boolean functions, describing that there exist sectors of 2nd and 3rd group in simulated run. They belong to set \( \{0, 1\} \).

When running on curve a component \( f_0(v, k) \) should include in the simulation such phenomena as centrifugal force.
- linear and angular accelerations were recorded in the chosen points of driver's cabin,
- accelerations were recorded in the range 0.2-0 Hz.

Measurement points in cabin are shown on figure 3.

In total, 10 signals were recorded: 8 accelerations (sensors 1-8) and two angular velocities (sensor 9, 10 on figure 3).

The sensors were situated so as to assure the choice of signals to control simulator, taking into account the representation of vibrations of a real cabin during its run.

The simulator should make the simulation of run on track possible with different quality of maintenance and consisting of different sectors (straight track, curve, turnout, crossing and others), so the experiment was planed to enable suitable simulation run.

The signals recorded can be classified in the following way:

a) quality of maintenance of track
- very good maintenance, class A (velocity up to 160 km/h),
- good maintenance, class B (velocity up to 120 km/h),
- sufficient maintenance, class C (velocity up to 50 km/h).

b) sectors of track
- straight track,
- left and right curve,
- turnout,
- crossing,
- others.

Also runs with velocity changing from 0 km/h to maximal velocity permitted and braking process were recorded. All recorded signals were converted into disc files and ASCII code. The obtained results were analysed in time and frequency domain to obtain data necessary to build model signals controlling movements of simulator cabin.

Signals recorded for every run were converted and analysed to obtain:
- power spectral density (PSD),
- root mean square (RMS),
- correlation (also partial) coefficient,
- frequency transfer functions.

Figures 4a and 4b show vertical (Oz direction) and lateral (Oy direction) accelerations which were recorded by the sensors no.3 and no.4, on the straight A class track (between 43 and 44 kilometres of a rout) for speed equal 120 km/h. Yet the spectral characteristics in the form of power spectral density of the accelerations are presented in the figures 4b and 4c, respectively.

Owing to the analysis of results obtained, it was possible to simplify, during the process of making, the model of control of movement (vibrations) of the simulator cabin. Steering the servo-motors movements, which excite platform
It was assumed that
\[ f_0(v, k) = f_0'(k) \cdot \frac{v^2}{R} \]  
(4)

where: \( f_0(k) \) - constant, representing a class of track, \( R \) - curve's radius.

Field experiments were carried out on a track consisting of different sectors and the results were recorded every 20 km/h beginning at 20 km/h up to \( v_{\text{max}} \).

It means that the signals exist for different, but constant velocities. However, steering the simulator cabin movement is a continuous process and, during the simulation of changing the velocity of locomotive transition from one to another, data set prepared to generate function (3) is necessary. It was presumed that this transition can be interpolated linearly.

Formulas necessary to calculate the expressions in (3) for \( v \in (v_1, v_2) \) are as follows:
\[ f_{no}(v, k) = f_{no}(v_1, k) + \frac{v \cdot (f_{no}(v_2, k) - f_{no}(v_1, k))}{v_2 - v_1} \]  
(5)

\[ df_n(v, k) = df_n(v_1, k) + \frac{v \cdot (df_n(v_2, k) - df_n(v_1, k))}{v_2 - v_1} \]

It is still necessary to describe the way of generating \( \phi(n) \) - phase shift of \( n \)-th harmonic. It seems impossible, however, to determine it be using experimental data, because the result will be obtained with a big error. That's why it was assumed to get \( \phi(n) \) for \( n \)-th harmonic as:
\[ \phi(n) = (2 \text{Rnd}(n) - 1) \cdot \pi \]  
(6)

where: \( \text{Rnd}(n) \) - generator of random numbers in a range (0, 1) uniformly distributed.

This generator should generate \( M \) random numbers during one step of simulator. Formulas (3)-(6) are a complete set describing a model of excitations of the cabin of simulator along one of Oxyz system axes, as marked on figure 1.

4. The example of controlling simulator's movement

As it was maintained before, the data used to generate simulator's cabin controlling in Ox, Oy, Oz directions is taken as forms of linear vibrations (amplitudes of n-ths harmonics) obtained from spectral analysis of signals recorded during experiment.
Taking into account the kind of run track class, velocity of the run, the files were created with the forms of vibrations and frequencies of linear accelerations in Ox, Oy, Oz directions and angular accelerations corresponding to them.

The program steering the platform movement excited by 6 servo-motors, uses files generated in that way and generates the functions (3) for every servo-motor. The examples of generated functions and the comparison between them as well as the recorded signals will be shown below.

Using the model of the excitation described by the formulas (3)-(6) and the data obtained from the analysis of the signals showed on figures 4a and 4b, the examples of the control in the accelerations form for vertical and lateral directions were generated. Next, the signals were analysed in the frequency domain and the power spectral density was obtained. The results obtained in this way are shown on the figures 5a-5d. The control signals for vertical and lateral directions are shown on the figures 5a and 5b, however, the power spectral density of the signals is shown on the figures 5c and 5d, respectively.

Comparing the real signals of the vertical and lateral cabins accelerations (Fig. 4a and 4b) with control signals (Fig. 5a and 5b), it is hard to notice qualitative harmony, yet the level of the quantitative value is rather the same. Comparing, however, the power spectral density of the real signals and control signals we can say that the qualitative harmony in the range till 10 Hz exists.

This is an important element in the process of the locomotive cabin movement simulation, as the Wickens [4] and Knothe [5] studies showed, the frequencies from this range have significant influence on the dynamic behaviour of the rail vehicle body as well as on the locomotive cabin. Similar comparison was made for other class of the track, the elements of the route and speeds, receiving satisfactory qualitative harmony. The method shown in the chapter 2, was applied in the process of generation the control signals which steer the platform and locomotive cabin movement.
A - points of connection between servo-motors and the platform on which simulator cabin is situated,
B - points of connection between servo-motors and the floor.

Figure 1b: Draft of servo-motors fastening

Figure 2: Block diagram of a simulator

Figure 3: A scheme of the sensors location in the I and II locomotive cabin
Figure 4: Examples of the real signals accelerations and their power spectral density functions: a) vertical acceleration, b) lateral acceleration, c) power spectral density of the vertical acceleration, d) - power spectral density of the lateral acceleration.
Figure 5: Examples of the signals controlling the simulator cabin movement and their power spectral density functions: a) - control of the movement in the vertical direction, b) - control of the movement in the lateral direction, c) - power spectral density of the vertical control, d) - power spectral density of the lateral control.

References


