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Research of Connection of Rolling Stock Primary Rubber Suspension and Ride Quality

ABSTRACT

All rolling stock during moving on tracks suffer the influence of environment, in other words, vibrational states caused by different influences such as unflatness of the bases along which they move, speeding up and breaking of vehicles, curves and other. Vibrational characteristics of passenger cars are manifested through ride quality defined by the standard ISO 2631, while vibrational characteristics of freight cars are manifested by increased loads on the body construction. Vibrational characteristics of rolling stock are defined by the following railway recommendations and regulations ERRI B153, ERRI B10, UIC 518 and other. The main aim of these regulations is to provide the dynamic stability and comfort in rolling stock running. Moreover, locomotives as draft (operating) vehicles need the protection in the view of the quality of work of complex systems by which they have been equipped.
On the Faculty of Mechanical Engineering in Niš the theoretical research of relevant parameters of rubber-metal elements has been executed, as well as complex laboratory testings of mechanical characteristics of the primary suspension of electric locomotives of the Serbian Railway. Besides, measurements of dynamic characteristics of electric locomotives on different lines in Serbia have been executed, regarding ride comfort. This research is motivated by the needs of Serbian industry and the obtained results are of the special importance for the Serbian Railway. The program of the executed testings and obtained results are to be presented in this paper.

1. INTRODUCTION

Rolling stock suspensions can be made as helical, torsion or leaf steel springs, air bags, rubber-metal springs, hydraulic shock absorbers and so on. The suspension with rubber-metal elements presents one of favorable constructive solutions for rolling stock suspension, especially for electric locomotives. The basic reason for this can be recognized in rubber characteristics. The rubber strengthened with tin steel segments provides favorable characteristics of elasticity, and alongside, it affords satisfactory level of striking loads amortization and noise reduction. The main lack of rubber springs is the inconstancy of rubber characteristics on raised temperatures and under effect of ozone. That can cause the change of the statical deflection characteristic causing the respective appearance of permanent deformation which negatively reflects on characteristics of the suspension. Besides to the classic analysis of influences of physical characteristics of rubber mixtures and constructive solutions of rubber-metal elements of rolling stocks, for the purpose of testing safety and comfort of the transportation in the railway traffic new technologies are used more and more. One of such contemporary approaches is for example the usage Global Positioning System (GPS) technology in combinations with other appliances. In such way multiple benefits can be achieved: protection of living environment, improvement of the transportation comfort, reduction of transportation costs, reduction of maintaining costs of the traffic infrastructure and rolling stock, increasing of rolling stock overturn and so on. In this paper, besides to the classic testing of mechanical characteristics of rubber mixtures for the rubber-metal elements of suspensions of locomotives, the Serbian producer TIGAR – "Technical rubber" Pirot, Serbia produces rubber mixtures for cooperated Serbian firms that produce final rubber-metal elements mainly for selling on the national market, the usage of GPS on railway vehicles has been presented, as well as the measurements which have been executed by using a equipment developed at the Faculty of Mechanical Engineering in Niš, Serbia, for the purpose of determining dynamic characteristics, that is the ride quality of electric locomotives on rails of the national railway operator Serbian Railways.

2. RUBBER-METAL ELEMENTS OF ROLLING STOCK SUSPENSIONS

The rubber is a very adaptive material with so much favorable characteristics which are the reason for successful applications in all fields of the technique for more than a hundred years. Because of excellent physical characteristics the main usage of the rubber is for making springs, mufflers, shock absorbers and similar damping devices. Unlike the metal, the rubber has significantly larger flexibility, it owns some damping effect that is especially convenient when resonant vibrations appear. It can also accumulate the energy in the larger scale than some other materials, for example the steel. At rubber-metal elements the rubber has been joined for the metal on a specific way. That combination with metal plates provides more convenient fastening and positioning. Mounting and maintaining of rubber- elements is very simple and cheap.

Mechanical characteristics of rubber suspension, beside the mixture composition, depend on many parameters just as are: way of mixture producing, tool for the vulcanization, vulcanization procedure, characteristics of the rubber-metal connection, the way of warehousing, installing procedure, exploitation conditions and other. Providing of high quality of primary suspension rubber-metal elements requires exceptionally wide theoretical and experimentally research.

All rolling stock during moving on tracks suffer the influence of environment, in other words, vibrational states caused by different influences such as unflatness of the bases along which they move, speeding up and breaking of vehicles, curves and other. Vibrational characteristics of passenger cars are manifested through ride quality defined by the standard ISO 2631, while vibrational characteristics of freight cars are manifested by increased loads on the body construction. Vibrational characteristics of rolling stock are defined by the following railway recommendations and regulations ERRI B153, ERRI B10, UIC 518 and other. The main aim of these regulations is to provide the dynamic stability and comfort in rolling stock running. Moreover, locomotives as draft (operating) vehicles need the protection in the view of the quality of work of complex systems by which they have been equipped.

These categories of problems are, next to the representation in the design process of the rolling stock, present a lot during the repair and maintenance actions of railway vehicles as well. Tha fact is that all rolling stock are designed for the exploitation in a longer time, by the special attention has to be dedicated to the regular maintenance. In that way activities for the purpose of maintenance and repair of locomotives are of the special importance. Those imply the continuous control of the vital systems and assemblies of locomotives, special their suspensions. Therefore during the development of rolling stock suspensions, in respect to very intensive dynamic loads, it is necessary to bear in mind the following:

- to eliminate all wearing elements;
- to provide three degrees of freedom to spring elements, i.e. vertical, transversal and longitudinal;
- to ensure that a suspension system can have the changeable stiffness of springs and the damping effects.

On Fig. 1 rubber-metal suspension systems (primarily and secondary suspension) of a bogie are presented.

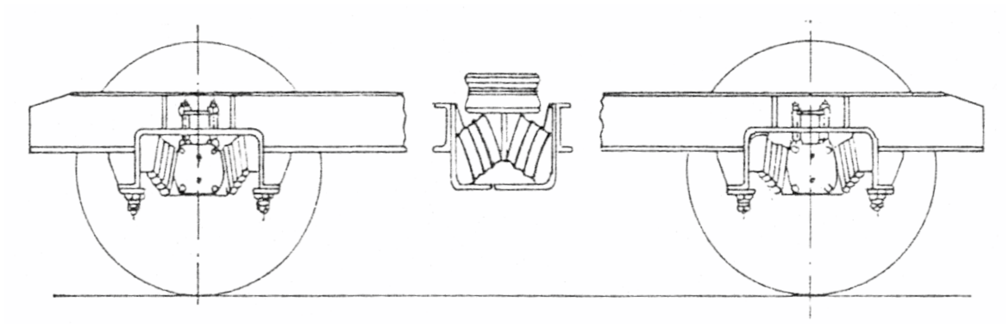

Fig. 1 Rubber-metal suspension systems (primarily and secondary suspension) of a bogie

If the connection of the housing of axial bearings with the frame of the bogie is completely realized by rubber-metal elements, then the wearing metal on metal elements are completely eliminated. In this case rubber elements enable, during the passing a vehicle through a curve, at the same time with the realization of the necessary vertical movement the enough axial movement of the axle assembly in respect to the frame of the bogie. Rubber suspensions also have advantage over other ones by giving the exponential dependence between loads and deformations. Moreover, the rubber eliminates the lack of steel springs, i.e. the acoustical transfer of high frequencies and mechanical vibrations.

3. RESEARCH OF RUBBER MIXTURES CHARACTERISTICS

Problems which exist in the railway traffic significantly affect increasing of maintenance costs and decreasing of the efficiency of the transportation. Such problem is from one aspect of view caused with aged infrastructures i.e. unsettled geometric characteristics of rails, and from the other side with characteristics of vehicles which do not coordinate with exploitation conditions. For that purpose, a problem of appearing large values of the permanent deformation has been considered together with a problem of appearing changeable qualities of characteristics of the elasticity of rubber-metal elements of suspensions during the exploitation.

Therefore the research of dynamic working conditions of electric locomotives on rails of the national railway operator Serbian Railways has been performed and these parameters have been related with characteristics of rubber-metal elements of primary suspensions. The aim is determining optimal parameters of suspensions which correspond to particular exploitation conditions, i.e. the condition of the infrastructure. Presented considerations also refer to research activities which can contribute that already during the production of new rubber-metal elements their characteristics can satisfy complex technical and technological requirements in particular exploitation conditions.

For that purpose the following testings have been performed:

- Establishing of relevant parameters of rubber-metal elements which are used for suspensions of rolling stock;
- Testing of physical-mechanical characteristics on test samples of different rubber mixtures (elasticity module, hardness, strength, strain and others);
- Testing of the permanent strain under the defined load;
- Testing of the permanent strain under the defined height;
- Testing by artificial aging;
- Comparative analysis of characteristics of different mixtures;
- Establishing of recommendations for the production of rubber-metal elements of rail vehicles suspensions.

Averaged results obtained by indicated testings are systematized in Table 1 of comparative characteristics of experimental mixtures.

Table 1 Comparative characteristics of experimental mixtures

CHARACTERISTICS	Unit	Standard	Research institution	Research conditions	Serial number of mixture					
					1624/1	1624/2	1626/1	1626/2	1628	1629
					1	2	3	4	5	6
Hardness	Sh-A	JUS G.S2.125	TIGAR Pirot	without aging	66	66	64	65	47	53
				after aging	69	67	65	66	49	49
Module 200	MPa	JUS G.S2.127	TIGAR Pirot	without aging	11.5	9.8	8.0	9,2	3.0	5.9
				after aging	10.9	10.1	8.8	9,9	3.4	4.5
Module 300	MPa			without aging	16.3	15.6	13.0	14.7	5.5	6.2
				after aging	16.8	15.9	14.0	15.2	6.2	7.3
Strength	MPa			without aging	21.4	22.2	19.8	21.2	26.5	20.6
				after aging	20.5	21.1	19.4	20.2	27.1	27.1
Strain (at breaking)	%			without aging	428	444	456	460	623	540
				after aging	376	396	428	422	603	603
Permanent strain at defined height	%	JUS G.S2.130	TIGAR Pirot	$20^oC - 72^h$	5.0	5.8	9.14	9.14	6.67	5.83
				$70^oC - 72^h$	23.5	24.5	25.5	29.9	26.70	26.98
Permanent strain at defined load	%	JUS G.S2.134	Faculty Niš	$20^oC - 72^h$	1.20	1.74	3.41	2.06	1.96	2.22
				$70^oC - 24^h$	2.93	2.63	4.08	3.73	4.81	5.3
Statical hysteresis at load of 1,2 kN		KRS 50409	Faculty Niš	without aging	0.230	0.229	0.409	0.388	0.140	0.169
				after aging	0.241	0.242	0.393	0.384	0.175	0.224
Statical hysteresis at load of 2,0 kN		KRS 50409	Faculty Niš	without aging	0.229	0.219	0.361	0.349	0.152	0.163
				after aging	0.244	0.243	0.354	0.343	0.206	0.223
Yerzley's hysteresis	%	ASTM D 945-92	Faculty Niš	without aging	37.1	32.7	41.1	43.7	19.5	21.5
				after aging	36.2	33.2	44.7	46.0	18.3	17.6
Yerzley's degree of elasticity	%	ASTM D 945-92	Faculty Niš	without aging	62.9	67.3	59.9	56.3	80.5	78.5
				after aging	63.8	66.8	55.3	54.0	81.7	82.4
Yerzley's degree of elasticity	%	ASTM D 945-92	Faculty Niš	without aging	74.3	76.8	67.7	65.4	87.4	86.1
				after aging	75.7	77.5	69.7	67.0	89.5	88.8
Frequency	Hz	ASTM D 945-92	Faculty Niš	without aging	2.85	2.75	2.75	2.93	1.86	1.93
				after aging	2.54	2.70	2.88	2.86	2.12	2.16
Effective dynamical module of elasticity	N/mm^2	ASTM D 945-92	Faculty Niš	without aging	5.985	5.087	5.043	5.772	2.390	2.592
				after aging	4.733	5.146	6.097	6.012	2.113	2.176
Absorbed energy of impact	J/m^3	ASTM D 945-92	Faculty Niš	without aging	298.2	268.8	266.4	231.8	236.6	238.1
				after aging	308.5	272.2	298.8	298.2	121.3	120.3

(Note: Used codes for mixtures: 1624/1 (TG-AC-732); 1624/2 (TG-AC-732/02); 1626/1 (TG-A-628/3); 1626/2 (TG-A-628/4); 1628 (TG-A-523/5); 1629 (TG-A-523/6))

Presented mechanical characteristics of rubber-metal products, next to the composition of the mixture, depend from many parameters just as are: way of the mixture producing, tools for the vulcanization, vulcanization procedure, characteristics of the rubber-metal connection, way of warehousing, mounting procedures, exploitation conditions and others.

In respect to the previous, the realization of high quality rubber-metal elements of primary suspensions of locomotives is a very complex job that requires an exceptionally wide interdisciplinary research.

If the following criteria are set:

- the minimal permanent strain at a statical load,
- the minimal (up to the mean) value of the statical hysteresis,
- the mean (up to the maximal) value of the elasticity module,
- the mean (up to the maximal) value of the damping of the magnitude of oscillations,
- slightly changing of characteristics after the aging.

the sequence of the tested mixtures will be the following: 1624/1, 1628, 1624/2, 1629, 1626/2, 1626/1.

4. DETERMINING OF DYNAMIC CHARACTERISTICS – THE RIDE QUALITY

The task of the measurement being performed in the experiment presents the determining of dynamic characteristics i.e. accelerations in three directions (longitudinal, lateral and vertical), at the manoeuvre locomotive "Škoda" of series 621, Fig. 2.

Fig. 2. “Škoda” manoeuvre locomotive of series 621

Measures are performed on the relation between the railway station “Crveni Krst” and the railway station “Niš”. The largest attention has been directed on possible changes of the acceleration which happened during the transfer of the locomotive across turntables, turnouts, bridges and in curves. For the measurement of the size of the acceleration the LIS3LV02DQ sensor has been used. The LIS3LV02DQ is a three axes digital output linear accelerometer that includes a sensing element and an IC interface able to take the information from the sensing element and to provide the measured acceleration signals to the external world through an I2C/SPI serial interface. The IC interface is manufactured using a CMOS process that allows high level of integration to design a dedicated circuit which is factory trimmed to better match the sensing element characteristics. The LIS3LV02DQ has a user selectable full scale of ±2g, ±6g and it is capable of measuring acceleration over a bandwidth of 640 Hz for all axes. The device bandwidth may be selected accordingly to the application requirements. A self-test capability allows the user to check the functioning of the system. The device may be configured to generate an inertial wake-up/free-fall interrupt signal when a programmable acceleration threshold is crossed at least in one of the three axes. The LIS3LV02DQ is available in plastic SMD package and it is specified over a temperature range extending from -40°C to +85°C.

The sensor is connected with the central acquisition appliance EUROACC. This appliance, shown on Fig. 3, is specially made for the purpose of determining dynamic characteristics and the ride quality of rolling stock at the Faculty of Mechanical Engineering, Department of Mechatronics, Niš, Serbia.

It enables the autonomous measuring and acquisition of acceleration data from the sensor. It posses an internal memory for the data placing of the capacity of 128 Mb, a real time clock, an USB interface for the connection to PC’s or laptops, as well as a GPS module which enables additional actions like determining the current position, as well as the velocity of the testing object moving. The appliance is battery-powered (a lead-acid battery with a gelified electrolyte, 12V/1.1Ah) which makes possible the working autonomy of the appliance up to four hours.

Fig. 3. Central acquisition appliance EUROACC

Signals from the acceleration sensor are in the digital form. The microcontroller collects these signals through the SPI interface. The microcontroller firstly descrambles the signals and separates the acceleration data for each axis and allocates them in the buffer. Additionally, the microcontroller serves the real-time clock, memory module, analog-digital conversion of RS232 communication and GPS module. The internal memory is provided by a memory stick card which also uses SPI protocol to communicate with the microcontroller. The GPS module has been based on SirfStar III chipset. Besides registering the current position and velocity it also gives possibilities of further improvements and wider applications of the appliance. The complete appliance is integrated in a plastic housing. Internal regulators of voltage provide supplying the memory module and GPS module with the voltage of 3.3V, while the rest electronics is supplied by the voltage of 5V.

For the purpose of the acquisition and analysis of the measuring data software programs EUROAccCom and EUROAccAnaliza are specially developed. This program makes possible fast and simply adjusting of the threshold for data acquisition starting, adjusting of the real-time clock, displaying of the control data form an AD converter that is necessary for the appliance calibration. Moreover, it is possible to choose the GPS transparent mode, when the data received from the GPS module are directly transferred to a connected computer without internal processing.

The program EUROAccAnaliza makes possible the analysis of previously archived data on the computer in the shape of the graphic presentation. From this program data can be exported in Excel CSV format. By this program it is also possible to read the minimal and maximal values of accelerations for all of the three axes, velocities, GPS positions, as well as to present locations on the Google map via the Internet.

5. MEASURING RESULTS AND THEIR ANALYSIS

The measuring place with the acceleration sensor, the central appliance for the data acquisition EUROACC and a laptop computer for the data processing has been presented on Fig. 4.

Fig. 4 The measuring place with the acceleration sensor, the central appliance EUROACC and a laptop computer

For testing dynamic behavior of the manoeuvre locomotives of series 621 the acceleration sensor was set for the first case on the housing of the axial bearing, while for the second case it was positioned on the carrier of the bogie. During the measurements the largest attention was directed on values of vertical and lateral accelerations.

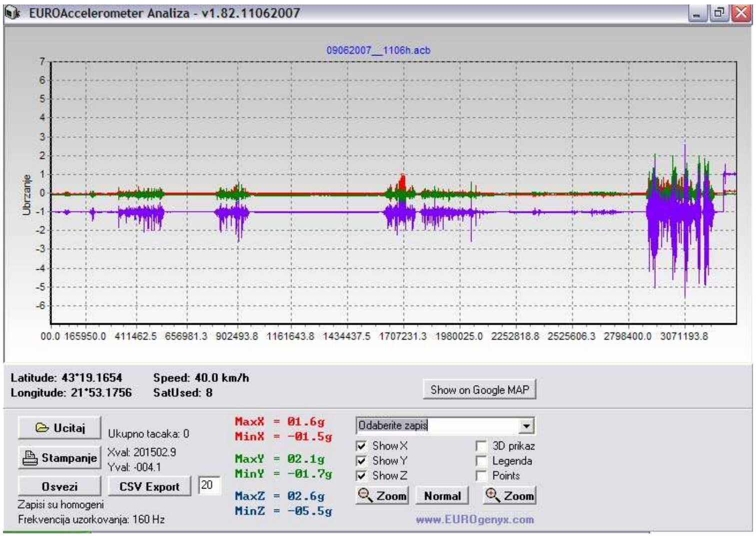

Fig. 5 The graphic presentation of values of accelerations in the all three axes for the total duration of the measurement

On Fig. 5 there is the graphic presentation of values of accelerations in the all three axes which were recorded in the time interval of 75 minutes. In some segments the locomotive was not move so there were no accelerations, what can be seen on the graphics in the shape of straight lines. The acceleration in the vertical direction is presented on the graph by blue color, while the accelerations in longitudinal and lateral directions are presented by green and red color respectively. The values of accelerations in the direction of Z axis (blue color) take into account the effect of the acceleration of gravity so it is necessary to correct them for +1g. Next to the graphic presentation of accelerations in the three axes from the user interface of the program EuroAccelerometarAnaliza it is possible to read the following data as well:

- Latitude and Longitude of the locomotive at a determined moment;
- Velocity of the locomotive at a determined moment;
- Number of satellites used for the position defining at a determined moment;
- Locomotive position on the Google map at a determined moment;
- Values of maximal and minimal accelerations for each of the three axes recorded during the whole measurement;
- Sample rate for the measuring, i.e. the number of recorded measurements in a second (for this measuring it was 160Hz).

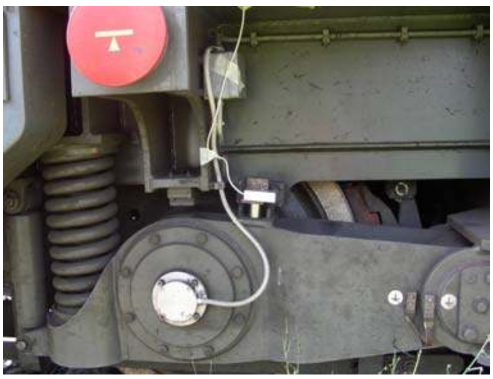

Fig. 6 The position of the acceleration on the housing of the axial bearing

Fig. 7 shows the appearance of the user interface at the moment when the locomotive went down from a turntable at the railway station “Niš” and moved towards the railway station “Crveni Krst”. For this measuring the sensor was set on the housing of the axial bearing, Fig. 6.

Fig. 7 The appearance of the user interface at the moment when the locomotive went down from a turntable at the railway station “Niš”

For this case it can be seen that the maximal acceleration had the value of -0.8g in the vertical direction, while the maximal accelerations in the longitudinal and lateral directions were the same - 0.3g.

Fig. 8 The appearance of the user interface at the moment when the locomotive crossed over the turnout 1

Fig. 8 shows the appearance of the user interface at the moment when the locomotive crossed over the turnout 1. The velocity of the locomotive, as it is shown on the user interface, was 1.8km/h. The acceleration in the vertical axis was 1g in the negative direction and 0.3g in the positive direction. The longitudinal and lateral accelerations were within limits from -0.3g up to 0.2g and -0.2g up to 0.2g respectively.

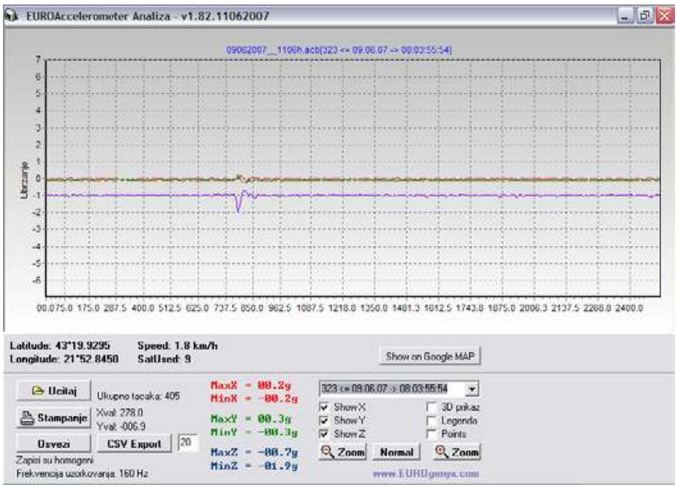

Fig. 9 The appearance of the user interface at the moment when the locomotive crossed over the turnout 2

Fig. 8 shows the appearance of the user interface at the moment when the locomotive crossed over the turnout 2. The velocity of the locomotive was again 1.8km/h. The acceleration in the vertical axis was 0.9g in the negative direction and 0.3g in the positive direction. The longitudinal and lateral accelerations were within limits from -0.3g up to 0.3g and -0.2g up to 0.2g respectively.

Fig. 10 The position of the acceleration on the carrier of the bogie, above the axial assembly

In the following segment of the testing the position of the acceleration sensor was changed. The sensor was set on the carrier of the bogie, above the axial assembly, as it is shown on Fig. 10.

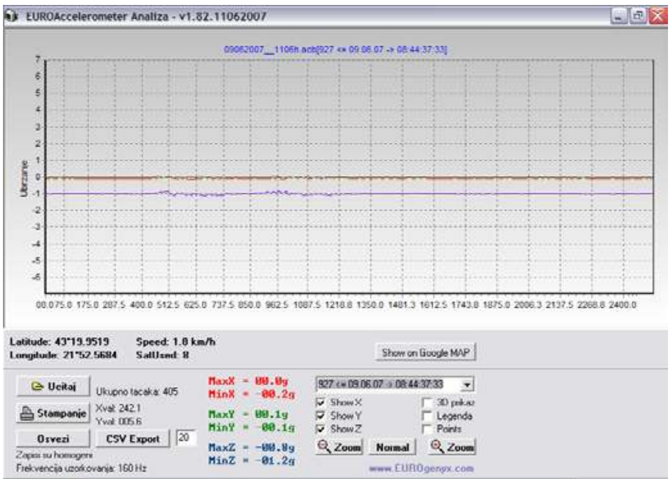

Fig. 11 The appearance of the user interface at the moment when the locomotive crossed over a turntable at the railway station "Crveni Krst"

Fig. 11 shows the appearance of the user interface at the moment when the locomotive went down from a turntable at the railway station “Crveni Krst” and came back towards the railway station “Niš”. The velocity of the locomotive was the same as previous 1.8km/h. However, the acceleration in the vertical axis was 0.2g in the negative direction and 0.2g in the positive direction. The longitudinal and lateral accelerations were within limits from -0.1g up to 0.1g and -0.2g up to 0.0g respectively. For this case, when the locomotive crossed over a turntable at the railway station “Crveni Krst” with the acceleration sensor positioned on the carrier of the bogie above the axial assembly, it can be concluded that the values of accelerations were lower and damped for the all three axes compared to the case when the locomotive crossed over a turntable at the railway station “Niš” with the acceleration sensor positioned on the housing of the axial bearing.
For the following measuring the acceleration sensor was positioned back in the original position, i.e. on the housing of the axial bearing.

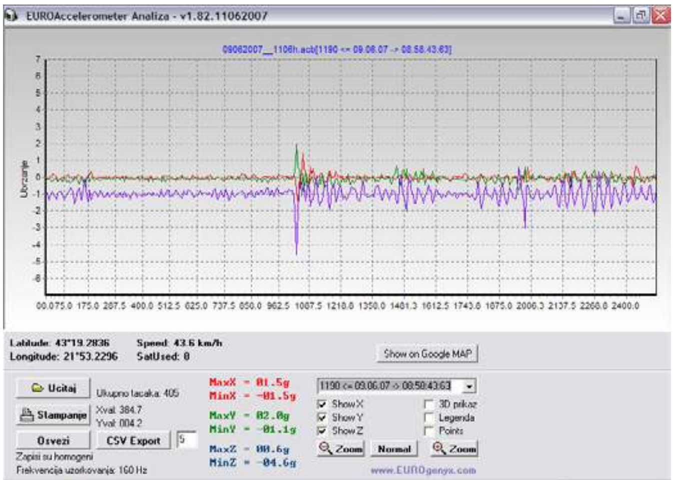

Fig. 12 The appearance of the user interface at the moment when the locomotive crossed over a bridge

Fig. 12 shows the appearance of the user interface at the moment when the locomotive crossed over a bridge. The velocity of the locomotive was 43.6km/h. The maximal acceleration reached the value of 3.6g in the negative vertical direction and 1.6g in the positive vertical direction The longitudinal and lateral accelerations were within limits from -1.1g up to 2.0g and -1.5g up to 1.5g respectively. Regardless the fact that in this case the locomotive passed across the bridge, it is obvious that accelerations, especially in the vertical direction, are much larger with the growth of the locomotive velocity.
Because of a better visibility and with the purpose of comparing in Table 2 values of accelerations in the all three directions are shown for different locations and velocities.

Table 2 Summary of values of accelerations in the all three directions for different locations and velocities

Location	Velocity(km/h)	Longitudinal acceleration (g)	Lateral acceleration (g)	Vertical acceleration (g)
Turntable	1.8	-0.3÷0.2	-0.3÷0.3	-0.8÷0.3
Turnout 1	1.8	-0.3÷0.2	-0.2÷0.2	-1.0÷0.3
Turnout 2	1.8	-0.3÷0.3	-0.2÷0.2	-0.9÷0.3
Brigde	43.6	-1.1÷2.0	-1.5÷1.5	-3.6÷1.6

6. CONCLUSION

Problems that exist in the railway traffic significantly affect the enlargement of maintaining costs and decrease the efficiencies of the transportation. In Serbia these are caused, from one side, by the old rail infrastructure characterized with unsettled geometric characteristics of tracks, and from the other side, by characteristics of rolling stock that do not conform to exploitation conditions.
For that purpose, in this paper problems of occurring large values of the permanent deformation and changeable qualities of characteristics of the elasticity of rubber-metal elements of electric locomotives suspensions during the exploitation have been considered. Therefore, at the Faculty of Mechanical Engineering in Niš, Serbia, a research of dynamic working conditions of electric locomotives on railroads of the national railway operator Serbian Railways has been carried out. Results of the research are related with mechanical characteristics of rubber-metal elements of primary suspensions of electric locomotives for the purpose of determining optimal parameters of suspensions that can satisfy complex technical-technological demands in particular conditions of the exploitation. All of these have been done with the intention of the promotion of the production of rubber-metal elements of electric locomotives suspensions by Serbian manufacturers with the purpose of the final reduction of electric locomotives maintenance costs.

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