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MEASUREMENTS OF NOISE OF DIESEL MOTOR TRAIN OF SERIES ŽS 711

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Abstract - *Serbian Railways recently introduced several new types of rail vehicles in operation. In 2012, multiple diesel unit of class 711, manufactured by Russian company "Metrovagonmash" was purchased by the Serbian railroad operator. These train units are expected to replace old diesel rail-buses that operate on sections without electric power, and, therefore, to become the dominant type of rail vehicles on Serbian local railway lines. This paper presents results of measurements of the equivalent level and one-third octave spectrum of noise emitted by a stationary unit of class 711 and a class 711 train moving at constant speed. All measurements are performed according to the ISO 3095:2013 standard.*

1. INTRODUCTION

Environmental noise is frequently described as undesirable sound caused by transport, industrial or recreational activities [1]. According to the World Health Organization, noise can significantly affects human health and productivity, causing stress, sleep disturbance, cardiovascular problems, etc., as it has been shown in many studies during past decades [2-4].

The major sources of noise pollution in the living environment are transportation systems [5]. European authorities are trying to increase the transport of passengers and goods by rail transport systems due to economic aspects, but also in order to reduce GHG emissions. Increase of the volume of the rail transport will lead to increase of the railway noise pollution.

2. SOURCE OF NOISE ON RAIL VEHICLES

Rail vehicles are complex mechanical systems, with multiple noise sources that emit sound waves due to [6]:

- interaction between contact surfaces in wagon assemblies,
- interaction between the outer surfaces of locomotives and wagons with air during motion,
- interaction between the track and the substrate,
- interaction between wheels and breaks,
- running of basic and additional equipment in locomotives and wagons.

Based on type of interaction, noise of rail vehicles may be classified in following categories [7]:

- rolling noise,
- curve squeal,
- aerodynamic noise,
- bridge noise,
- ground noise and vibration,
- internal noise and vibration,
- traction noise.

The wheel – rail contact represents dominant noise source of rail vehicles for speeds within the range between 40 km/h and 140 km/h. Rolling noise, which is caused by the interaction between the wheel and the track, increases with train speed v at a rate of about 30log(v) [7]. Traction motors, engines and railway vehicle equipment are main sources of traction noise, which dominates at lower speeds. The aerodynamic noise, caused by air motion around vehicle and pantograph system, is dominant at higher speeds (over 140 km/h). Further, rail vehicles in the curves produce a squeal noise due to sliding of the wheel over the top of the rails. The various infrastructure objects, such as bridges and tunes, also have great influence to railway noise generation.

Table 1 *Frequency range for different types of railway noise*

Noise type	Frequency range [Hz]
Rolling	250 - 5000
Flat spots	50 – 250 (function of speed)
Ground borne vibrations	4 – 80
Engine	50 - 250
Top of rail squeal	1000 - 5000
Flanging noise	5000 - 10000

Frequency ranges for different types of railway noise are shown in Table 1.

3. MEASUREMENTS

In March 2012, multiple diesel unit of class 711 began commercial service from Belgrade to Vršac, Serbia. These new units are planned to replace old railway coaches that run on the sections without electric power by the end of 2016.

Fig. 1 *Class 711 diesel multiple unit train*

The characteristics of the ZS 711 multiple train units are given in Table 2.

Table 2: *ZS 711 characteristics*

Weight (two units)	109 t
Length(two units)	45 m
Width	3.140 m
Engine type (per unit)	Diesel
Power output	2 x 250 kW
Maximal speed	120 km/h
Operating speed	100 km/h
Maximum number of passengers	246

Considering that the Class 711 diesel trains are relatively new and information about their noise emission is not available, this paper presents the results of the measurements of the stationary unit noise, as well as the noise emitted by the train unit running at a constant speed. The measurements were performed according to the ISO 3095:2013 standard [8].

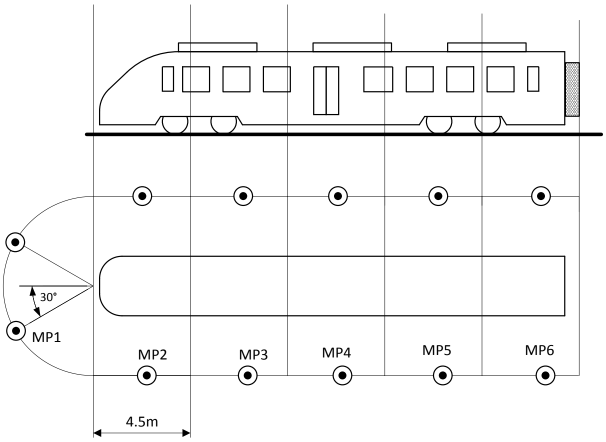

Fig. 2 *Measurement points for stationary speed test*

Measurement positions were located at distance 7.5 m from the track centerline, at a height of 1.2 m above the rail upper surface. The area within radius three times larger than the distance between the measurement point and the track centerline was free of large reflecting objects. Further, the area between the track and the microphone position was free of natural and artificial obstacles to sound propagation, sound absorbing matters and reflective coverings.

3.1 Stationary test

The noise emitted by a stationary unit was measured using a Bruel&Kjaer hand-held analyzer type 2270. The car was divided into areas with identical horizontal length of 4.5 m, and five measurement positions were located at middle of the corresponding areas. An additional measurement position was located at 30° from the track centerline, on a circle having a radius of 7.5 m and center in the midpoint of the unit end, as shown in the Figure 2. The measurements were performed only on one side of the unit, since both sides of the unit are acoustically identical. Ground surface was in level with the top of the rail surface.

3.2 Constant speed test

Bruel&Kjaer PULSE analyzer was used for measurement of the noise produced by railway vehicle that ran at a steady speed. Free-field microphones and a suitable microphone windscreen were used. The vehicle moved at a speed of 60 km/h along the track whose curvature has the radius larger than 1000 m.

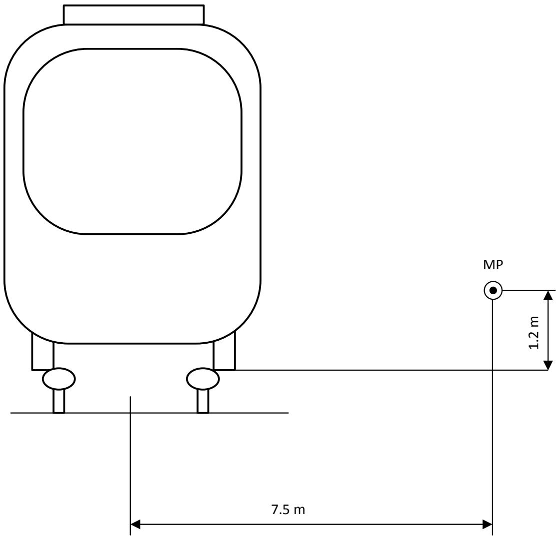

Fig. 3 *Measurement point for constant speed test*

The location of the measurement point relative to the rail track is shown in Figure 3. The ground surface level was up to 1.5 m below the top of the rail. The acoustic rail roughness has not been observed. The state of the rail running surface is shown in Figure 4.

Fig. 4 *Track condition on the measuring site*

4. RESULTS

Equivalent A-weighted noise level and one-third octave spectrum of the stationary unit were measured during 20 s time interval. The obtained noise levels at each measurement positions are given in Table 1.

According to ISO 3095 standard, noise emission level of the unit shall be calculated by energy averaging of $L^{i}_{pAeq,T}$

measured noise levels at all positions i according to the following equation:

$$\langle L_{pAeq,T} \rangle_{unit} = 10\log\left(\sum_{i=1}^{n} \frac{l_i}{l_{tot}} 10^{L^i_{pAeq,T}/10}\right), \quad (1)$$

where n is the number of measurement positions, l_i length of the wagon part where measurement position MPi is located, while l_{tot} represents the sum of lengths of all n wagon parts. Calculated noise emission level of the stationary unit of class 711 has value 72.63 dBA, and, therefore, satisfies the acoustic requirements of the Technical Specifications for Interoperability (TSI) [9], which was introduced for the purpose of harmonization of European rail traffic and reduction of rail traffic noise. TSI defines noise level of 73 dBA as the limiting value for the stationary noise of the diesel multiple unit.

Table 3 *Stationary unit noise levels*

	MP1	MP2	MP3	MP4	MP5	MP6
LAeq	66.93	70.93	74.59	75.36	75.09	72.73
31.5 Hz	36.28	38.98	40.26	37.48	34.63	29.23
40 Hz	42.38	43.72	44.97	42.37	45.96	41.78
50 Hz	28.73	30.57	31.05	29.43	29.88	30.11
63 Hz	28.75	30.77	35.2	35.39	35.75	35.67
80 Hz	32.78	34.74	39.16	39.79	41.85	39.78
100 Hz	35.5	41.33	41.99	41.19	42.56	42.55
125 Hz	34.76	36.01	39.88	42.5	43.45	41.98
160 Hz	31.21	32.81	35.54	40.55	37.6	35.27
200 Hz	36.48	41.32	45.95	45.73	46.31	40.96
250 Hz	44.35	50.2	52.67	49.87	57.48	51.42
315 Hz	42.96	50.2	50.46	52.12	52.51	53.22
400 Hz	45.75	49.1	52.24	52	51.01	53.8
500 Hz	53.83	56.32	58.69	61.65	58.17	51.58
630 Hz	55.66	60.67	66.59	66.51	66.35	62.89
800 Hz	55.5	61.59	69.2	66.76	66.87	65.14
1 kHz	59.94	61.82	65.47	68.85	67.07	64.27
1.25 kHz	56.68	63.08	64.45	66.36	66.68	62.87
1.6 kHz	57.32	61.08	61.45	63.21	63.42	62.98
2 kHz	59.39	62.54	64.43	65.97	66.61	64.51
2.5 kHz	55.09	58.39	60.48	61.97	62.24	60.03
3.15 kHz	52.23	55.28	57.92	59.44	58.75	57.09
4 kHz	55.24	59.52	61.15	61.87	62.37	60.58
5 kHz	49.38	52.01	54.31	55.75	55.75	53.8
6.3 kHz	47.2	50.3	52.51	53.75	53.67	51.63
8 kHz	44.83	47.93	51.04	51.64	51.33	49.29

Figure 5 shows one-third octave noise spectrum at measurement position with the highest measured equivalent noise level (MP4). Noise levels of the unit were more than 10 dB above the background noise level, which was measured during a time interval of 20 s.

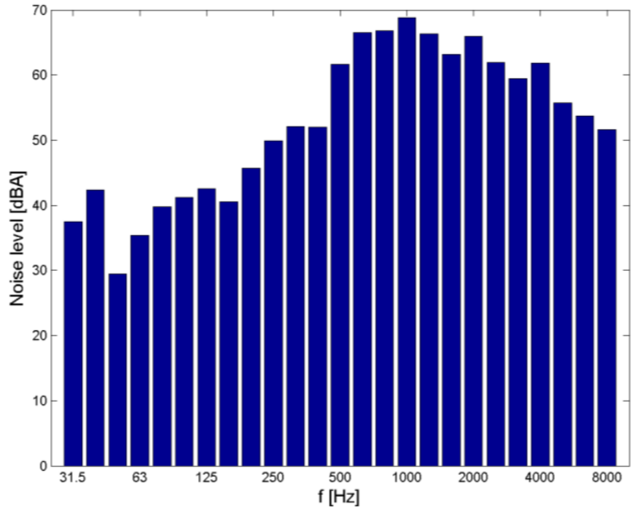

Fig. 5 *One-third octave noise spectrum at MP4*

For the constant speed test, equivalent A-weighted noise level and one-third octave noise spectrum were measured during time interval of passage of the whole unit by the measurement position. The obtained noise levels, as well as the background noise measured during 20 s time interval, are shown in Table 3.

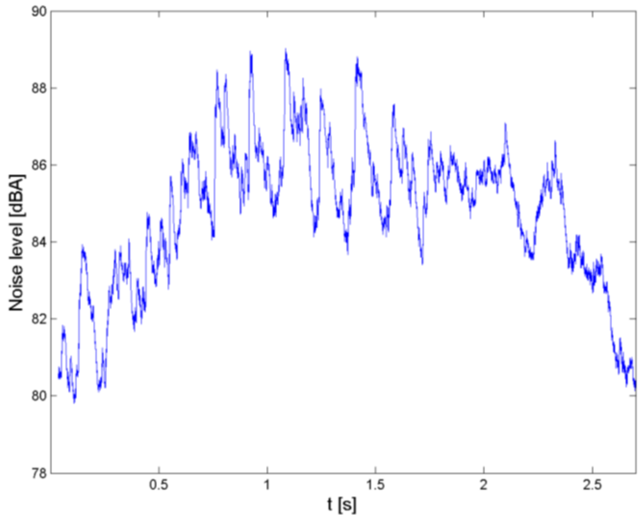

Fig. 6 *Railway vehicle pass-by noise*

Measured sound pressure level during railway vehicle pass-by is shown in Figure 2, while the Figure 3 shows corresponding one-third octave noise spectrum.

5. CONCLUSIONS

The measurements of the noise generated by multiple unit of class 711 in stationary conditions and during vehicle running have been presented in this paper. The obtained A-weighted levels of the equivalent noise are very close to the limit values requested by TSI specifications.

In the case of the stationary unit noise measurement, the highest values of the noise levels are obtained at the measurement point MP4, which is located in front of the diesel engines. The lowest noise level is measured in front of the vehicle, at measurement point MP1.

Table 4 *Vehicle pass-by noise levels*

	$L_{A,eq}$ [dB]	
	Rail noise	Background noise
f [Hz]	85.09	49.87
31.5	30.128	13.725
40	38.522	15.895
50	39.235	21.03
63	42.722	21.308
80	55.513	20.868
100	57.172	22.512
125	61.76	23.175
160	64.347	25.76
200	65.601	29.976
250	65.862	37.826
315	69.009	41.725
400	72.443	38.863
500	75.844	41.224
630	76.603	41.224
800	76.767	40.869
1000	77.33	40.064
1250	73.986	38.966
1600	71.795	37.084
2000	71.617	35.188
2500	71.055	32.599
3150	69.697	29.188
4000	68.853	26.352
5000	65.992	23.123
6300	63.848	19.483
8000	62.604	15.958

While the equivalent noise levels at three measurement points (MP4-MP6) are higher than 75 dBA, the average stationary noise of this type of vehicle satisfies the acoustic requirement of TSI specification.

Since the limit value of 85 dB, which is defined for the pass-by noise of diesel multiple unit at speed of 80 km/h, is achieved by the vehicle that runs at 60 km/h, noise emission of class 711 unit is expected to exceed the limit value recommended by TSI for the vehicle speed of 80 km/h.

Considering that rail acoustical roughness has not been taken into account, the emitted noise level of this type of vehicle may deviate significantly from presented results at different railway sections.

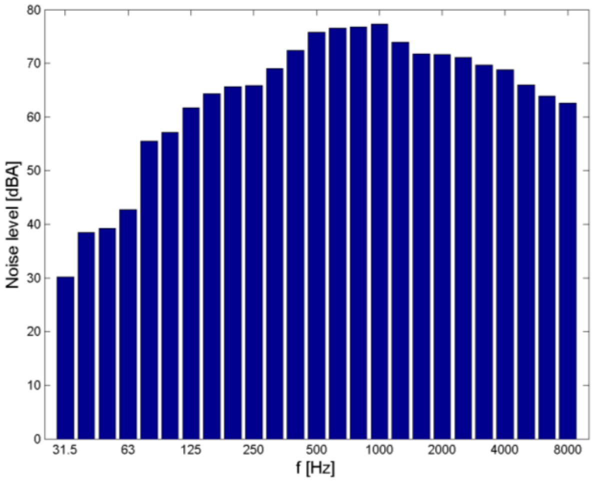

Fig. 7 *One-third octave spectrum of railway vehicle pass-by noise*

In order to fully characterize the noise emission of class 711 diesel unit, the series of pass-by noise measurements should be performed at different vehicle speeds. Further, all important track parameters and their influence on noise emission should be determined.

ACKNOWLEDGEMENT

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