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NOISE CONTROL FOR A BETTER ENVIRONMENT

Noise and vibration evaluation of the Budapest metro train's monoblock and duoblock wheels

Nagy, Daniel Szilveszter[1]
Vibrocomp Ltd.
Hungary, Budapest, 1118 Bozókvár str. 12.

Bite dr., Maria[2]
Vibrocomp Ltd.
Hungary, Budapest, 1118 Bozókvár str. 12.

ABSTRACT

The renewal of the subway cars of line M3 has started in 2016 and the first new Russian trains were in operation since January 2017. Older - almost 40 years old – trains were still on the track with duoblock wheels which were replaced by monoblocks during the renewal. In 2010, the old trains of line M2 were replaced by modern Alstom subway cars with monoblock wheels due to the increased noise and vibration problems. Population complains also increased regarding line M3. Meanwhile, line M3 has also declined dramatically and began to be reconstructed intermittently from 2017.

We performed noise and vibration measurements in several residential houses and in a hospital building before and after the renewal of the trains. According to the results of the measurements, the noise and vibration emission of the renovated trains are higher than the old ones. Therefore, regulation limits were defined before the reconstruction in order to meet the limit values laid down by law.

Reconstruction of the track will completely replace the rails and new, softer rail pads will be installed at different sections due to vibration protection. After the reconsruction monitoring noise and vibration measurements will be carried out to assess the adequacy of vibration protection.

The difference between monoblock and duoblock wheels and the resulting noise and vibration emission values will be shown in the presentation. Moreover, the estimations based on measurements and the different types of wheels and their expected noise and vibration levels after the reconstructed track in the protected buildings are also will be presented.

Keywords: Noise, vibration, Subway

1. INTRODUCTION

Metro line 3 connects the Northern and Southern parts of Budapest on the Pest side. The metro line can be divided into 3 main parts: north and south parts run in shallow tunnel, in the downtown area in deep tunnel. End of 2017 started the reconstruction of the

[1] info@vibrocomp.com
[2] bite@vibrocomp.com

Northern section. Russian metro cars run on metro line. January 2017, the first renovated / reconstructed subway car started to operate along the metro line.The

Figure 1: Old and renew Russian metros

2. NOISE AND VIBRATION INVESTIGATIONS

Noise and vibration investigations were prepared considering the following methods:

Noise investigations

During the investigations the SEL values of passages were recorded and we determined the equivalent sound pressure level values for daytime and night-time periods in the room to be protected with help of the daily traffic.

The following noise limit values shall be met in the rooms to be protected:

Premises to be protected from noise	Limit value (LTH) for LAM rating level* (dB)	
	daytime 06-22 h	night-time 22-06 h
Hospital wards and infirmary	35	30
Residential rooms in residential buildings	40	30

Table 1: Noise limits inside buildings

Vibration investigations

According to the standard, the maximum value of the weighted vibration acceleration generated during the passage of a subway car measured with the time constant "F" was recorded at the test points.

The measurements were fulfilled in the following points:

- Right and left track, between the track (rails)
- Along the walls next to the metro track

- In the closest building to be protected (in residential buildings and hospital)

In Hungary, investigation thresholds and load limit values for vibration on human beings shall met the following limit values in buildings:

Nr.	Building, premise		Vibration investigation threshold* (mm/s2)	Vibration load limit values* (mm/s2)	
			A0	AM	Amax
1.	Particularly sensitive room for vibration (eg. operating room)		3,6	3	100
2.	Residential building, recreation building, social housing, accommodation service buildings, hospitals, rest and residential premises of sanatoriums	daytime 06-22 h	12	10	200
		night-time 22-06 h	6	5	100

Table 2: Vibration limits inside buildings

In residential buildings and tunnel, noise and vibration measurements were made as follows:

In residential rooms, one three-directional acceleration meter and a microphone were placed in the middle of the room. In the rooms, the noise and vibration values were measured with a 4-channel sound and vibration level meter at the same time.

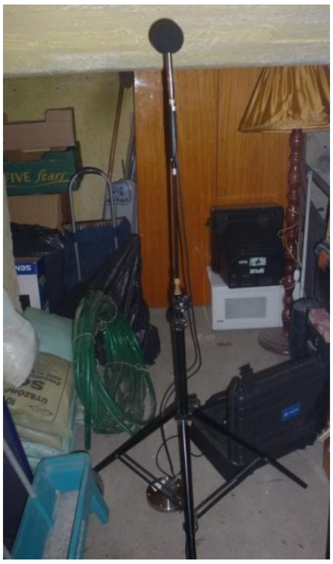
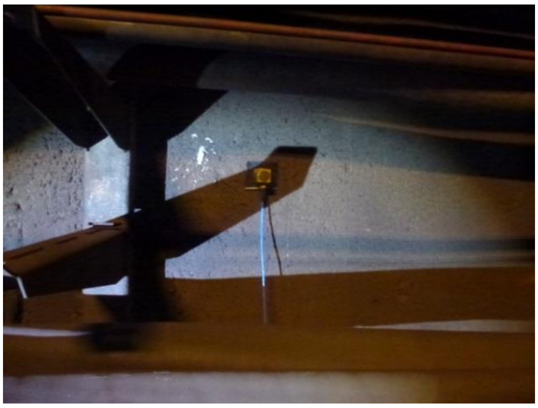


Figure 2: Noise and Vibration Measurement inside buildings

Parallelly, two acceleration meter were placed in the tunnel: one three-directional in the axis of the track on the track plate and 1 one-directional on the tunnel wall.

Picture 3-4: Vibration measurement in the tunnel

In the residential building and in tunnel at the same time fulfilled measurements, in order to identify the subway cars passed by the time of the meters were harmonised.

2.1 Description of noise and vibration sources

The primary environmental noise and vibration source in the M3 tunnel is the passage of Metrovagonmas 81-717.2K and 81-714.2K old and renewed subway cars between 4 am and 24 pm. The cars run every 10 minutes early morning and late night, every 3-5 minutes during the day.

Previously, the allowed speed limit was 80 km / h along the track, but with its deterioration, the rakes are running at 60 km / h currently.

3. RESULT OF NOISE INVESTIGATIONS

The following table shows the authoritative values of noise load determined during measurements:

Measurement Point Number	Location	Authoritative sound pressure level ’A’ calculated from equivalent[dB]		Authoritative sound pressure level ’A’ calculated from SEL_A [dB]		Limit Value [dB]		Value of Exceedance [dB]	
		daytime	night-time	daytime	night-time	daytime	night-time	daytime	night-time
MP1	1091 Budapest, Üllőiút 167.	33,6	30,1	**32,5**	**26,1**	40	30	-	-
MP2	1082 Budapest, Üllőiút 78.	42,3	40,1	**34,6**	**28,2**	35	30	-	-
MP3	1085 Budapest, Üllőiút 18.	30,1	23,8	**26,0**	**19,6**	40	30	-	-
MP4	1051 Budapest, Bajcsy-Zsilinszkyút 22.	25,4	20,5	**25,8**	**19,4**	40	30	-	-
MP5	1054 Budapest, Bajcsy-Zsilinszkyút 54.	38,1	30,9	**32,6**	**26,2**	40	30	-	-
MP6	1138 Budapest, Váciút 136.	30,5	24,8	**29,3**	**22,8**	40	30	-	-
MP7	1042 Budapest, Árpádút 90-92.	33,3	26,3	**26,6**	**20,2**	40	30	-	-

Measurement Point Number	Location	Authoritative sound pressure level ’A’ calculated from equivalent[dB]		Authoritative sound pressure level ’A’ calculated from SEL_A [dB]		Limit Value [dB]		Value of Exceedance [dB]	
		daytime	night-time	daytime	night-time	daytime	night-time	daytime	night-time
MP8	1131 Budapest, Madarász Viktor u. 22-24.	33,8	23,9	**28,2**	**21,7**	35	30	-	-

Table 3: Noise measurements results in the buildings

The following statements can be made from the previous table:

- Authoritative sound pressure level ’A’ calculated from equivalent can differ significantly (>3 dB) from the Authoritative sound pressure level ’A’ calculated from SELA. The reason is that the road traffic noise load appears at the test points. Where the difference is significant, road traffic is the dominant source of noise.
- At MP4 measurement point the Authoritative sound pressure level ’A’ calculated from SELA (during the daytime) is higher than the Authoritative sound pressure level ’A’ calculated from equivalent. In this case, the metro is the dominant source of noise.

4. RESULT OF VIBRATION INVESTIGATIONS

The following tables show the values of passages giving the highest vibration values of the passages.

Location	**Average vibration acceleration ($A_{w,eq}$) [mm/s^2]**	**Maximum vibration acceleration (A_{Max}) [mm/s^2]**	**Frequency range [Hz]**	**Allowed Velocity [km/h]**
KMRP–1 Bajcsy-Zs u 54	1,0	3,2	50-125	80
KMRP–2 Üllői út 167	2,0	6,8	50-125	80
KMRP–3 Üllői út 18	0,8	2,0	50-125	80
KMRP–4 Üllői út 78	2,7	12,4	50-125	80
KMRP–5 Váci út 164c	0,6	2,0	50-125	80
KMRP–6 Bajcsy-Zs u 22	1,5	4,1	50-125	80
KMRP–7 Madarász u 22-24	0,8	2,3	50-125	80
KMRP–8 Árpád út 90-92	1,8	4,3	50-125	80

Table 4: The highest vibration loads measured in buildings at metro passages

Vibration levels determined during vibration investigations:

Due to the different buildings, it is understandable that there are significant differences in the buildings at a car passage in noise and vibration level aspects. The difference between the maximum vibration values was 2-3 mm/s2 on average. During the time of a passage the highest vibration acceleration was measured at Üllői út 78 (Semmelweis University II. Clinic of Obstetrics and Gynaecology).

The average vibration acceleration of the cars at Gyöngyösi út are summarized in the following table:

Rake	Velocity (km/h)	Averaged maximum vibration acceleration **along the track** (mm/s^2)	Averaged maximum vibration acceleration along the **wall** (mm/s^2)	Averaged maximum vibration acceleration at the **hospital** (mm/s^2)
2 new	60	1468,8	6,8	1,7
3 old	60	21,9	3,7	1,2
4 old	60	23,1	2,6	1,2
5 new	60	908,2	21,2	1,7
6 old	60	623,9	5,8	1,2
7 new	60	406,2	12,4	1,5
8 new	60	921,2	19,3	1,6
9 old	60	1400,5	8,2	1,4
10 new	60	608,8	6,3	1,0

Table 5: Averaged maximum vibration load of rakes measured at the right tunnel at Gyöngyösi út (green: low vibration emission, yellow: medium vibration emission, white: high vibration emission)

Based on the measurements, two groups can be distinguished from vibration acceleration aspect at the measuring points at Gyöngyösi út based on the vibration accelerations measured along the track.

- Cars with low vibration value (<30mm/s2): 3 old, 4 old
  along the track 21,9-23,1mm/s2,
  Along the wall 2,6-3,7 mm/s2,
  at the hospital 1,2-1,2 mm/s2

- Cars with high vibration value (>100 mm/s2): 2 new, 5 new, 6 old, 7 new, 8 new, 9 old, 10 new,
  along the track 313,2-1468,8 mm/s2,
  Along the wall 5,8-29,3 mm/s2,
  at the hospital 1,0-2,1 mm/s2.

The average vibration acceleration of the rakes at **Station Klinikák** are summarized in the following table:

Rake	Velocity (km/h)	Averaged maximum vibration acceleration **along the track** (mm/s²)	Averaged maximum vibration acceleration **along the wall** (mm/s²)	Averaged maximum vibration acceleration **along the hospital** (mm/s²)	Averaged maximum vibration acceleration **at Üllői út 18** (mm/s²)
1 old	60	128,8	14,3	3,8	0,8
2 new	60	34,4	11,1	3,6	1,3
3 old	60	78,5	7,9	3,1	3,6
4 old	60	154,7	9,4	2,5	3,0
5 new	60	104,7	11,4	3,8	1,9
6 old	60	22,4	7,0	6,0	2,5
7 new	60	53,3	17,3	3,3	3,2
8 new	60	116,4	46,4	10,1	1,8
9 old	60	17,0	6,9	2,1	2,4
10 new	60	24,0	8,1	2,5	1,7

Table 6: Averaged maximum vibration load of rakes measured at the right tunnel at Klinikák (green: low vibration emission, yellow: medium vibration emission, white: high vibration emission)

Based on the measurements, three groups can be distinguished from vibration acceleration aspect at the measuring points at Station Klinikák based on the vibration accelerations measured along the track.

- Cars with low vibration value (<30mm/s2): 3 old, 4 old,
  Along the track 17-28,4 mm/s2,
  Along the wall 6,9-9,8 mm/s2,
  at the hospital 2,1-6 mm/s2,
  at Üllői út 1,3-3,4 mm/s2

- Cars with medium vibration value (30<100 mm/s2): 7 new,
  Along the track 33,8-98,4 mm/s2,
  Along the wall 7,9-29,4 mm/s2,
  at the hospital 2-5,7 mm/s2,
  at Üllői út 1,1-3,7 mm/s2

- Cars with high vibration value (>100 mm/s2): 2 new, 5 new, 6 old, 8 new, 9 old, 10 new,
  Along the track 101,5-272,2 mm/s2,
  Along the wall 9,4-46,4 mm/s2,
  at the hospital 2,5-10,1 mm/s2,
  at Üllői út 0,8-3 mm/s2

The average vibration acceleration of the rakes at **Pöttyös utca** are summarized in the following table:

Rake	Velocity (km/h)	Averaged maximum vibration acceleration **along the track** (mm/s^2)	Averaged maximum vibration acceleration **along the wall** (mm/s^2)	Averaged maximum vibration acceleration **at Üllői út 167** (mm/s^2)
2 new	60	21,3	8,1	3,8
3 old	60	27,4	11,4	3,7
4 old	60	15,6	6,4	2,9
5 new	60	57,8	18,6	13,2
6 old	60	17,0	5,7	2,6
7 new	60	12,4	4,4	2,9
8 new	60	21,7	7,8	6,0
9 old	60	24,3	9,5	7,4
10 new	60	14,3	5,8	3,1

Table 7: Averaged maximum vibration load of rakes measured at the tunnel at Pöttyös utca (green: low vibration emission, yellow: medium vibration emission, white: high vibration emission)

Based on the measurements, two groups can be distinguished from vibration acceleration aspect at the measuring points at Pöttyös utca based on the vibration accelerations measured along the track.

- Cars with low vibration value (<30mm/s2): 2 new, 3 old, 4 old, 6 old, 7 new, 8 new, 9 old, 10 new,
Along the track 8,7-27,7 mm/s2,
Along the wall 3,8-12,1 mm/s2,
at Üllői út 1,5-7,4mm/s2

- Cars with medium vibration value (30<100 mm/s2): 5 new,
Along the track 37,7-73,4 mm/s2,
Along the wall 13,4-22,9 mm/s2,
at Üllői út 9,2-16 mm/s2

From the previous tables followings can be stated:

- There are significant differences in the maximum vibration acceleration averages between the individual test points (in the immediate vicinity of the cars, beside the rails). The reason for this can be the difference in track quality between stations.
- The average maximum value of the vibration accelerations determined at Gyöngyösi utca is extremely high, which assumes that the suspension of the rails is getting loose.
- From the measurement results it can also be clearly seen that the vibrations transmitted to the wall are significantly lower than measured along the rails.
- This is due to high frequencies of vibration accelerations. The higher frequency vibrations can be attenuated to a greater extent over shorter

paths than lower frequency vibrations. (According to our investigation these vibrations in the ~ 400-Hz 1/3 octave band were significantly attenuated at the wall, but were hardly detectable at the place to be protected)

- From the average maximum value of the vibration accelerations determined at Station Klinikák can be stated that typically lower vibration accelerations are caused by old type (non-renovated) cars. The reason for this is due to the wheels of the renovated rakes. The surface of the wheel of the old type is surrounded by a rubber ring which acts as a vibration-reducing element. While this vibration-reducing element is missing from the renovated rakes.

During the measurements, frequency analysis was performed in 1/3 octave band. The frequency spectrum of the measured vibration at the different measurement points on the left and right tracks is illustrated in the following figure:

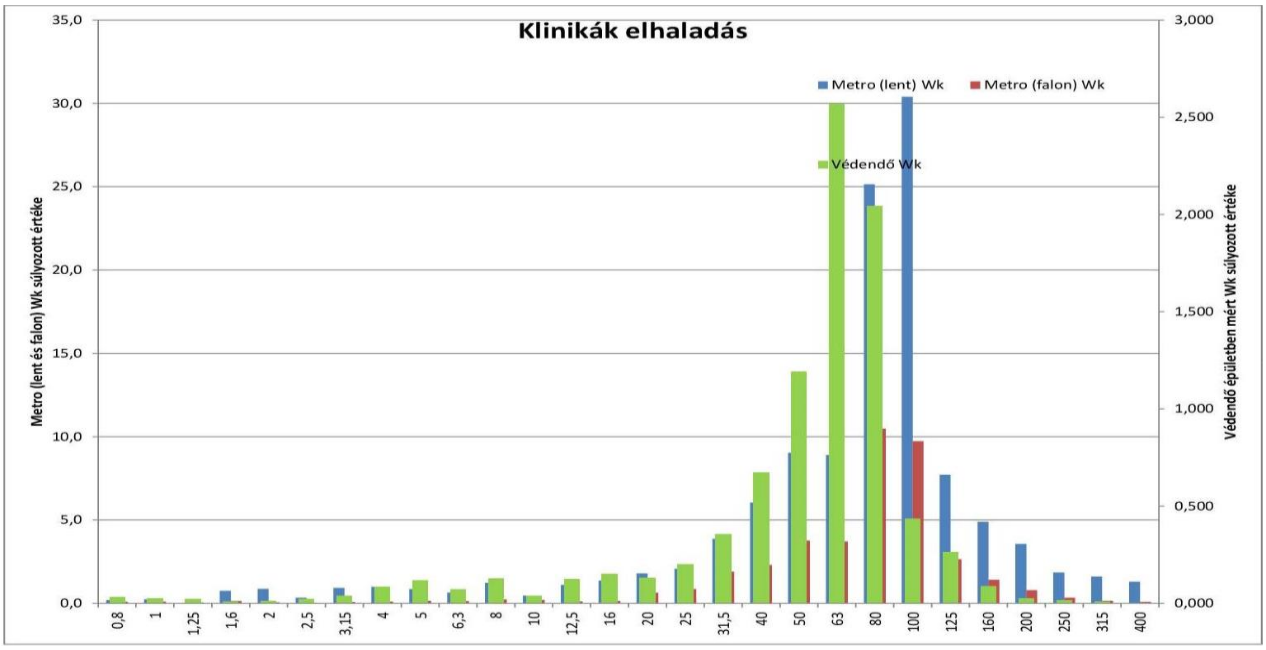


Figure 5.: 1/3 octave band spectrum (0.8-400 Hz) of an average metro rake passage at Station Klinikák

Based on the previous figure, it can be stated that the vibration load from the metro passage propagates significantly in the 63 to 80 Hz spectrum from the tunnel to the buildings.

Comparing the previous measurements and the results of vibration emissions in the tunnel, it can be concluded that a coherent relationship in the vehicle-track-tunnel – residential building system cannot be clearly established - the vibration peaks occurred at different times. Therefore, it can be stated that a particular point along the track cannot be assigned with sufficient certainty, where the problem is constantly present in case of each vehicle.

5. CONCLUSIONS

Noise protection

Based on the measurements, it can be concluded that the authoritative sound pressure level 'A' calculated from metro passage (SELA) at each test point meets the limit values of the regulations. The authoritative sound pressure level 'A' calculated from equivalent can differ significantly.

Vibration protection

Based on the tests, it can be concluded that the problem causing the vibration load is generated by a system interaction. But it is caused by the track structure and the cars in a dominated way. The 50-63-80 Hz range, which appears in the residential buildings, is the system's own frequency – therefore, it gets transmitted with a significantly lower attenuation through the ground to the determination points. The vibration emission of the cars with old-type (rubber-ringed - duoblock) wheels is in average lower than the vibration emission of the new type of renovated cars (monoblock).