AN ANALYSIS OF NOISE POLLUTANTS IN CITY SUBWAY TRANSPORTATION

Retta ZEWDIE[1], David MARČEV[1], Martin HALBERŠTÁT[2]

[1]Department of Vehicles and Ground Transport, Faculty of Engineering, Czech University of Life Sciences in Prague, Czech Republic
[2]ŠKODA AUTO, Mladá Boleslav, Czech Republic

Abstract
Noise in general, is any unwanted sound in any mode of transportation, and exposure to it can be a serious threat to health. Subways are among those considered as sources of urban noise, which adversely affect health. This paper, presents the results of survey conducted on noise levels of Prague City subways transport system. Over 240 noise measurements were made. Noise levels were measured using a sound level meter on both subway lines, Line A (green) and line B (yellow) lines for comparison. On both lines the return measurements were conducted namely in the first, third and fifth compartments. The maximum average noise level measured on the line A (green) subway in all three compartments was 94.1 dBA (decibel-A weighting) and 96 dBA in Line B (yellow) respectively. These results indicate that the maximum noise levels in subway cars have exceeded recommended exposure guidelines from the World Health Organization.

Key words: *excessive sound, hearing damage, sound level, rail noise.*

INTRODUCTION

Noise irritates or worsens the mood of individuals in passenger compartments and even disturbs or damages hearing capacities if it continues for long periods. In rail transport, the dominant source is the rolling noise caused by speed increase, depending on the acoustic pressure. Traction, chassis, and aerodynamic noises are among the prominent excess noise producing components which should be addressed carefully. Rolling noise is mainly caused by wheel surface contact with the rail. It is also produced at the chassis where friction occurs. Rolling noise is determined by the quality of the track, and the quality of the vehicle, especially the chassis system. A high incidence of noise and long exposure to it often causes permanent effects on to human health. Measurements should be taken both in the daytime and at night.

Noise level measurements serves to find ways to reduce noise and consequently provide guidance to effectively fight for environmental protection. Higher noise levels increase the risk of damage to the body, especially to an individual's hearing. If a person is present long-term in an environment where the noise is 65 dB, the human vegetative reactions change. These are mainly changes in behaviour, irritation and other negative symptoms that are difficult to identify initially. Another signs may be more frequent headaches. In the case of permanent residence in the 85 dB environment, permanent hearing disturbances occur, which can lead to permanent hearing loss. At the same time, the effects on the vegetative system and the whole nervous system become more apparent. Hygiene limits of noise at work stations is provided by Czech Government Decree No. 272/2011 Coll. (*Liberko, 2004*; *Nový, 2001*; *Zewdie & Kic 2016)*. These noise limits apply only to the engine-driver cabin and excludes the noise caused in passengers compartments. Neither standard nor law regulate noise limits in public areas of stations and platforms in enclosed spaces such as metro tunnels. From the point of view of passengers in individual cars, the Czech standard CSN 281310 is used *(Nový & Kučera 2009)*. However, this standard no longer distinguishes between surface and subsurface transport. The result limits are approved by the manufacturer upon confirmation of the Rail Authority.

The concept of the noise level impacts primarily on passengers and the highly exposed engine-drivers. Researchers *Persinger, 2014; Jandak, 2007* have come to the conclusion that noise is the quality of sound interaction with human biology. The extensive research work led by *Nelson, J. T. et. al., 1997,* states that noise is also included in the provisions of Section 30 of the Public Health Protection Act. The technical sources of noise are the subject of state health surveillance carried out by public health authorities. The research conclusion states that noises and vibration from rapid transit systems are caused by wheel/rail interaction and is influenced by factors such as wheel and rail roughness track supports and variations of surface contact stiffness.

These sources of noise are generated by the interaction of wheel and rail, and radiated by the wheel and rail to the vehicle interior and wayside *(Thopson, 2009).* The human ear is capable of responding to a very wide range of sound pressures; at the threshold of pain the sound pressure is roughly 1 million times as large as the sound pressure at the threshold of hearing. Physical definitions cannot be determined because noise is a subjective impression and depends on the individual's relationship to the given sound. Recommendations for station platform noise levels should be especially considered because, trains entering and leaving subway stations should not produce noise levels in excess of 85 dB. The noise level limits for above grade stations are 80 and 85 dB for concrete sleeper track beds, respectively. Noise levels 5 dB below these limits are desirable. Compartment noise levels are normally measured at 1.5m above the platform, roughly midway between the platform edge and rear wall, or 1.5m from the platform edge, whichever is closer to the track *(Persinger, 2014).*
The noise levels apply to the total noise level, including noise due to rail sources as well as traction engine equipment, vehicle ventilation and air conditioning equipment, and brake systems. (The APTA guidelines also provide limits for continuous noise levels caused by station and subway ventilation fans, and recommend station reverberation times to control speech intelligibility of public address systems.) Tangent track rolling and curving noises are due to wheel and rail roughness, which may include rail corrugation and random surface defects. Smooth rolling surfaces produce less vibration The average noise level measured on the line A (green) subway in all three compartments was ~ 76 dB (decibel-A weighting) and ~ 78 dB in Line B (yellow) respectively. These results indicate that the average noise levels in subway cars have exceeded recommended exposure guidelines from the Czech health standard recommendation. The maximum average noise level measured on the line A (green) subway in all three compartments was 94.1 dB (decibel-A weighting) and 96 dB in Line B (yellow) respectively. The results show a breaking of the safe exposure limit of 74 dB.
The aim of this study is to explore specific areas where excessive noise levels appear to be the highest and passengers likely to be adversely affected by the Prague metro's rail transport. The investigation on the cause of noise level presence was carried out on both sides of metro drive.These findings reveal the confirmation that noise potentially poses a health threat to passengers.

MATERIAL AND METHOD

To carry out this research the authors used a very precise measuring instruments which is shown in Fig. 1, and two Prague metro lines, line A (green) and line B (yellow). The measurement was held on both lines in first, third and fifth compartments (wagons) from each line including the reverse ride. The location of the measuring device with the stand is shown in Fig. 2 in the wagon**.** For the noise level measurement a frequency analyser of the brand made by CESVA instrument, a brand manufactured in Barcelona was applied. The SC 310 has a measurement range that allows it to measure noise without adjusting the range. Device settings have been selected with respect to the required data. The sound pressure level setting with slow time weighing was selected during the measurement.

Fig. 1 Measuring device

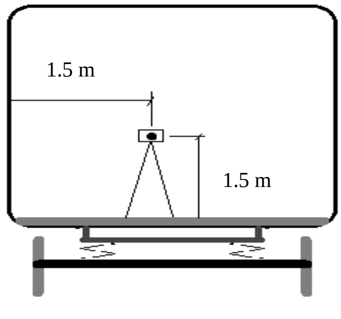

Fig. 2 Placement of measuring device

Fig. 1 shows noise level measurement device. It is a frequency analyser of the brand made by CESVA instruments, producing acoustic devices and Fig. 2 indicates the placement of the measuring device

CESVA in the wagon for noise levels data collection, which is normally measured at 1.5m above the compartment floor, roughly midway between the side edge and rear /front side, 1.5m from the surface edge.
Line A (green) has a length of 17.129 km. The entire route takes 30 minutes to ride with the shortest train arrival/departure interval of two minutes at peak hours. Up to 200,000 passengers use the line daily. *Motol Hospital* and *Depo Hostivař* stations are surface stations. The deepest place is located in the *Náměstí Míru* station at a depth of 52 meters below the surface. The maximum set speed is 80 km/h one train can accommodate up to 1580 passengers
Line B (yellow) is 25.7 km long and connects the, densely populated western Prague district *Stodůlky*, with the equally populated eastern area of *Černý most*. The route has 24 stations. The peak time train arrival/departure interval is 2.5 minutes. Line B serves (yellow) serves up to 350,000 passengers a day. The total ride time is 41 minutes. The deepest station is *Můstek*, which lies at a depth of 40.3 meters below the surface. The route also has two unusual features and these are transparent overland bridges. These are between the stations *Hůrka* - *Lužiny* and *Rajská zahrada* - *Černý most*. The metro line has three surface stations.

Tab. 1 Table of standard CSN 281310 (interior)

Noise interior cabin	
Carriage speed 60 km/h	78 dBA
Noise in the drivers cabin at 60 km/h	74 dBA

(Source: CSN 28 1310 - Subway cars for passenger transport - Basic technical requirements and tests)

Tab. 1 shows the recommended noise level Czech Republic hygiene standard for subway cars passenger transport. Measurements were adapted to individual needs in kits, so as to be able to absorb the noise as well as register most passengers. Measurements were taken over the weekend due to the lower frequency of passengers out of peak hours.

RESULTS AND DISCUSSION

An important factor is the intensity of the noise barriers surrounding distance from the noise source. On most routes subway lines are routed down their own separate tunnel and metro trains visually and acoustically meet only at stations. On some sections however there are metro tunnels for both metro trains. These sections have a larger space where acoustic waves can travel through the environment. Noise from the perspective of long-term load in individual sections of lines, but also selected local and short-term noise impulses. The reasons are different factors, notably the speed and the technical condition of vehicles *(Thopson, 2009)*. However, noise can be accurately determined and analyzed over longer periods of time. When comparing the noise level of individual metro lines, the largest noise load on line B (yellow) was measured with an average value of 78.17 dB (*Zličín* - *Černý Most*) respectively 78.63 dB in the opposite direction ride. The noisiest sections of the line B have repeatedly exceeded 90 dB and this is more than the Czech standard ČSN 28 1310 prescribes. The measured data confirms at stations between *Jinonice – Radlicka* and *Hloubetín – Rajská Zahrada*. The line A was measured and the average noise was 75.65 dB and 75.94 dB respectively. The highest values then appeared in the *Dejvická* - *Bořislavka* and *Náměstí Míru* - *Jiřího z Poděbrad* sections, where they repeatedly reached over 90 dB.

Tab. 2 Measured data of Line A (Green)

Line "A"	Motol to Hostivař			Hostivař to Motol		
	1. wagon	3. wagon	5. wagon	1. wagon	3. wagon	5. wagon
Max [dBA]	97.3	92.8	93.2	91.9	97.3	91.8
Min [dBA]	56.9	54.0	58.4	53.7	56.9	59.8
Average [dBA]	75.83	75.43	75.63	75.33	75.89	76.64
SD [dBA]	8.1	9.1	7.5	9.1	8.1	6.9

Tab. 2 shows the results of the first measurement that took place on March 26, 2016. On this day, data on line A (green) were recorded in both directions. All six records were measured continuously.

Tab. 3 Measured data of Line B (Yellow)

Line "B"	Zličín to Černý Most			Černý Most to Zličín		
	1. wagon	3. wagon	5. wagon	1. wagon	3. wagon	5. wagon
Max [dBA]	95.3	93.9	97.9	96.9	96.3	95.9
Min [dBA]	58.4	61.6	59.4	58.5	60.9	62.5
Average [dBA]	76.97	78.46	79.02	78.04	78.41	79.52
SD [dBA]	8.6	8.0	8.7	8.6	8.6	8.0

Tab. 3 indicates the Line B (yellow) line measurement that took place the following day, ie on March 27, 2016. The last line B was measured 2.3.2016. All six measurements were continuous. On the last day of the measurement, the values from the selected stations were recorded for comparison. The record was recorded at noise level meter CESVA SC310. An illustration of the location of the sound level meter is shown in Fig. 2 for measurements in the wagon interior. The front seat of car was chosen because of the axle and chassis location.

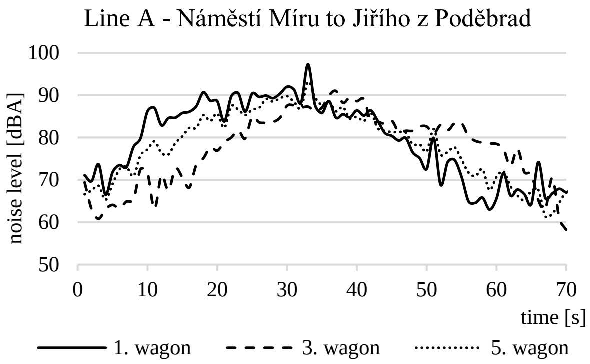

Fig. 3 Graph of the noise level between two stations

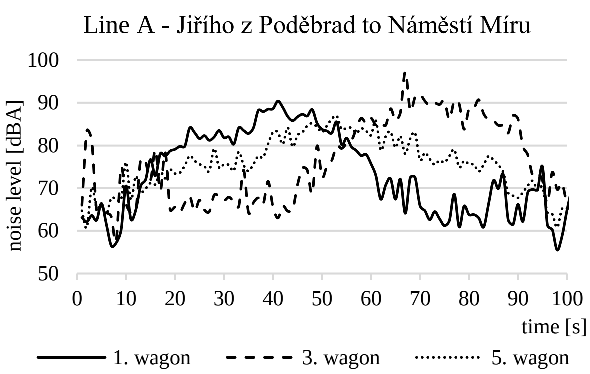

Fig. 4 Graph showing the reverse ride

Fig. 3. Shows the noise level characteristics of line A (Green) from *Náměstí Míru* stop to *Jiřího z Poděbrad*. The maximum values are observed on the 32-33 seconds ride, in the 1st and 5th wagons respectively, 97.3 dB and 93.2 dB. These values could be the result of crossing a rail switch *(Thopson, 2009)*. It is clear from the graph that a similar course of noise level during the ride was recorded during individual rides. This similar pattern is the result of adherence to the timetable, where in this case the metro trains were perfectly on time.

Fig. 4 Shows the reverse ride of line A (green) from *Jiřího z Poděbrad* to *Náměstí Míru,* where very different noise levels were observed. Interestingly, a different style of driving was observed given to compliance with the timetable. From the data the noise level in the third wagon was recorded and there was a maximum 97.3 dB. The noise level between stations on this ride was higher than the noise noise level on the other runs.

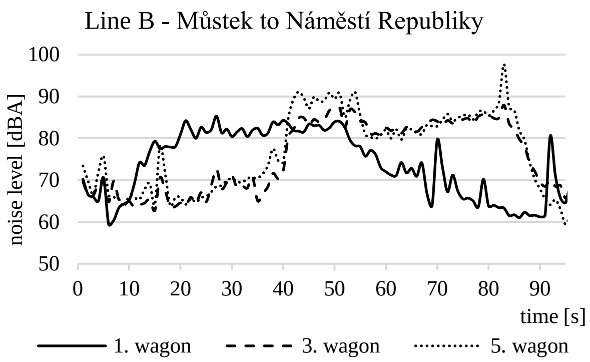

Fig. 5 Graph of the noise level between two stations

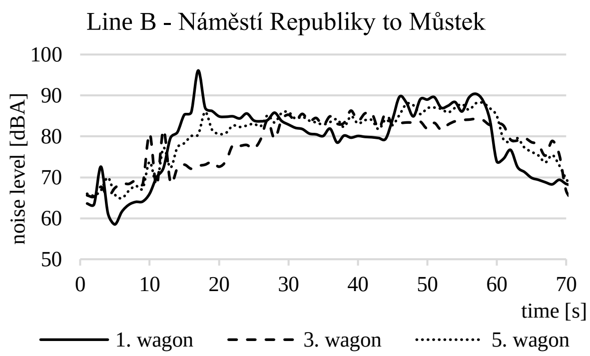

Fig. 6 Graph showing the reverse ride

Fig. 5. During measurements on the subway line B (yellow) pronounced maximums were recorded between *Můstek* and *Náměstí Republiky*, and also between stops *Luka* and *Lužiny* stations. The graph shows the record of the measurements between stops *Můstek* and *Náměstí Republiky*, where a different

driving style of metro trains is again evident. The drive recording shows measurements in the first wagon were different from the third and fifth wagon measured.
Fig. 6. In the opposite direction, the trip logs were almost identical, showing the same driving style during all measurements. Only when measuring the noise level in the first wagon a significant peak maximum of 96.1 dB was recorded, which is not reflected in the other runs.

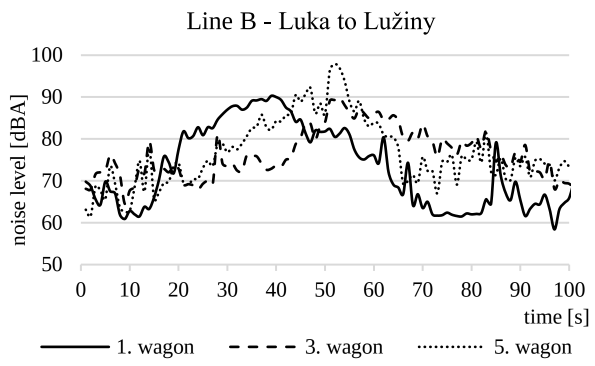

Fig. 7 Graph of the noise level between two stations

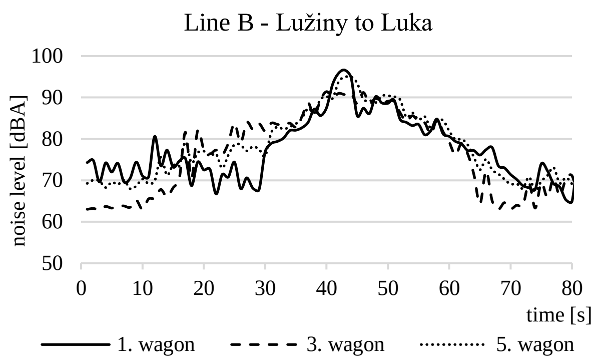

Fig. 8 Graph showing the reverse ride

Fig. 7. On the same route, subway lines maximum noise levels were recorded even during the ride between *Luka* and *Lužiny*. The maximum value was recorded when measuring the noise level in the fifth wagon (97.9 dB).
Fig. 8. When measuring in the opposite direction between *Lužiny* and *Luka*, very similar noise levels were recorded for all rides. The maximum values were recorded in the 1st and 5th wagons measurements (96.6 dB and 95.0 dB). From the measured values it can be seen that the noise level measurement is dependent on the style of driving assembly, which is influenced by the need for punctuality.

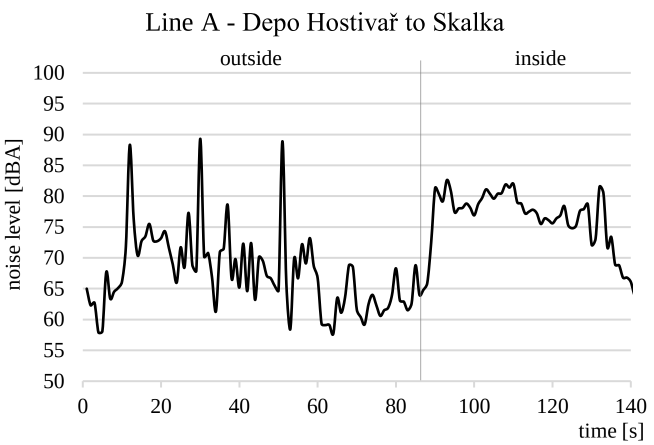

Fig. 9 The metro train noise level of outside and inside ride

The graph on Fig. 9 shows the noise level differences at the surface ride of the subway (0 - 88 s). From the graph, it is clearly observed that as soon as train enters the tunnel the noise level increases. The interior tunnel average surface noise level was 71.5 dB, whereas riding in a tunnel shows 10 dB less noise level. The registered noise level peaks on the surface are caused by crossing the sliding rail.

CONCLUSION

Sound absorption barrier walls made of concrete or brick reflect practically all of the energy contained in the acoustic waves which strike them directly. However, these reflected waves may still find their way over the wall by being subsequently reflected off the train car and then diffracted. That was what has been observed in tunnels of Prague subway tunnels. To prevent this, absorptive material may be fixed to the surface of the wall. The absorbing mechanism is caused by friction between moving air and the loose fibres or pore walls in the sound absorbing treatment. The friction between the air and porous

or fibrous absorptive material converts the acoustic energy to heat, thereby attenuating the sound. The excavated stations include *Dejvice*, *Strašnická* and *Skalka*. Other tunnels are built by punching.
The data obtained from subway line A (green), it is evident that the section between stops *Dejvická – Nemocnice Motol* was higher noise level observed in the recent built tunnel than prior built sections. Tunnels built by *Tunnel Boring Machine* and *Earth Pressure Balance* (TBM – EPB) technologies, with six segments of reinforced concrete thickness of 250 mm and width of 1.5m with insulation clenched in the joints, confirms the theory by *Nový, 2001 & Nelson, 1997,* principles of noise expansion based on ambient conditions. The measured data in general indicate that subway cars riding on the surface satisfy the Czech health standard recommendation, whereas in tunnels exceed. It has also been confirmed that noise levels depend mainly on vehicle speed and associated chassis noise and aerodynamic noise.

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Corresponding author:
Dr. Ing. Retta Zewdie, Department of Vehicles and Ground Transport, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 165 21, Czech Republic, phone: +420 22438 3101, e-mail: zewdie@tf.czu.cz