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PROBLEMATIKA HLUKU TRAMVAJOVÉ DOPRAVY A JEJÍ VLIV NA ŽIVOTNÍ PROSTŘEDÍ

PROBLEMS OF TRAM TRANSPORT NOISE AND ITS ENVIRONMENTAL IMPACT

Summary

This work is the first systematic processing of the problems of noise from tram transport in relation to the construction of the tram track in the Czech Republic. It brings a summary of a great quantity of acoustical measurements on tram tracks, and presents new variants of evaluation of noise from tram transport. In addition to the commonly used evaluation by means of the equivalent noise pressure level, the possibilities of evaluation of noise levels by means of average spectra of noise levels and by means of multispectra of noise levels are extended, which allows a considerably more detailed and higher-quality characterization of the acoustical behaviour of particular structures of tram tracks.

Acoustical measurements were performed from 1997 to the beginning of 2003 on different structures of the permanent way of tram tracks, and in this way the influence of different changes in these constructions on the resulting noise levels was tested. The constructions were selected according to the requirements of the Prague Public Transit Company. The measured noise levels of tram train passes along the measuring place were continuously recorded on a measuring tape-recorder. The records were then processed in the laboratory on different analysers according to the required outputs.

In all, 139 tram train passes over 11 existing constructions of the tram track permanent way were measured and evaluated in order to evaluate the noise levels of current constructions. All the tram tracks have been in operation for some years. The aim of this measurement was to find the differences between the noise levels of these constructions, and to qualify the optimal construction of the tram track permanent way that minimally pollutes the environment in the city with noise.

Further on, reduction in the noise levels of tram transport due to the grinding of the railhead surface table, first performed in Prague in 1997 by a new special grinding machine of foreign origin, was monitored. This section was exposed to long-term monitoring every half a year – in total, 139 passes of tram trains were measured. It was necessary to design a new evaluation method of an “average spectrum” for the evaluation of this long-term measurement, which was later used for the evaluation of other measurements where the reference tram cannot be used.

The area of further monitoring was the measurement of noise levels of tram transport before and after a complete reconstruction of the tram track permanent way, mainly in such cases when an absolutely different construction was used, or where noise-absorbing elements were inserted. The aim of this measurement was to find the effect of different types of permanent way constructions and noise-absorbing elements on tram transport noise reduction. In all, 429 passes of tram trains on six reconstructed tram tracks were measured and evaluated.

In the conclusion, research findings and recommendations for the design of environmentally-friendly tram track constructions are summarized. The result of long-term measurements is a design method for a complex evaluation of the measurement of noise levels from tram transport, which allows a more precise characterization of the effect of the tram track on noise emissions.

Souhrn

Práce je prvním systematickým zpracováním problematiky hluku tramvajové dopravy ve vztahu ke konstrukci tramvajové trati v České republice. Přináší přehled velkého množství akustických měření na tramvajových tratích a nové varianty hodnocení hluku tramvajové dopravy. Mimo běžně používaného hodnocení pomocí ekvivalentních hladin hluku, rozšiřuje možnosti hodnocení o průměrná spektra hladin hluku a časové rozvoje spekter hladin hluku, které umožňují podstatně podrobnější a kvalitnější popis akustického chování jednotlivých konstrukcí svršků tramvajových tratí.

Akustická měření byla prováděna od roku 1997 do začátku roku 2003 na různých konstrukcích svršku tramvajové tratě s cílem určit vliv nejrůznějších změn v těchto konstrukcích na hladiny hluku. Konstrukce byly voleny v souladu s požadavky Dopravního podniku hl. města Prahy. Měřené hladiny hluku při přejezdu tramvajového vlaku kolem měřicího stanoviště byly průběžně zaznamenávány na měřicí magnetofon. Záznamy byly potom zpracovávány v laboratoři na různých analyzátorech podle požadovaného výstupu.

Bylo změřeno a vyhodnoceno celkem 139 přejezdů tramvajových vlaků po 11 stávajících konstrukcích svršku tramvajové tratě pro vyhodnocení hlučnosti stávajících konstrukcí. Všechny tramvajové tratě byly několik let v běžném provozu. Cílem těchto měření bylo zjištění rozdílů v hlučnosti jednotlivých konstrukcí a vytipování optimální konstrukce svršku tramvajové tratě nejméně zatěžující hlukem životní prostředí ve městě.

Dále bylo sledováno snížení hlučnosti tramvajové dopravy vlivem broušení hlav kolejnic, provedené v roce 1997 poprvé v Praze novým zahraničním speciálním strojem na broušení hlav kolejnic. Úsek byl sledován dlouhodobě v půlročních intervalech – celkem bylo změřeno 139 přejezdů tramvajových vlaků. Pro hodnocení tohoto dlouhodobého měření bylo potřeba navrhnout novou vyhodnocovací metodu „průměrného spektra“, která byla později využita i při hodnocení jiných měření, kdy nebylo možné použít referenční vozidlo.

Další oblastí sledování bylo měření hlučnosti tramvajové dopravy před a po komplexní rekonstrukci svršku tramvajové tratě, zejména tam, kde byla použita zcela jiná konstrukce svršku nebo byly v konstrukci použity protihlukové prvky. Cílem bylo zjištění vlivu jednotlivých konstrukcí a protihlukových prvků na snížení hluku tramvajové dopravy. Celkem bylo změřeno a vyhodnoceno 429 přejezdů tramvajových vlaků na šesti úsecích rekonstruovaných tramvajových tratí.

V závěru jsou shrnuty poznatky a doporučení pro navrhování konstrukcí tramvajových tratí šetrných k životnímu prostředí. Výsledkem víceletých akustických měření je navrhovaná metoda komplexního vyhodnocování měření hladin hluku tramvajové dopravy, která umožňuje přesnější charakterizování vlivu konstrukce tramvajové tratě na hlukové emise.

Klíčová slova
městská hromadná kolejová doprava, tramvajová doprava, dopravní hluk, konstrukce svršku tramvajové tratě, kryt tramvajové tratě, broušení povrchu hlavy kolejnice, pružné bokovnice, nové prvky v konstrukci tratě, ekvivalentní hladiny hluku, spektra hluku, časový rozvoj spekter hladin hluku, procentní hladiny hluku

Keywords
city mass rail transport, tram transport, traffic noise, construction of tram track permanent way, tram track cover, grinding of rail head surface, resilient filling blocks, new elements in track construction, equivalent sound pressure levels, noise spectra, time multispectra of noise, percentage noise levels

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1. Introduction

To start with, a historical overview is usually given. The history of a really serious monitoring of noise impact on the human body, however, is not very long. Although he negative influence of high noise levels on human health was known long ago (so-called cannoneer disease), due to the fact that they did not represent a serious threat to anybody's life, other problems were given preference. It was only a steep growth in civilization diseases in the last several decades that brought about the necessity of monitoring the negative effects of all sorts of emissions, (including noise emissions) on the human body and the environment.

One of the most significant properties of sound (and noise) is that it spans relatively large distances, hundreds of metres and more. At the same time, it propagates through air, water or solid mass as well, e.g. through the structure of buildings. In specific conditions, it can reflect, refract and diffract. Consequently, noise acts on everybody who is within the reach of its energy spreading, i.e. also on the persons who have nothing in common with the noise source. For such people, this noise is undesirable and useless. The situation gets worse in enclosed and semi-enclosed spaces, as in the streets of cities (Fig. 1). Then, the people exposed to traffic vehicle noise are not only those exploiting the respective means of transport, but also thousands of people on the streets of the cities and in the neighbouring buildings.

Fig. 1 Sound pressure levels in Vodickova street in time of tram pass

Protection of the environment is one of the most important tasks of current communities. Next to much more strongly perceived air and water pollution, noise as well is one of the major risk factors of the acceptable environment. Only seemingly is noise less dangerous than chemical pollution, and doctors demonstrated its dangerousness even in the cases, when it does not cause reduction in hearing sensibility or directly deafness. Noisiness in the environment grows with progressive technicalization of our life in a such scale that not only highly exceeds the limits of hygienic tolerability, but in many cases gets out of control in the sense that it exceeds the technical and economic possibilities of keeping the consequently growing noisiness of the environment below acceptable (even though surpassing hygienic tolerability) limits. Excessive noise exposure of people at work lowers their productivity and quality of work, endangering also significantly the health and safety at work. In the social and cultural context, noise reduction is closely connected with increasing the standard of living, namely in terms of living and spending free time.

2. Legislative

The area of noise produced by tram transport began subject of systematic monitoring in the Czech Republic only in the 1990s. The several acoustic measurements preceding this date served special-purposes and were carried out only once, without monitoring data enabling any comparison.

The first obligatory regulation in our republic was issued as late as in 1977 - it was ministerial regulation of MZd CSR No. 13/1977 Sb., on health protection against harmful effects of noise and vibrations, and Sanitary Regulations of MZd CSR volume 37/1977, which contained:

- Directive No. 41/77 Highest permissible values of noise and vibrations
- Directive No. 42/77 Method of measurement and evaluation of noise and ultrasound in working surroundings
- Directive No. 43/77 Method of measurement and evaluation of noise in buildings for living, in civic buildings and in outdoor spaces
- Directive No. 44/77 Method of measurement and evaluation of noise from air traffic.

In the year 2000, Act No. 258/2000 Sb. on public health protection was issued, which clearly defined that noise is generated from the operation on roads. The previous regulation allowed a statement saying that noise is generated only by vehicle movement and as such it, in fact, is not in any relation to the traffic route. To Act No. 258 relates a government decree No. 502/2000 Sb. on health protection against harmful effects of noise and vibrations, which establishes unexceedable hygienic immission limits of noise and vibrations at workplaces, in buildings for living, in civic buildings and in outdoor spaces, and the method for their measurement and evaluation.

In 2003, the amendment to Act No. 258/2000, Act No. 274/2003 Sb. was issued, where, apart from surface roads, tracks are also mentioned. In 2004, the government decree No. 502/2000 was amended by the government decree No.

88/2004 Sb., giving more precise definitions of protected spaces and a simpler specification of limits. Because of a high quantity of objections, this regulation is being reviewed again. According to this regulation, e.g. tram transport cannot be unambiguously classified and the corresponding hygienic limit cannot be found. No tram traffic, but only railway traffic and traffic on roads, is mentioned there.

Emission limits of noise are set by special regulations, usually separately for a specific group of sound sources (such as kitchen appliances). Outdoor noise of transport vehicles is legislatively defined for planes, road vehicles and even riverboats. Formerly, the standard CSN ISO 3095 Acoustics. The measurement of noise radiating from rail-mounted vehicles, was in force in our country, however, evidently did not include trams, because the prescribed conditions were totally unreal for trams, e.g. the reference track type, speed range etc. It was cancelled without replacement after 2000.

3. Tram transport

Tram transport experienced its largest bloom in the first quarter of the 20th century, when it constituted a reliable type of high-capacity mass city transport. At that time, at least one tram track existed in the major part of economically significant cities of the world. Later on, trams were gradually replaced by bus, trolley transport, or by metro in large cities, and then by individual car transport. Except for the states of Central and Eastern Europe and a few exceptions in the world, tram transport was badly restricted in the 1960s. As a consequence of the critical environment deterioration in large cities and their congestion by cars, renaissance of light rail transport as in the classic – "tram" form, so-called "light rail transport" in the modern terms, has occurred starting from the 1970s-80s. In the English speaking countries, this term is in general used for the systems of city rail transport with a light rolling stock of modern shapes, using modern technologies and materials.

Tram transport represents one system of the city mass rail transport. It is characterized by short distances between stops, especially in the city centres, and short intervals between trains, which produces, on one hand, a relatively high transit capacity (in a range of 14 000 – 20 000 passengers per hour), and, on other hand, an average travel speed in a range 15 – 18 km per hour, (but the highest technical speed ranges from 60 – 80 km per hour). Tram trains consist mostly of one to three coaches, at present also fully or partially equipped with a low floor. The tracks are mostly double-tracked, placed on street level together with road transport, or on its own segregated track in the centre or along the edge of city roads. If the operation system is not totally separated from the other kinds of transport and from pedestrians, or if crossings with other types of transport are not solved as a multi-levelled system, the safety and service reliability, and the possibilities of utilization of full-scale automation of operation control, lead to a more and more rigorous separation of the tram transport track from the other kinds of transport, including pedestrians. Tram transport is also the most suitable transport mode for servicing pedestrian precincts.

4. Environmental impact of tram transport

Due to the fact that the recently implemented systems of light rail transport should also help to improve the environment in the cities, the major focus is not only on capacity, speed and operating costs, but, for the first time in the history of rail transport, on its environmental impact. The systems of tram and especially light rail transport present themselves as ecologically the most positive modes of mass city transport (with the exception of metro). The main factors of tram transport, which contribute to the increasing quality of life of the inhabitants of the city, are:

- vehicle drive by electric power which creates no pollutants in the place of tram train operation,

in comparison to other traffic systems of road city transport, tram transport:

- has lower demands on space occupation,
- is less power exacting,
- is much safer.

The only negative effects of tram transport on the environment are the emissions of noise and vibrations. The noise emissions of tram transport, are in a range of not only over the limits of annoyance, but often also even over the limits of negative effects on health. Although the number of people affected by the noise of tram transport is much lower than the number of persons affected by the noise from road or air transport, the noise of tram transport affects a significant proportion of the inhabitants of larger cities of industrial countries. Vibrations from tram transport acting on inhabitants mostly do not exceed the permitted limits, they may, however, have an adverse influence on some building materials and elements, especially on brickwork masonry, pargets and sculptural decorations of facades, historical monuments etc.

In many cities of the world, research on the wheels and the structure of tram tracks proceeds. Single city tram networks are not interconnected, there is no so-called reference vehicle, even within one state, as transportation of a tram train to another city would be too difficult. Vehicle characteristics are variable in time, regardless of the fact if the vehicle is or is not in operation. For the same reason, the results of measurements from one city made with the same type of vehicle, but with a time delay also have only limited comparability.

The independence of transit companies providing tram transport are frequently the significant reason why, up to now, there exist no Czech or European standards that would deal with the noise of tram transport radiated outside the vehicle, especially in relation to the type of the vehicle and the type of the tram track construction. The absolute majority of tram systems are owned by municipalities, in contrast to the railway, in which the state has its majority share, and whose integration in the legislation is therefore necessary. The finding and exploitation of an acoustically suitable type of tram train and track structure are additionally frequently restricted by the economic possibilities of transit companies of these cities.

All measurements of tram transport noise and loudly promoted low noise levels achieved are invariably valid just for a particular section of the tram track of the considered city and one measured vehicle. There do not exist any generally valid relations, which would make it possible to define the effect of using a certain element in the tram track or vehicle structure on noise reduction.

5. Noise of tram transport

The noise of tram transport (as well as of all rail mounted transport) is always a randomly changing noise in a time domain in whose spectra all frequencies are represented. The time and frequency variation contains several maxima; the spectrum is down trended with significant components up to 2 kHz. The volume of the noise is affected by the speed of the vehicle (tram train), the type of the vehicle and tram track construction, the number of vehicles in the considered time interval, the conditions of the track and vehicles' maintenance, the distance of the monitored point from the source of noise etc. Diffusion of noise is further affected by the shape and surface of landscape, by the placement, dimensions and surface of obstacles (natural or artificial) and climatic conditions (rain, snow, wind).

The noise of tram transport is composed of many partial noises whose sources are in all moving components. As the tram train moves along the tram track, the vibrations are carried inside it as well, and are further propagated by the structure of the tram track and the surrounding soil in a form of vibrations. The noise is then partly emitted directly by the vehicle and the tram track as air noise, partly it is propagated in the form of vibrations, and it can affect the structures within its range of reach, which it makes vibrate, or eventually it is able to make surface elements swing and evoke so-called secondary noise.

The sources of tram transport noise may be subdivided into four groups with different properties:

1. **rolling noise,** arising by the rolling of wheels over the rail and by their roughness; rolling noise also includes all noises from the vehicle undercarriage and all noise radiating from the tram track,
2. **driving noise** (the noise of the driving engine, cooling, compressors, suction etc.), the noise due to oscillation of the coach body and the noise of service aggregates (ventilation, air-conditions, lighting, etc.),
3. **noise of electric current collector**,
4. **local traffic noises** (the noise of starting and braking, alert signals, driving over turnouts, bridges etc.).

While noises in points 1 - 3 operate at every place of the tram track, noise 4 is always only of local character.

Rolling noise and driving noise are emitted at different heights (Fig. 2) and depend on the running speed (each in a different way though). The noise of the collector depends namely on the material used. For tram transport, this noise has only a small effect on total noise. In 1995 –96, aluminium ledges of collectors were exchanged for graphitic ones, but no acoustic measurement was published. The degree of annoyance of local traffic noises is difficult to predict, and they are often necessary for the safety of operation.

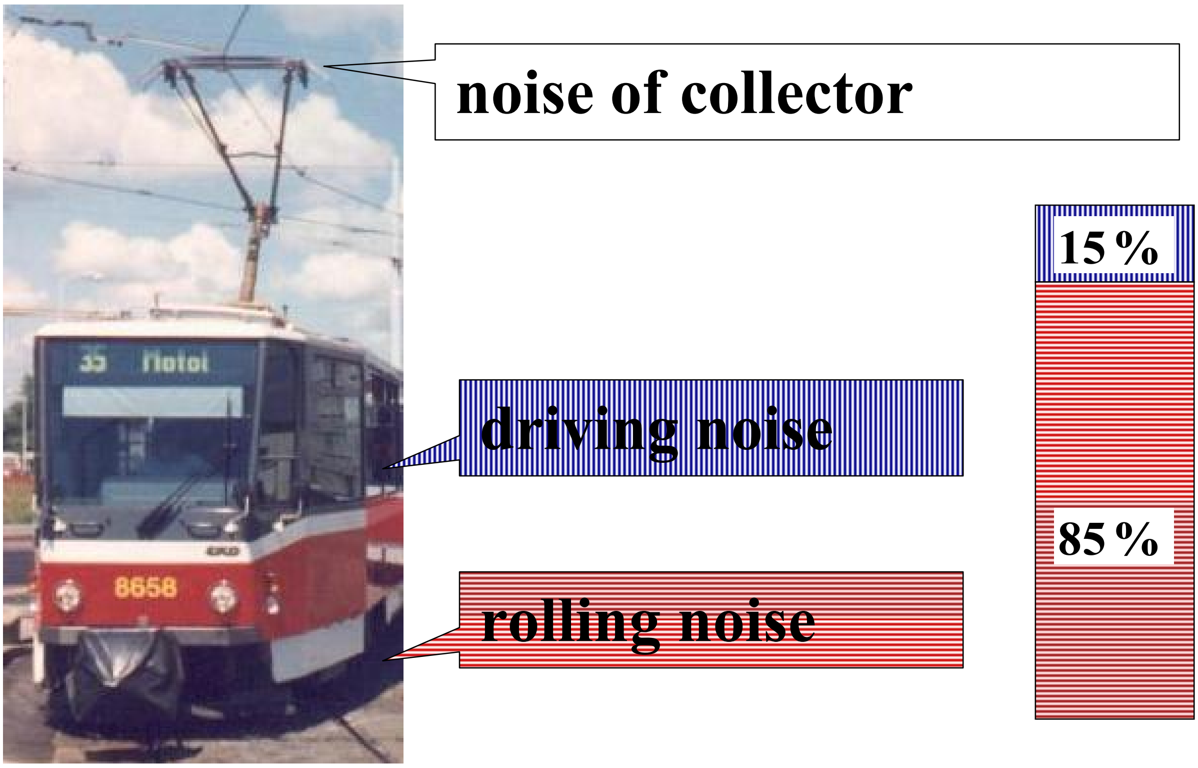

Fig. 2 Sources of tram transport noise

For speeds of up to about 60 km per hour, rolling noise dominates, which grows linearly (for higher speeds driving noise dominates, which grows with the cube of speed). For tram transport with most frequent speeds of up to 40 km per hour, therefore, the effect of speed is usually not so significant. Partial noises participate in the total acoustic emission from tram transport by a bigger or smaller proportion. Worldwide research demonstrates that rolling noise forms the most significant components of the total noise of rail mounted transport, which is greater, when the vehicle moves more slowly. At ordinary speeds of tram transport in central parts of cities, rolling noise composes 80 - 90 % of the total noise emission from tram transport (Fig. 2). Further on, it is necessary to take into account that rolling noise from tram transport can be emitted no higher than at the height corresponding to the vehicle floor, i.e. max. at about 0.75 m, and often lower.

6. Tram track construction

Tram transport is an unreplaceable unit of mass city transport in large cities, which is reflected by the global trend of using tram transport as a connecting traffic system to metro or other underground tracked systems. It operates especially in areas with a high density of living, working or moving people. It is also an acceptable means for providing transport service in pedestrian precincts. Trains of a new generation are often used, which technically and by their design meet the requirements for modern transportation modes. Tram transport participates in the number of transferred persons in Prague by 31 %.

The construction of the tram track consists, in principle, of the substructure and the permanent way. The tram track substructure consists of soil formation, drainage devices, culverts, supporting, retaining or revetment walls and other components. The tram track permanent way is made of a railbed (trackbed), a rail grid and a tram track cover. The railbed is a structural part that transfers the load from rail bars onto the tram track substructure. The railbed may be composed of ballast, structural layers, cross sleepers, longitudinal concrete bars, slabs of sleepers, monolithic or prefabricated slabs etc. The cover of the tram track levels the space inside and outside the rail grid to the surface level of rail heads, and also allows road vehicles to drive over the tram track (some types of slab structures of the tram track can create a slab railbed into which rails are mounted and, at the same time, they can serve as the track cover). The tram track cover may significantly affect the noise emission from tram transport.

The tram track cover forms mainly a bearing and safely running surface for road vehicles, but has also a number of other functions, for example its appearance markedly aesthetically contributes to the finishing touches of urban road environments. In historical parts of cities, it used to be most frequently made of granite blocks, in other parts of cities of concrete slabs, paving bricks, bituminous or concrete paving surfaces, combinations of concrete slabs and floated asphalt, and in the last years also of a layer of organic soil with grass cover. To separate the tram track cover from rail bars and to fill the space beneath the head of grooved rails, so-called filling blocks are used, formerly of concrete, today of rubber, rubber-based composites and similar materials.

7. Reduction of tram traffic noise

Considering tram transport as a unchangeable means of city mass transport, especially in the parts of cities with the highest density of living, working and moving people, it is necessary to pay adequate attention to protection of their health against adverse effects of noise of tram (but also other) transport. The existing city road infrastructure, especially in the historical and shopping areas of cities, does not provide any space for additional noise absorbing protection, and so the only way of noise reduction is the way of reducing the noise emissions of tram transport already at their source, i. e. solely by modifications on tram vehicles and in the structure of tram tracks.

By their activity, noise-absorbing devices can be divided into **active** and **passive.** Active devices reduce noise emissions of noise sources, while passive devices protect inhabitants against excessive stress from noise emissions.

Reduction of noise emissions of vehicles and rail mounted tracks may be reached, among other ways, by engineering devices. Vehicles are fitted with various special dampers and suspensions, cowls of undercarriage rolling parts, different materials are used for the collectors, vehicles are properly maintained to be in good technical condition etc. For the rail mounted track, structures emitting less acoustic energy and ensuring its top maintenance may be used. For tram transport, the noise emitted is closely related to the quality of the geometric situation of the track and the qualities of the rail head surface. In order to reduce noise, rubber or composite material elements (mostly utilizing recycled rubber materials) are inserted into the structure of the tram track, like, for example sub-ballast matts or elastic filling blocks (Fig. 3). Subballast matts have an effect on vibration reduction, while filling blocks damp mainly the noise emission from the rail.

Fig. 3. Rubber composite filling blocks

Since 1993, the recon-struction projects of the tram track in Prague have been increasingly applying, step by step, resilient clips Skl - Fig.4 (of various types) instead of rigid clamps ZS 3 for the faste-ning of rails; this has markedly helped to delay the degradation of the geometric situation of the tram track. The top geo-metric situation of the track contributes to the reduction of (especially rolling) noise of tram transport.

Fig. 4 Resilient clip

The size of acoustic emissions from tram transport is significantly affected by rail joints and roughness variations on the rail head surface. Tram track rails are, in the maximum possible extent, performed as continuously welded, i. e. with all rail joints welded. The most frequently appearing roughness variations on the rail head surface are variously shaped microroughness differences of the surface with short spacing. These periodical roughness variations of the rail head surface, creating longitudinal wavelets with a distance of single waves from 3 to the 8 cm and a depth from 0,02 to 0,2 mm, are called wavelets (Fig. 5).

Roughness variations on the rail head surface (wavelets, roughness in the area of welded rail joints and others) are removed by grinding by means of grinding rolling stocks or grinding machines, fitted with several rotating grinding disks fixed on an inclinable head, which makes it possible not only to remove roughness variations, but also to provide the most exact shaping of the correct rail profile.

Fig. 5 Wavelets on the rail head surface and bad rail joint

8. Tram noise measurement and evaluation

The commonly used descriptors, such as equivalent sound pressure level, percentage or extreme levels etc., are not very evidential for the classification of tram track structures either. To obtain a comparable database of measurements, the "average" spectrum (the spectrum of average noise pressure levels) method, which allows carrying out measurements in regular everyday traffic, was designed and evaluated. The noise of tram passings was scanned by a Brüel & Kjaer sound level meter Type 2231 and saved on a Sony DAT recorder. This signal was subsequently analysed by different types of analysers, according to the needed output. All measurements were taken with the microphone at a 7,5 m distance from the axe of the measured track (Fig. 6).

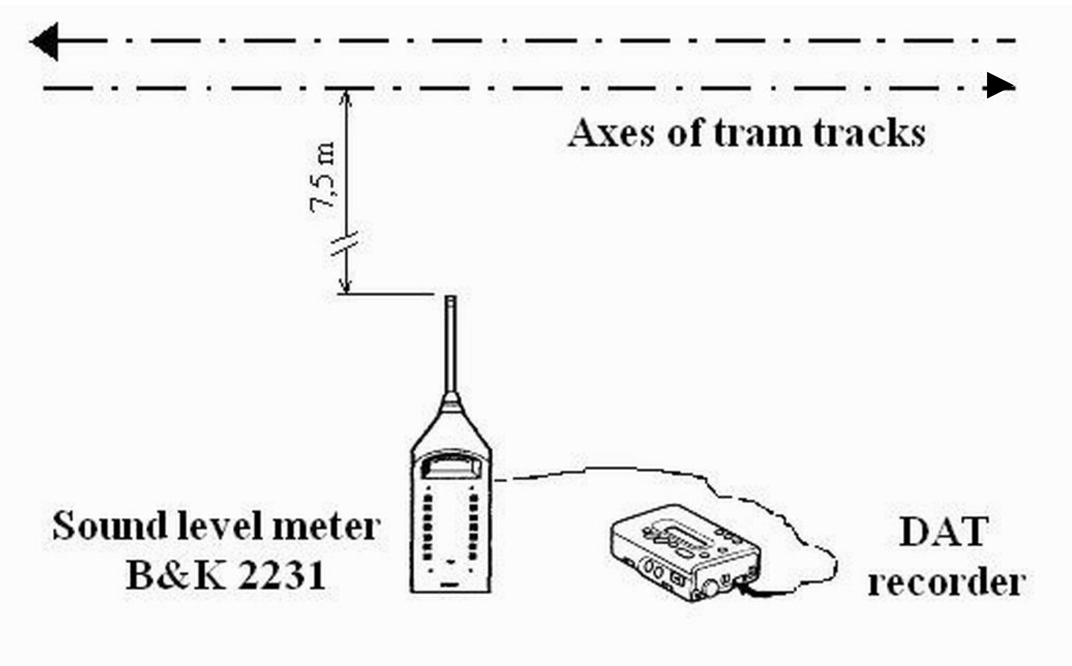

Fig. 6 Scheme of measurement

9. Results of tram noise monitoring (examples)

9.1 Monitoring the influence of rail surface grinding

Measurements on the following construction were taken in regular everyday traffic.

- **Modrany**: grooved rails, concrete sleepers, resilient clip fastening, direct fixation of rails, open ballast bed; segregated track (Fig. 7).

Fig. 7 View on measured track "Modrany"

Average equivalent sound pressure levels obtained are shown in Table 1.

Table 1: Average equivalent sound pressure levels

	Modrany				
Date	02/1997 before grinding	02/1997 after grinding	09/1997	02/1998	09/1998
L_{eq} [dB]	**92.9**	**87.2**	**84.9**	**86.4**	**88.0**
L_{Aeq} [dB]	**87.0**	**81.4**	**80.8**	**80.7**	**82.2**
Noise emission was reduced by 6 dB for long time					

9.2 Monitoring the influence of changes in tram permanent way construction

Measurements on the following constructions were taken in regular everyday traffic.

- **Vodickova**
  to May 2001: panel track system BKV, buried crane rails; street level (Fig. 8);
  from October 2001: grooved rails, concrete sleepers, resilient direct clip fastening, sound-reducing filler profile flanking the rail, sub-ballast matts; stone block pavement, street level (Fig.9).

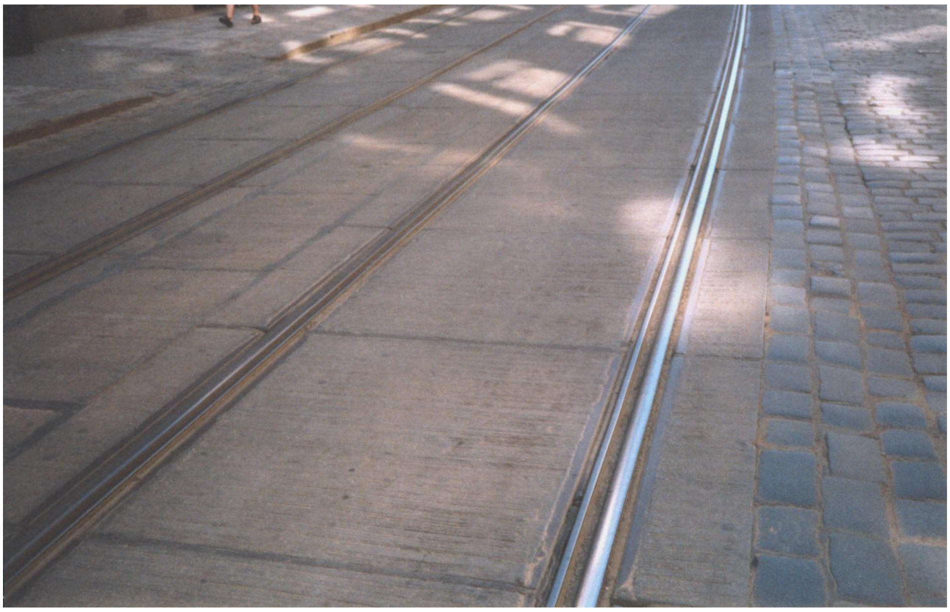

Fig. 8 View on measured track “Vodickova” before May 2001

Fig. 9 View on measured track “Vodickova” after October 2001

Average equivalent sound pressure levels obtained are shown in Table 2.

Table 2: Average equivalent sound pressure levels

	Vodickova	
Date	05/2001	10/2001
L_{eq} [dB]	**90.4**	**87.5**
L_{Aeq} [dB]	**78.1**	**72.7**
Noise emission was reduced by 5 dB		

Measurements on the following construction were taken both in regular every-day traffic and during the night by the same tram train.

- **Milady Horakove**
  to April 2002: grooved rails, concrete sleepers, resilient direct clip fastening; segregated track (fig. 10);
  in June 2002 the above-mentioned construction was completed with a sound-reducing filler profile and the tram track was embedded in grass cover (Fig. 11).

Fig. 10 View on measured track "Milady Horakove" before April 2002

Fig. 11 Finishing of cover on measured track "Milady Horakove" in June 2002

Average equivalent sound pressure levels obtained are shown in Table 3. Comparison of them is in Fig. 12.

Table 3: Average equivalent sound pressure levels

	Milady Horakove				
	in daytime		at night		
Date	02/2002	06/2002	04/2002	06/2002	09/2002
L_{eq} [dB]	**88.4**	**84.8**	**89.0**	**82.4**	**82.8**
L_{Aeq} [dB]	**81.8**	**78.4**	**84.6**	**73.6**	**74.4**
Noise emission was reduced by 3 dB			… by 10 dB !		

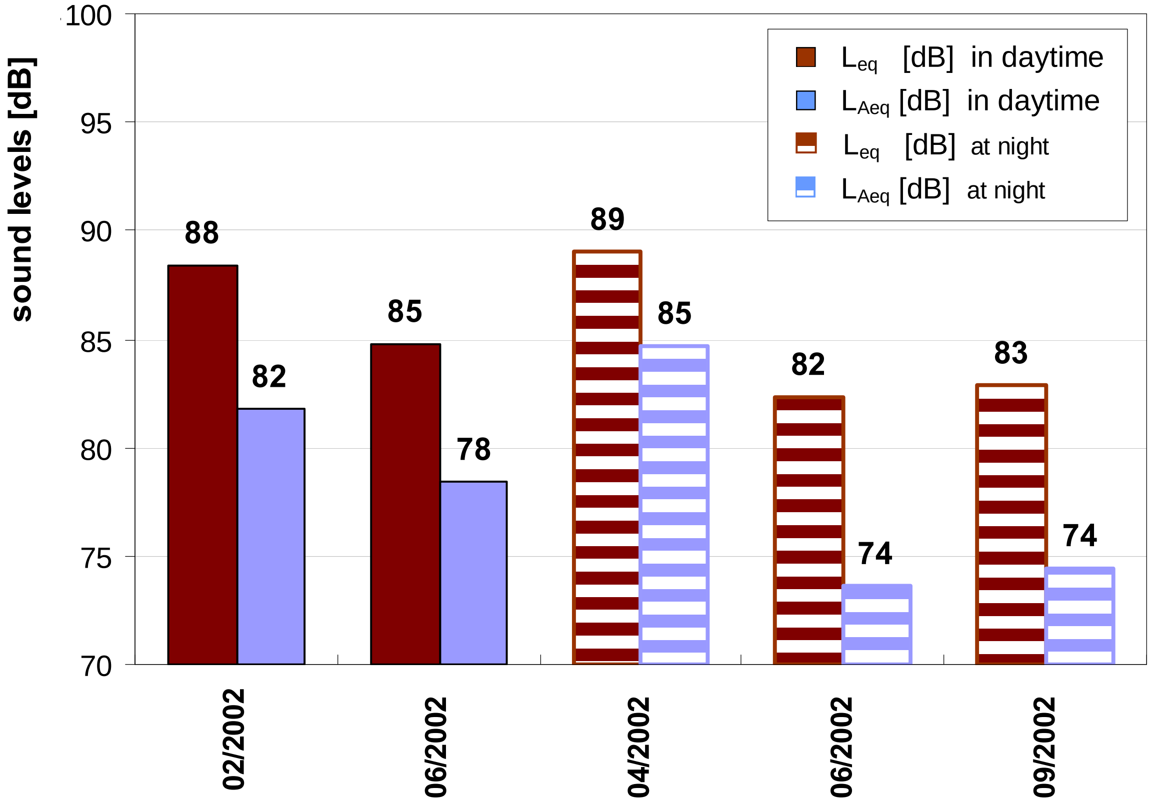

Fig. 12 Comparison of equivalent sound pressure levels

10. Conclusion

- The emission of rolling noise from the tram track significantly depends on the geometric quality of the rail head surface.
- With regards to the type of permanent way construction, the tram track with an open ballast bed is the most noiseless. On the contrary, top noise emissions are emitted by the BKV panel track system.
- If some cover is necessary, the best is grass cover, while all paved covers increase the noise emission.
- Elastic filler profiles, flanking the rail, significantly reduce the noise emission.
- The effect of sub-ballast matts on noise emissions from tram transport is still doubtful.

The results of the measurements do not allow us to draw final conclusions. Therefore, the measurement will be continued. Tram track in future may be completely separated and look like on Fig. 13.

Fig. 13 View on new tram track on Barrandov

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