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FREQUENCY ANALYSIS OF VERTICAL VIBRATIONS ACTING ON A BABY TRANSPORTED IN A CHILD CAR SEAT

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Abstract

The biggest dangers that may result from human exposure to vibrations caused by vehicle movement occur in automotive transport [6]. The vibrations experienced during vehicle ride may cause a variety of pathological symptoms arising in people. The adverse health effects may also include reduced motion control, blurred vision, or impairment of the ability of free communication, memory processes, or perception [6].

The paper covers the impact of vertical vibrations on a baby riding in a safety seat in a car, with addressing in particular the dangers caused by mechanical vibrations to children in transport facilities. Two options were considered, with the safety seat being installed on either the front or rear car seat. Experimental road tests were carried out with using a dummy representing the baby. The lack of research work on this issue has been emphasised.

For the sake of maximum safety, babies should be transported in safety seats. The type approval tests of child safety seats are chiefly focused on the evaluation of protection from harmful collision effects, according to UN ECE Regulation No. 44 [S13]. Regrettably, they do not include tests to determine the influence of vibrations, especially those occurring during "normal" ride, on the child's body.

Keywords: *baby in a car seat, vibration impact, ride comfort, human body vibration*

1. Introduction

Among the vibrations caused by technical means of transport, those occurring in motor transport impose the greatest hazard [7]. Although the ride comfort is improving, the amount of time spent by people travelling by cars is growing at the same time [5].

Recently, particular attention has been increasingly often paid by researchers to the children transported in safety seats. The type approval tests of child safety seats are chiefly focused on the evaluation of protection from harmful collision effects [S14]. They do not cover the impact of vibrations (occurring during "normal" ride in a car) on the child's body, while the vibrations actually have a considerable harmful health impact.

When the issue of the influence of vibrations on children is analysed, a tendency arises at first to take exclusively the existing normative documents, e.g. [S2, S3, S7–S9, S12], as a basis for evaluating the impact of mechanical vibrations on a child riding in a safety seat in a car (child's ride comfort). Such an approach, however, should be considered insufficient [11]. The influence of vibrations on adult people's bodies has been relatively well described hitherto, which is reflected in numerous normative acts [S1–S12]. For children, however, the studies on these issues are still at an early stage.

The undertaking of the issue of the influence of vibrations on a child riding in a car is very reasonable from the point of view of both scientific research into this topic and the obtaining of knowledge about the practical effects of this influence. It is an important task for designers of cars and child safety seats to minimize the loads caused by vibrations to the child's body. However, we should remember at the same time that the construction of a vehicle that would be "good" in terms of ride comfort related to vibrations would not simultaneously ensure "optimum" characteristics in terms of driving safety [8].

In global terms, rising trends can be seen in the volumes of road passenger transport. The road transport makes 79% the total market, as against the market shares of airborne and railway transports recorded as 5% and 6%, respectively. People's mobility increased from 17 km a day in 1970 to 35 km a day in 1998, while the motor vehicle fleet trebled in the same period and it is growing at a rate of three million vehicles a year [5].

It has been highlighted here on the other hand that numerous research works have been carried out to determine the harmful impact of vibrations on adults' bodies but very few data have been published as regards small children as passengers of transport facilities [1]. It has been shown here that the vibration absorbing capacity of the body of a small child differs from that of an adult. The frequency range where the child's body most easily absorbed vibrations was 3–16 Hz, according to tests carried out.

The vibrations experienced during vehicle ride may cause a variety of pathological symptoms arising in people, such as alimentary system disorders, pains in the lumbosacral region and in the cervical spine section, joint and muscular pains, labyrinth disorders (travel sickness), or headaches. The adverse health effects may also include reduced motion control, blurred vision, or impairment of the ability of free communication, perception, etc.

Bearing in mind the fact that such symptoms may also occur in children, we can realize how important a problem we are facing.

This paper has addressed the issue of the impact of general vertical vibrations on a baby, transmitted to the baby's body through a safety seat during a car ride.

2. Experimental road tests

Based on previous research work done at the Automotive Industry Institute (PIMOT) [9], it has been shown in publications [11] and [12] that experimental tests are needed to investigate into the impact of vertical vibrations on the body of a child (small baby inclusive) riding in a safety seat in a car.

The road tests were carried out with the use of a medium class passenger car DAEWOO Lanos (see Fig. 2 and 3).

A child safety seat designed for a small baby and meeting the type approval requirements laid down in UN ECE Regulation No. 44 [S13] was used for the measurements.

A BABY dummy (with a mass of 3.4 kg) was fixed in the safety seats under tests in accordance with the instructions of use attached to the seats. The measurements were carried out with the use of uniaxial acceleration sensors placed as follows:

– Sensor No. 1: in the head of the BABY dummy;
– Sensor No. 2: in the hip of the BABY dummy.

The sensors were positioned to measure the accelerations along the vertical axis, i.e. in the direction where the highest vibration amplitudes occur during vehicle ride.

The measurement results were used to plot time histories of the random accelerations resulting from the unevenness of the test road section.

The measurements were carried out during drives on three test road sections with different surface types:

– "Even" asphalt (Fig. 1), drive speed 60 km/h;
– "Rough" road with significant unevenness (Fig. 2), drive speed 60 km/h;
– The crossing of a "hump" (400×50 mm, Fig. 3), drive speed 40 km/h.

The following symbols have been adopted in the description of the test results:

A – "Even" asphalt,
a – Vertical acceleration,
B – Acceleration sensor placed in dummy's hip,
Br – "Rough" road with significant unevenness,
N – BABY dummy,

G – Acceleration sensor placed in dummy's head,
Gb – Crossing of a "hump",
p – Placement of the BABY dummy on the front seat,
T – Acceleration sensor placed in dummy's chest (torso),
t – Placement of the BABY dummy on the rear seat.

Example of symbol combinations: NGBr – BABY dummy (N), acceleration sensor in dummy's head (G), rough road with significant unevenness (Br).

Fig. 1. Test road section with "even" surface (asphalt)

Fig. 2. Test road section with "rough" surface

Fig. 3. Test road section with a "hump"

The road tests were carried out for two options, with the safety seat being installed on either the front (Np) or rear (Nt) car seat (Fig. 4 and 5, respectively).

Fig. 4. Safety seat with the BABY dummy, installed on the front seat

Fig. 5. Safety seat with the BABY dummy, installed on the rear seat

A comparison between the acceleration vs. time curves plotted for the NGp and NGt cases, for three road surface types, has been presented in Figs. 6, 7, and 8. The curves are similar to each other in qualitative terms; however, quantitative differences can be noticed.

At the test drives on the asphalt road section (A), higher amplitudes were recorded for the dummy placed on the front seat (Fig. 6).

At the test drive on the road section with "rough" surface (Br, Fig. 7) and at the crossing of a "hump" (Gb, Fig. 8), higher amplitudes were recorded for the dummy placed on the rear seat. Simultaneously, at the crossing of a "hump" (Gb), four "peaks" of similar acceleration values were recorded for the NGt case and a single "peak" of the same kind was recorded for the NGp case. This indicates the fact that when the car crossed a "hump," the baby in the safety seat placed on the rear car seat was evidently affected by shocks separately coming from the front and rear wheels of the car.

For different road surface types (A, Br, and Gb), the impact of vibrations on the BABY dummy depended on the placement of the safety seat (on the front or rear car seat). For the test drives on

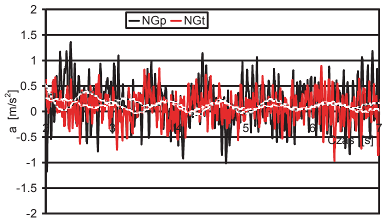

Fig. 6. Time histories of the head accelerations: test drives on the road section with "even" (asphalt) surface (A, cases NGp and NGt)

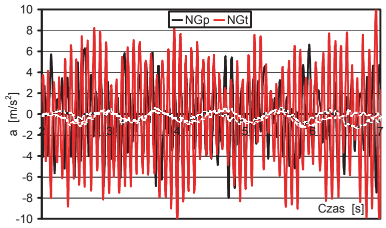

Fig. 7. Time histories of the head accelerations: test drives on the road section with "rough" surface (Br, cases NGp and NGt)

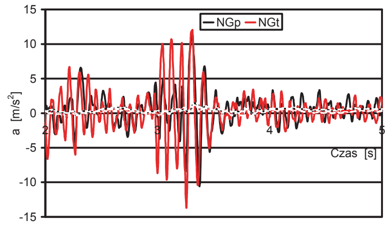

Fig. 8. Time histories of the head accelerations: test drives with crossing a "hump" (Gb, cases NGp and NGt)

the A road surface, higher acceleration values were recorded for the safety seat placed on the front car seat but for the test drives on the Br road surface and for the crossing of a "hump," the dummy acceleration values were higher when the safety seat was placed on the rear car seat.

In general, it should be stated that the acceleration vs. time curves recorded are hardly legible, which makes them difficult to be analysed and unequivocally interpreted. Only some general remarks may be formulated based on these records; this was more comprehensively discussed in publications [5, 8]. Therefore, other methods should be employed to analyse the acceleration vs. time curves recorded.

3. Analysis in the frequency domain

Based on the acceleration vs. time curves recorded, an analysis was carried out in the frequency domain by determining and comparing power spectral density (PSD) values for the signals recorded by individual sensors during the test drives on the road sections with three different surface types. The power spectral density of a signal is a characteristic of the signal, describing the power distribution of the signal in the frequency domain; therefore, it is a tool suitable for making comparisons.

Then, comparisons were made between the PSD values of the signals recorded by sensors installed in the N (BABY) dummy, i.e. the NT and NG sensors, for the safety seat placed on the front and rear car seat; the comparisons have been shown in Fig. 9–14.

For the test drives on the road section with asphalt surface (Fig. 9 and 10), the power spectral density values for the Np and Nt cases were similar to each other in both qualitative and quantitative terms. Noticeable differences occurred at 1.5–1.6 Hz frequency values.

As regards the test drives on the road section with "rough" surface (Fig. 11 and 12), the signals recorded for the Np and Nt cases showed both qualitative and quantitative differences. However, some qualitative and quantitative similarities can also be seen in the frequency range of up to 5.5 Hz. If the signal from the NG acceleration sensor is considered, the PSD values in the frequency range from 9 to 13 Hz for the NGt case grew above those for the NGp case to become from more than twenty to more than 100 times as high as the latter. For the NT sensor, a similar growth (from more than twenty to more than 100 times) in the PSD values of the NTt signal in comparison with those of the NTp signal can be seen in the frequency range from 10 to 12 Hz. For the frequency range exceeding 14 Hz, the PSD values faded out.

At the test drives with crossing a "hump" (Fig. 13 and 14), both qualitative and quantitative differences occurred between the signals recorded. In this case, a more than hundredfold growth of the PSD values of the Nt signal in comparison with those of the Np signal was recorded at a frequency of 1 Hz. At frequencies higher than 1 Hz, the PSD values of the NGp signal grew in relation to those of the NGt signal, with the ratio of this growth ranging from more than twenty to over one hundred. For the NT sensor, the growth (more than hundredfold) in the PSD value of the NTt signal occurred at frequencies exceeding 6 Hz.

Based on comparisons between the PSD values of specific signals, recorded for the safety seat

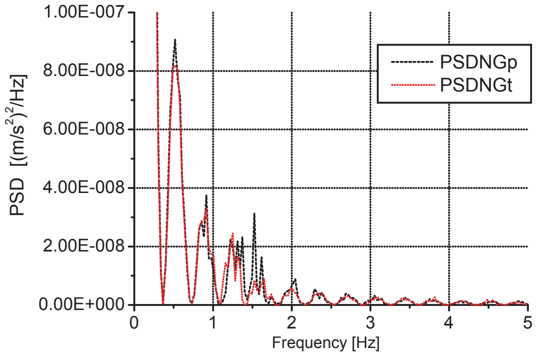

Fig. 9. PSD: test drives on the asphalt road section (A), comparison between NGp and NGt

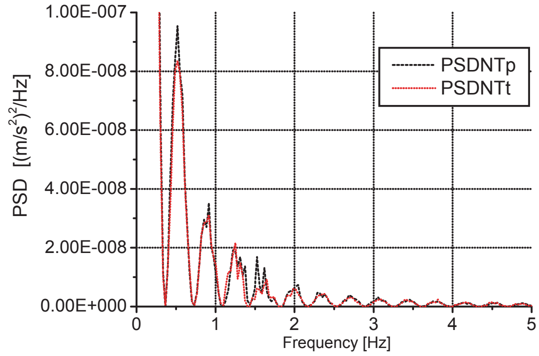

Fig. 10. PSD: test drives on the asphalt road section (A), comparison between NTp and NTt

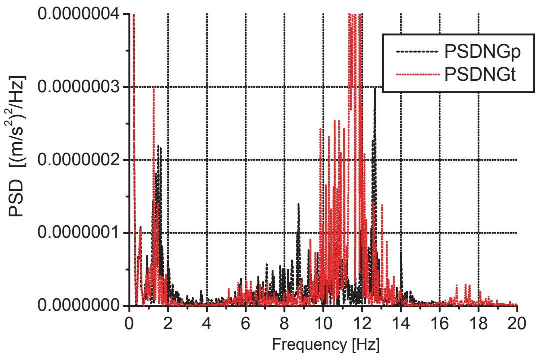

Fig. 11. PSD: test drives on the "rough" road section (Br), comparison between NGp and NGt

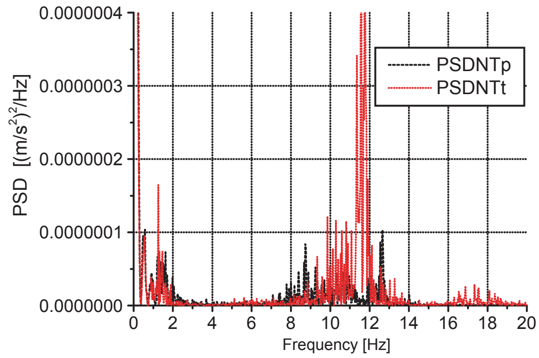

Fig. 12. PSD: test drives on the "rough" road section (Br), comparison between NTp and NTt

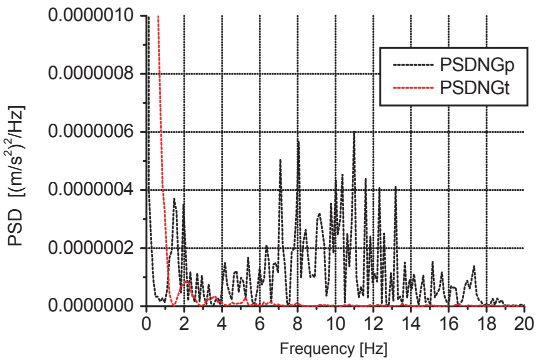

Fig. 13. PSD: test drives with crossing a "hump" (Gb), comparison between NGp and NGt

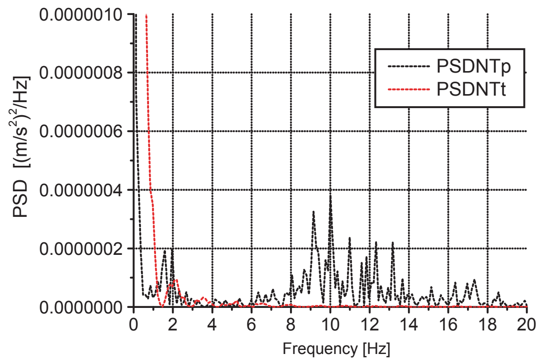

Fig. 14. PSD: test drives with crossing a "hump" (Gb), comparison between NTp and NTt

installed on the front and rear car seat during drives on roads with different surface types, the following findings may be formulated as regards the impact of vibrations on children.

1) Test drives on the road section with "even" (asphalt) surface

Noticeable differences arguing against the placing of the BABY dummy on the rear car seat occurred at frequencies of 1.5-1.6 Hz; the PSD values for the Np case were several times as high as those for the Nt case.

2) Test drives on the road section with "rough" surface.

The PSD values of the signals recorded when the BABY dummy was placed on the front and rear car seat (the Np and Nt signals, respectively) showed qualitative and quantitative differences, but some qualitative and quantitative similarities can also be seen within the frequency range of up to 5.5 Hz. For the head acceleration (NG) in the frequency range from 9 to 13 Hz, the PSD values of the signal for the rear location of the safety seat (NGt) grew above those for the front location (NGp) to become from more than twenty to more than 100 times as high as the latter. For the torso acceleration (NT), the PSD values of the signal for the rear location of the safety seat (NTt) grew from more than twentyfold to over hundredfold above those for the front location (NTp) in the frequency range from 10 to 12 Hz. For the frequency range exceeding 14 Hz, the PSD values faded out.

3) Test drives with crossing a "hump"

When the car crossed a "hump" during the tests, both qualitative and quantitative differences occurred between the signals recorded. In this case, a more than hundredfold growth of the PSD values of the torso acceleration signal for the rear location of the safety seat (NTt) in comparison with those for the front location (NTp) was recorded at a frequency of 1 Hz. At frequencies exceeding 6 Hz, a more than hundredfold growth occurred again. For the head acceleration, the PSD values of the signal for the front location of the safety seat (NGp) grew in relation to those for the rear location (NGt) at frequencies higher than 1 Hz, with the ratio of this growth ranging from more than twenty to over one hundred.

As regards children, almost no information is available about how vibrations are felt by them. The child's body most easily absorbs vibrations in a frequency range of 3-16 Hz [1]. In general, it should be noticed that for the front and rear location of the safety seat (the Np and Nt cases, respectively), the acceleration values both grew within this frequency range, and this should be considered an adverse effect.

4. Conclusions

In this paper, some problems related to the impact of vertical vibrations on a baby riding in a car in a safety seat have been discussed, with two options, i.e. with the child safety seat installed on the front and rear car seat, having been considered.

Based on an analysis carried out in the frequency domain for test drives on roads with different surface types, the following findings may be formulated as regards the child's ride comfort:

1) Within the range of the vibration frequencies recorded for the Np and Nt cases at the test drives on roads with different surface types, a "frequency shift" occurred, in result of which, in the case of a child, the vibration frequencies came into the range from 3 to 16 Hz, where the vibrations are most easily absorbed by the child's body. An exception was observed for low frequencies of 0.5 and 1.5 Hz, where the PSD values were found to be close to each other in qualitative and quantitative terms.
2) The analysis in the frequency domain has shown that the power spectral density values increased at frequencies exceeding 8 Hz, where the susceptibility of the child's body to vibrations absorbed is enhanced (this phenomenon occurred with the highest intensity in the frequency range from 3 to 16 Hz).
3) At the test drives on the road section with asphalt surface, carried out with the front and rear safety seat locations (the Np and Nt cases, respectively), the vibration impact levels were close to each other and the noticeable differences arguing against the Nt case occurred at frequencies of 1.5–1.6 Hz.
4) At the test drives on the road section with "rough" surface, the vibration impact on the child's body was higher when the child was transported in a safety seat installed on the rear car seat.
5) At the test drives with crossing a "hump", the vibration impact on the child's body was higher when the child was transported in a safety seat installed on the front car seat.

The road tests results have confirmed the need for investigations of this kind to be continued on a special simulation test stand.

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