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STUDY OF SOUND QUALITY IMPROVEMENT FOR CAR AUDIO SYTEM

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1. INTRODUCTION

Many researchers have been devoted to the car audio sound quality improvement: sound image enchancement at driver's ear positions by sound control units[1], sound field simulation for finding optimal location by using sound ray tracing method[2], sound field reproduction control method for direct and reflected sounds to create a spatial impression and presence like as a concert hall or stadium by using digital signal processing technologies[3,4]. In this paper it has been discussed that which one is mainly affecting nonflatness of the frequency response of sound pressure level(SPL) at driver's ear positions. Those are closely related with car audio sound quality : sound field characteristics in car cabin, loudspeaker acoustic features, loudspeaker installation and so on.

2. STEADY STATE RESPONSE(SSR) FOR SOUND CHARACTERISTICS IN A CAR CABIN

For the sedan type vehicle, sound characteristics have been tested by using the binaural head recording system. Four loudspeakers were directly excited without audio head units. Fig.1 depicts frequency responses at both ears of the binaural dummy head.

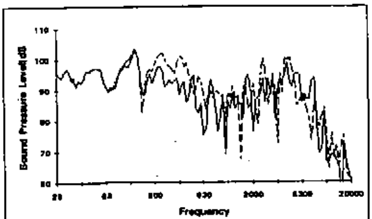

Fig.1 SPL at driver's ears under operating front and rear loudspeakers, 1 Watt(—— : left ear, — : right ear)

Fig.2~ fig.3 describe frequency responses under exciting only two front loudspeakers and two rear loudspeakers respectively. As shown in fig.2, it is not so good responses under 100 Hz but relatively good for 1 kHz range. In fig.3, the characteristics under 100 Hz range is good compared to fig.1 but it seems to be not good for 1 kHz range, since the rear loudspeakers do not contribute in this range.

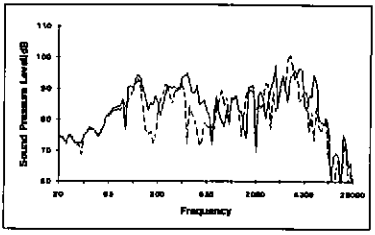

Fig.2 Sound pressure level at driver's ears under operating front loudspeakers, 1 Watt (—— : left ear, --- : right ear)

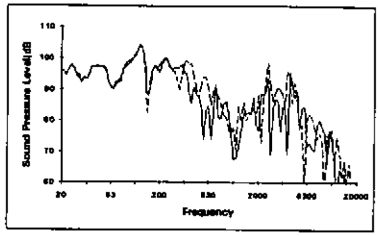

Fig.3 SPL at driver's ears under operating rear left and right loudspeaker, 1 Watt (—— : left ear, --- : right ear)

3. LOUDSPEAKER ACOUSTIC CHARACTERISTICS

On-axis acoustic response

Fig.4 for the front loudspeakers attached at a baffle shows nearly flatness between 100 and 20,000 Hz ranges. Therefore, it is confident that deterioration under 100 Hz in fig.2 is due to the loudspeakers. Fig.5 and fig.3 show that bad response in 1 kHz band is due to the car cabin spatial sound characteristics but not the rear loudspeakers characteristics.

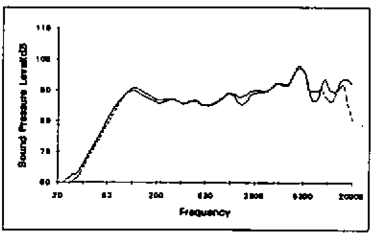

Fig.4 SPL for front left and right loudspeaker under finite baffle installed (—— : front left, --- : front right)

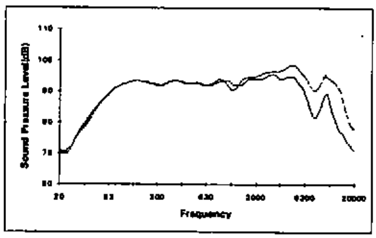

Fig.5 SPL for rear left and right loudspeaker under finite baffle installed (—— : rear left, — : rear right)

Off-axis acoustic response

Fig.6 represents off-axis frequency responses for the front left loudspeaker. Over 3.5kHz there are much discrepancies between 0 degree and the other cases(30, 60, 90 degree). It means that the loudspeakers installation angle must be considered in order to obtain the desired flat frequency response for over 3.5 kHz.

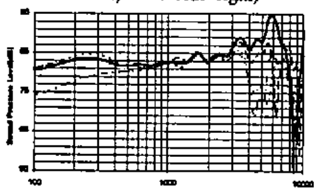

Fig.6 Frequency response for front left loudspeaker,off-axis (solid: 0°, broken : 30°, dotted: 60°,broken-dot: 90 °degree)

Modeling for loudspeaker

To obtain the freequency responses in a car cabin by modifying the parameters of the loudspeakers. it is required to identify the parameters (Thiele/Small parameters)[5]. Parameters have been indentified by the method proposed predecessors[6,7,8](Table 1).

4. ACOUSTIC CHARACTERISTICS AT DRIVER'S EAR POSITIONS BY TIME DELAY SPECTROMETRY METHOD(TDSM)

Results obtained in section 2 are the averaged SPL which is useful to get overall frequency responses. But it is not for obtaining an information for time-varying sound features. The sound listened to driver is composed of three parts according to arrival time[4]: direct sound, first reflected sound, reverberation sound. Fig.7 obtained by TDSM[9] shows the responses between baffled and car installed with front left loudspeaker.

Five tests have been performed by changing the arrangements of the front loudspeakers(Table 2). Fig.8 represents Case 4 which shows the improvement in over 6 kHz frequency ranges compared to Case 1(Fig.1).

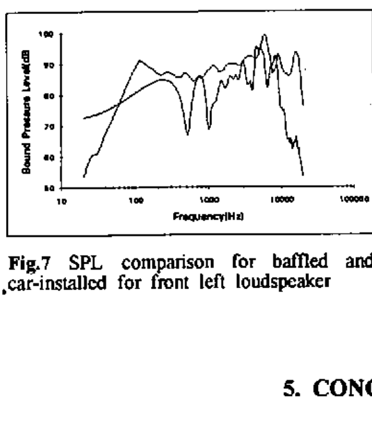

Fig.7 SPL comparison for baffled and car-installed for front left loudspeaker

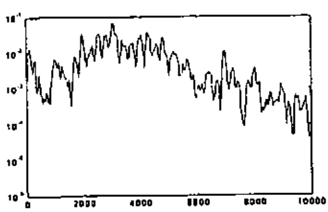

Fig.8 Frequency response for Case 4

5. CONCLUSIONS

In the process of sound quality improvement for the car audio system, the characteristics in sound field at driver's ear positions using binaural dummy head recording system have been tested by steady state response and time delay spectrometry methods. Acoustic characteristic test for the loudspeaker mounted on the finite baffle have been performed. Theses results approved that the sound pressure level differences and non-flatness in frequency responses at driver's both ears are due to the asymmetric arrangement and installment angle of loudspeakers against driver's ears. Also, Small/Thiele parameters identified by electric impedance test may be used for redesigning the loudspeaker for optimal sound field at the ears positions of driver connected with cabin acoustic features.

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Table 1. Identification of loudspeaker parameter for model SR-08B100

Case / Characteristics	Symbol, Unit	Given Data	Identified result
1. D.C.Resistance	Re, ohm	6.8	6.9
2.Resonance Frequency	Fo, Hz	62.19	62.19
3. Total Q Factor	Qts	0.4574	0.37
4. Electrical Q Factor	Qes	0.4834	0.39
5.Mechanical Q Factor	Qms	8.4	11.88
6. Equivalent Acoustic Compliance	Vas, Liters	26	35.07
7. Piston Area	Sd, m^2	0.0214	0.027
8.Volume Displacement	Vd, ccm	42.76	5305
9. Moving Mass of Diaphragm only	Mmd, g	13.03	16.5
10. Moving Mass of Diaphragm, AirLoad	Mms, g	15.56	19.04
11. Mass of Air Load on Diaphragm	Ma, g	2.54	2.54
12. Compliance($*10^{-4}$)	Cms, m/N	4.1	3.439
13. BL Product	BL, N/A	9.33	11.47
14. Rms	Nsec/m	0.7298	0.626

Table 2. specification for front loud-speakers installation

	Front left loudspeaker	Front right loudspeaker
Case 1	original state	original state
Case 2	30° upward	30° upward
Case 3	30° upward & 45° backward	30° upward & 45° backward
Case 4	60° upward & 45° backward	30° upward & 45° backward
Case 5	position to driver's left ear on dashpanel	position to driver's right ear on dashpanel

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UK POLICY AND STRATEGY TO REDUCE RISK TO HEALTH FROM HAND-ARM VIBRATION

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1. RISKS TO HEALTH FROM HAND-ARM VIBRATION

Health effects

Exposure to high levels of vibration through the use of hand-held tools or machinery causes hand-arm vibration syndrome (HAVS), the most common effect of which is Vibration White Finger (VWF). The damage is chronic rather than immediate, and cases will be the product of at least five years' and in some cases more than 20 years' exposure.

HAVS is a painful disease which can affect the blood circulation, nerves, muscles and bones in the hand and arm. VWF can result in loss of grip, which can become permanent, and an inability to do delicate tasks with the hands. The symptoms are worse in cold weather. Although the damage is most commonly caused to the hands, it is possible for similar harm to be caused where other parts of the body, such as the feet, are exposed to high levels of local vibration.

Size of the problem

Various surveys have suggested that over 160,000 workers in Great Britain may be exposed to hand-arm vibration, but the number of cases of HAVS and VWF is difficult to estimate. Cases of VWF reported for assessment for industrial injury benefit rose to a peak of 5,403 in 1990/91 but have since reduced to about 1,400 per annum, though much of the variation can be explained by changes to the benefit rules and in attitudes of employers, unions, insurers and solicitors. In the 1990 Labour Force Survey self-reports of VWF attributed to work yielded a prevalence estimate of 7,300, which is somehat lower than expected. Combining estimates from various sources suggests a best estimate of around 20,000 prevalent cases.

2. ASSESSING THE RISK

Other factors

Although high levels of vibration per se is the primary cause of HAVS there are other contributory factors such as the tightness of grip, the exposure pattern, factors affecting blood circulation such as temperature and smoking, and individual susceptibility. The relative importance of these factors is not well known.

Dose-response

There is also no dose-response relationship enabling the proportion of an exposed population who will suffer any degree of damage to be reliably estimated, though some rough estimates can be made where the nature of the vibration and the surrounding circumstances are constant, such as in the use of chain saws. It is likely to be a considerable time before there are relationships good enough to make reliable forecasts for all kinds of machinery.

Measurement

Sometimes it might be possible to assess the risk by measuring the vibration and assessing exposure. The risk depends on both the vibration magnitude and how long people are exposed to it. But measurement can often be difficult and costly, and firms may need to hire consultants to assess each discrete job.

A practical solution

It may be safer for employers to assume that there might be a problem wherever the use of vibration tools is a major part of a job. In particular, any job that causes tingling and numbness in the fingers after around five to ten minutes, or where employees develop attacks of finger blanching, should be regarded as suspect.

3. CONTROLLING THE RISK

Protective equipment

Anti-vibration gloves are not normally an effective way to reduce vibration exposure. In most jobs they do little, if anything, to reduce vibration reaching the hands and can even increase it. Their bulk may also impair the ability of employees to control equipment. Gloves are usually best chosen for their ability to keep hands warm and to protect them from accidental injury.

Reducing the vibration

The most effective course of action is to reduce the vibration by:

- substituting a process involving less vibration
- using tools designed for low vibration
- asking about vibration levels before buying tools
- maintaining the tools in good condition
- altering the job to reduce the grip, push and other forces
- using the right tool for the job
- designing work breaks to avoid long periods of exposure.

Helping the individual

This can be backed up by measures designed to protect the employee:

- training workers in operating techniques
- enabling them to keep warm when working in the cold
- informing them of the benefits of exercising the fingers
- encouraging them to cut down on smoking
- advising them of the hazards and signs of injury.

Health surveillance

Even when precautionary measures have been taken, some employees may remain at risk where high-vibration tools are used for long periods, and some tools may pose a problem when used for comparatively short periods. Employers may need to consider a programme of routine health surveillance, including regular checks by a doctor or a nurse who is familiar with the symptoms, so that employees can be advised about continuing to work with high-vibration equipment.

4. HSE STRATEGY TO REDUCE RISK

Legislation

The Health and Safety at Work etc. Act 1974 sets out a general framework of duties to secure the health and safety of persons at work. Among other things, it places duties on employers to ensure, so far as is reasonably practicable, the health and safety of their employees, and on manufacturers to ensure, so far as is reasonably practicable, that articles for use at work are safe and without risk to health. More specifically the Management of Health and Safety at Work Regulations 1992 require employers to assess risks to health and safety at work and take measures to control them, and the Provision and Use of Work Equipment Regulations 1992 require employers to ensure work equipment is suitable for purpose and properly maintained, and to provide adequate information and training.

These general duties apply to the risks from hand-arm vibration as they do to any other risk to health from work, but there is no health and safety legislation in Great Britain specific to vibration. The Health and Safety Executive (HSE) does not consider that such legislation would be appropriate; current uncertainties about dose-response would negate any attempt to specify in law detailed risk assessment requirements, while the complexities of measurement would make any such attempt costly for employers. We do not support the approach adopted by the European Commission in its proposal for a Directive on the protection of workers from physical agents, which sets a series of action levels which we believe have little scientific validity, which would prove excessively costly for employers to identify and act upon, and which would not provide commensurate benefit. HSE has produced a detailed and authoritative cost-benefit analysis of the effect the Directive would have if implemented in Great Britain.

More specific requirements for machine manufacturers and suppliers to reduce vibration emissions and provide information and instruction on vibration are contained in the Supply of Machinery (Safety) Regulations 1992 which are administered by the Department of Trade and Industry.

Guidance

Our strategy therefore is to increase awareness among employers, employees, manufacturers, health professionals and technicians of the risks from vibration and offer them practical guidance on assessment and control. We have published a comprehensive guide on hand-arm vibration, setting out, in line with the measures already described, how the risks from hand-arm vibration can be properly controlled. It offers advice both to managers and employers on assessment and reduction, and to specialists on how to implement programmes. For simpler advice we have also issued two free leaflets, one for employers and one for workers. We are also currently developing a dossier of case studies of how risks have been controlled in practice, which we will be publishing shortly.

HSE guidance has no legal status and is not compulsory. But it is held to illustrate good practice and can be referred to as such when our inspectors are seeking compliance with the law. The 1974 Act and the several 1992 Regulations are valuable sanctions when backed up by authoritative guidance.

Campaigns

It is important not only that guidance is issued but that the message actually reaches those to whom it is addressed. We have now reached the end of the first year of a major health management campaign "Good Health is Good Business" which is using a variety of publicity materials and initiatives to increase awareness of the major risks to health from work, and to press home the message that it is in employers' best interests to control these risks, which can often be addressed by adopting structured management techniques. Each year of the campaign will highlight two or three major health risks, and we propose in 1998/99 to place special emphasis on hand-arm vibration.

Research
We consider there is still much to learn about the effects of exposure to hand-arm vibration and how exposure might best be measured and controlled. Research is therefore an important element in any strategy to reduce risk and HSE will continue with its programme of research sponsorship. We are currently funding work on, among other things, the correlation between emission data and exposure, the accuracy of measurement, and the extent of exposure and symptoms and where the main problems areas are.

5. CONCLUSION

Hand-arm vibration is a significant industrial hazard from which the risks are preventable. Because of the uncertainties surrounding dose-response and the difficulties and costs of measurement the best strategy for prevention is not detailed prescriptive legislation but making employers and others aware of the risks and offering them practical guidance to reduce worker exposure which can be applied wherever high-vibration tools are used. In the long term, research should lead to better knowledge, which will enable more detailed advice to be offered.