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Anti-vibration Gloves – in Theory and Practice

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Foreword

In Occupational Health, we often see symptoms that can be related to the use of vibrating machinery. It is desirable to develop equipment that protects the user against the harmful vibrations.

Personal protective equipment is intended to protect the user against the harmful effects of their work, for example, protecting the ears from noise or the eyes against welding glare and sparks. It is the employer's responsibility that protective equipment is available and that the staff is trained to use it. Protective equipment should, however, always be the last resort and should be used where it is not possible to change the working environment to fit the worker. Before it can be introduced on the market, all personal protective equipment must meet the Swedish Work Environment Authority's regulations (AFS 1996:7). One of the offered solutions available on the market to reduce risks of tissue damage from vibrations is the use of anti-vibration gloves (AVGs). AVG must be CE-certified to prove that they meet the requirements of the standard ISO 10819 (ISO 2013).

Research can validate the quality of the labour protection gear available on the market as well as come up with recommendations and suggestions for improvements. This report describes how AVGs work and to which extent they reduce the effect of vibrations from hand-held machines. The report is intended for the occupational health service and the employer's occupational health and safety professionals. The abstract is comprehensive but free of technical jargon and technical details. The main report provides a more detailed description while the references to Annexes are intended to give an in-depth technical background.

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Abstract

Are anti-vibration gloves the solution to the problem of hand-arm vibration?

Vibrations from hand-held machinery are a major problem in the Swedish labour force. In 2009, 14% of men and 3% of women of employed in Sweden reported exposure to hand-arm vibration at least a quarter of their working time according to the Swedish Work Environment Authority (Arbetsmiljöverket 2010). It is tempting to imagine a protective glove that could reduce or even eliminate this problem.

Research can validate the quality of labour protection gear available on the market and then make recommendations and suggestions for improvements. This report from the Department of Occupational and Environmental Medicine in Lund and Gothenburg describes how anti-vibration gloves (AVGs) are experienced, and how they work and affect the exposure from hand-held machines.

Background

Today, gloves labelled “anti-vibration” (AV) are advertised as “reducing vibration by 40%”. To be marketed as “AVG”, a glove must be CE-certified and thereby comply with the requirements of International Organization for Standardization standard ISO 10819. The requirements apply only to the suppression of vibration in the palm of the hand, while in many work situations, vibration is transmitted to the fingers. However, in the ISO standard, it is pointed out that AVGs provide inadequate damping of vibrations of low frequencies. Such vibrations are common in many hand-held tools and machines in industry and crafts, such as different types of grinders. Some regular protective gloves can even provide amplification of low frequencies but cannot be approved in accordance with this standard.

Generally, all protective equipment disrupts work to a greater or lesser degree. Working without a helmet, protective mask, hearing protection, and protective clothing is preferred in most situations. Furthermore, the availability of gloves which are supposedly AV may give rise to an ethical dilemma: the user may handle the machines more intensely and for a longer time in the belief that the hand is protected from vibration damage.

But are those AV claims true and how do these gloves perform in practice? Is the experience regarding the gloves that they dampen the vibrations? To what extent do the gloves disturb the worker and interfere with the work? How much damping can be expected when using low-speed and high-speed grinders, respectively? These issues will be discussed in the following report.

Implementation

Nine subjects, whose work task was to deburr and grind aircraft engine components, were given the opportunity to test a specific AVG for 3 months.

They all worked with a variety of rotating air-powered and vibrating machines. All had extensive experience in this work. Usage times for the individual machines varied between ½ hour and 4 hours/day. The total usage times sometimes exceeded 4 hours/day. The most commonly used rotating machines rotate at high speeds, 100 000 revolutions per minute (rpm), but other machines with low speed, 500 rpm, were also used.

Only one model of AVG was tested. The back of the glove was made of porous polyester and the palm of a denser, elastic synthetic material. Approximately 7 mm thick, foam-like materials were built into the palm, thumb and fingers grip side of the glove. The glove was CE-marked and was claimed to comply with standard ISO 10819:1996.

The test subjects tried the glove for 3 months. After this period, they answered a questionnaire containing 14 questions including questions on hand temperature, grip, dexterity and self-reported vibration damping.

To assess the usefulness of the AVG, the vibration level and vibration frequency spectrum were measured on the machines used by the subjects. During the measurements, a skilled operator performed a typical deburring task.

Results and Discussion

The comfort in terms of hand temperature was rated mediocre. Grip was rated good while finger sensitivity was rated low. At a so-called “pencil grip”, required for handling small machinery, the gloves were uncomfortable; however, they worked well with larger machines.

The majority, eight of the nine individuals, responded that the glove offered good vibration damping. As the hand’s ability to perceive vibrations varies with the frequency of vibration the possibility to self-assess whether a glove is vibration-damping or not largely depends on how well the person can perceive the frequency of the machine in question. With a high-revving machine of, say, 50 000 rpm, the vibration tactility is fairly low, and so is, therefore, the ability to self-assess the glove’s damping properties. In addition, the vibratory sense in the hand does not reflect the hand-arm weighted vibration level which needs to be measured according to the Swedish Work Environment Authority’s regulations (AFS 2005:15). With regard to the vibrations, large differences between the various machines were measured; hand-arm weighted levels according to the regulations were between 0.8 and 8.3 m/s^2. High-revving, ≥55 000 rpm, machines gave the lowest weighted vibration levels. A machine’s rotation speed was found to cause the dominant vibration frequency; however, high frequencies from high-speed machines do not increase the hand-arm weighted exposure levels.

Conclusion

The vibrations from many of the machines in this study, which are used over long periods for deburring, will be damped to some extent. But it is not obvious that this damping neither can be experienced, nor give reduced daily vibration exposure in accordance with the regulations, or reduce the risk of vibration injury in the hands. So-called “AVGs” generally give insufficient reduction in vibration exposure. This is demonstrated already by the standard for CE certification of AVGs. For a glove to protect against normal, low-frequency vibrations, it would have to be too heavy and thick to be practical. Despite the limitations of the protection that the CE-marked protective gloves offer against vibrations, we still recommend the use of gloves because:

1. High-frequency vibrations, which are presumed to be harmful, will be damped.
2. The gloves will ensure that vibrations will not be amplified.
3. Gloves keep the hands warm, which is believed to reduce vibration-related disorders.

Background and aim

Vibrations at the workplace

Vibration in hand-held machines is a massive problem. Among employed persons in Sweden, 14% of men and 3% of women in 2009 reported exposure to vibrations from hand-held machines during, at least, a quarter of their working time (Arbetsmiljöverket 2010).

The risk of vibration damage has been highlighted by European Parliament and Council Directive (2002), which has led to special regulations from the Swedish Work Environment Authority. Their regulation AFS 2005:15 specifies the daily exposure limit value (5 m/s^2) and the daily exposure action value (2.5 m/s^2) for the acceleration time average (root mean square (rms)) calculated for an 8-hour reference period. A risk assessment is required to clarify whether the daily exposure action value is exceeded and if so, the concerned staff must be offered medical examinations (AFS 2005:6) and measures must be taken to reduce exposure. Exceedance of the exposure limit value requires immediate action.

Exposure measurements must be carried out according to the standard ISO 5349:1 and 2 (ISO 2001). The acceleration signal is filtered, which implies that vibrations at frequencies higher than 16 Hz are reduced in inverse proportion to the frequency and increasing frequencies thus contribute less and less to the measured value (Figure 1). This is one of the reasons why “AVGs” do not seem to reduce the exposure to hand-arm vibrations.

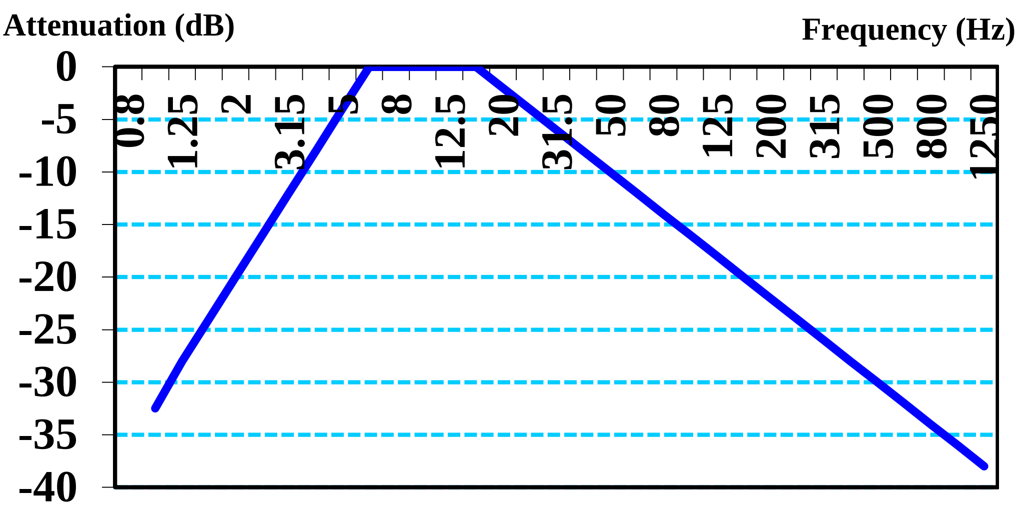

Figure 1: Filter characteristics for attenuation of hand-arm vibrations measured according to the test standard ISO 5349, “Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration”.

It is tempting to imagine a protective glove that could reduce and even eliminate the problem. Today gloves are sold that promise excellent AV properties, for example advertising a 40% reduction in vibration. The Physical Agents Portal (PAF), specifies an expected vibration reduction of <10% for percussive machines, adding that vibration reduction can amount to 10–60% for other machines.

Therefore, it seems the efficiency of damping is dependent on the type of machine a protective glove is used with.

The requirement of anti-vibration gloves

To be marketed as an AVG, a glove must be CE-marked and certified and thereby comply with the requirements of standard ISO 10819 "Mechanical vibration and shock – Hand-arm vibration – Method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand". This study was planned and performed when the previous version of the standard (ISO 10819:1996) was still valid, today the new version of the standard has been accepted (ISO 10819:2013). The revision of the standard does neither affect the methods nor the conclusions of this study.

The ISO standards are not public documents and must be ordered at a relatively high cost, which strongly limits availability. In addition, they often refer to other costly standards. Below follows a certain selected part of standard ISO 10819:1996 (page iii, Introduction):

> *… On present evidence, there have been no circumstances in which gloves have been shown to provide adequate attenuation of vibration to prevent vibration injuries.*
>
> *Within the current state of knowledge, gloves do not provide significant attenuation in the frequency range below 150 Hz. Some gloves may provide amplification in this frequency range. Also, the use of gloves might alter the gripping force which would alter the transmission of vibration into the arms, thus increasing the risk of damage. However, it must be emphasized that an important purpose of gloves is to keep the hands warm and dry, as this may help to limit some vibration-induced effects.*
>
> *This standard describes a method of measuring the vibration transmissibility of gloves in the laboratory, but as far as possible under conditions typical of use at actual working places. The measurement is performed at the palm of the hand and so does not give the transmission of vibration to the fingers. However, when evaluating the protective effects of a glove, it must be remembered that in many work situations, vibration is transmitted not only to the palm*

but also to the fingers. A different measurement procedure will be required to establish the vibration transmissibility of gloves at the fingers.

This standard describes a method of measuring the vibration transmissibility of gloves worn by a test subject. For the measurement of the vibration transmissibility of resilient materials which are used to cover handles of tools or make gloves, EN ISO 13753 should be consulted.

On page 11, under “7.2 Criteria for antivibration gloves”, the following note appears: “*The fulfilment of these criteria does not imply that the use of such gloves removes the hazard of vibration exposure.*”

In Chapter 7 of the standard, the test procedure is described in detail, including how the evaluation should be made. Testing takes place within two overlapping frequency ranges, 16–400 Hz and 100–1 600 Hz. For the lower frequency range, the only requirement is that the glove does not amplify the vibrations. For the higher frequency range, the glove is allowed to transmit no more than 60% of the vibrations.

Parts of the test procedure are described in Annex 1.

Comments on requirements for anti-vibration gloves

1. The measurement is performed only on the palm of the hand. However, in many work situations, vibration is also transmitted to the fingers. As yet, there is no standard for gloves considering the fingers.
2. Anti-vibration gloves provide inadequate damping of vibrations with frequencies <150 Hz. The frequency of 150 Hz corresponds to the dominating frequency of a grinding machine with a speed of 9000 rpm. Many machines in industry and crafts have much lower rpm, where gloves provide no, or only limited, protection.
3. Some gloves may even amplify vibrations if the frequencies are <150 Hz, but these gloves will not be approved in accordance with the standard.
4. The standard recommends but does not require, that data on damping at different frequencies are given for the gloves. This would facilitate the choice of the right glove if the machine’s vibration spectrum is measured or if rpm, and, therefore, the main frequency, is known.
5. The measurements are carried out in laboratory conditions, which may differ from actual use at workplaces.
6. Even if the standard is fulfilled, this does not imply that the glove will remove the risk of vibration exposure.
7. Gloves may require a higher grip strength, which increases the transmission of vibration to the arm and thus the risk of injury.

8. Gloves may keep the hands warm and dry, which may reduce the symptoms. However, it is unclear if the risk of injury is reduced.

Objectives of the report

The availability of gloves which purport to be “anti-vibration” gives rise to an ethical dilemma: the user may handle the machines more intensely and for a longer time in the belief that the gloved hand is protected from vibration damage. But are the AV claims true, and how do such gloves perform in practice? How much damping can be expected when using low-speed or high-speed grinders, respectively? Keeping hands warm is supposed to be good but what is the thermal insulation of an AV glove? These questions will be addressed.

Materials and methods

Subjects and machines used in the study

Nine subjects at an aircraft engine factory were asked to test a specific AVG for three months. All of them worked with vibrating machines and all had extensive experience in grinding work. Their work task was to grind and deburr airplane engine parts with different pneumatic grinders.

Usage times for the individual machines varied between ½ hour and 4 hours/day. The total usage times sometimes exceeded 4 hours/day. The most widely used machines were rotating machines with high rotate speeds, 100 000 rpm, but others with low speeds, 500 rpm, were also used. Information on the machines can be found in Annex 2.

The studied anti-vibration glove

As an example of an AVG, only one model was evaluated in this limited study. The glove is labelled: EJENDALS TEGERA, TEGERA PRO, vibration control, article number 9180”. The back of the glove consists of porous polyester (Spandex™) and the grip side of a denser elastic synthetic material (MicroThan™). A rubber-like foam layer (VibroThan™), approximately 7 mm thick, is built into the palm, thumb grip and finger grip side. The glove is available in sizes 7 to12 and should therefore fit most women and men. The glove claims to comply with standard ISO 10819:1996 and is CE-marked.

Figure 2: Anti-vibration gloves with the brand name TEGERA, model 9180. (Photo: EJENDALS).

Questionnaire for anti-vibration gloves

A field study was carried out by the physiotherapist at the subjects' workplace. The subjects tried the glove for 3 months and subsequently completed a questionnaire consisting of 14 questions about the quality of the glove:

1. Fit after first use
2. Fit "after some time of use"
3. Hand temperature
4. Grip
5. Fingertip sensitivity
6. Wear resistance
7. Resistance against dirt
8. Resistance against wetness
9. Vibration damping
10. User's total impression
11. "How does the glove compare with the one you usually use?"
12. "Have you previously used hand protection?" (Yes/No)
13. "How long did the hand protection you previously used, last?" (Hours, days)
14. "How long did the glove you have just tested last?" (Hours, days)

The questions concerned four aspects of protective glove use: comfort (questions 1–3), usability (4–5), strength and function (6–9), and durability and quality comparison (10–14). The first eleven questions used a 6-point scale, where 1 = poor and 6 = excellent. The response options for questions 12–14 are given above. The questionnaire was originally designed by EJENDALS but was modified for this study: the question about perceived vibration damping was added and a question asking the respondent to rate the glove’s size range was removed. The answers to the questionnaire are presented in the Results section.

Measurement of the frequency spectrum

To get an idea of the frequency content of the vibrations of the different tools and machines (Annex 2), a vibration meter (Norsonic Nor136, Markaryd, Sweden) with a triaxial accelerometer (Norsonic Nor1287, Markaryd, Sweden) was used. The instrument measures frequencies up to 1000 Hz. The accelerometer was attached to the handle of each machine with stretchable electrical tape (Figure 3).

A skilled operator was asked to do his polishing and deburring work in the usual manner. The vibration was measured during deburring (Figure 4), and in some cases also at idle. The measurements were started when the work was under way and each measurement lasted 60 seconds. After the measurements, the data were evaluated with the software NorVibraTest V1.4.5.1, Markaryd, Sweden.

Figure 3: The accelerometer is taped to the front of the machine. The vibration analyser can be seen to the right.

Figure 4: Performing deburring of an aircraft engine component during measurement. The operator is wearing the TEGERA anti-vibration glove.

Thermal insulation – protection against convective cooling

The glove's insulation against convective cooling was tested according to EN 511:2006. Air velocity in the wind tunnel was 4.05±0.21 m/s. As an extra test, the insulation was also tested at low air velocity (0.20±0.02 m/s). The thermal hand model was placed in the wind tunnel with fingers pointing down and with the direction of air flow into the palm.

Thermal insulation – protection against contact cooling

Protection against contact cooling was tested according to the modified standard (EN 511:2006). The group that proposed the standard test method (thermal hand model) (Nilsson et al., 1992) also proposed conducting a non-destructive contact cooling test with a mini hot plate (Nilsson et al., 1996). The modified method has shown to provide very similar results to the standard test, while not requiring breaking the glove or prototype glove. The modified method was applied flat on a sample area of the vibration protection glove and the standard pressure applied.

Results

Self-rated vibrations

The questionnaire was answered by nine subjects. The majority, eight individuals, responded that the glove offers good vibration damping.

Self-rated comfort, usability, and function

Comfort was affected by the fact that the fit of the glove deteriorated after a period of use. “Hand temperature” was rated as mediocre. Usability was rated good concerning “grip” while “fingertip sensitivity” was rated low. At a so-called “pencil grip”, required for handling small machinery, the gloves were rated uncomfortable although the subjects found that they worked well when gripping larger tools and machines. Strength and function were rated good concerning “resistance against dirt” while both “resistance against wetness” and “wear resistance” were rated as mediocre. The overall impression of the glove was rated as high. (Table 1)

Table 1. The questionnaire was answered by nine subjects. Translated from Swedish. Questions were answered with a 6-point scale, where 1 = "very bad" and 6 = "very good".

	The number of answers for each point on the scale						
	1	**2**	**3**	**4**	**5**	**6**	**Total number of answers for each question**
Fit after first use	0	0	1	1	7	0	9
Fit after some use	0	1	3	1	3	1	9
Hand temperature	0	0	5	3	1	0	9
Easy-to-grip	0	1	0	3	5	0	9
Fingertip sensitivity	2	2	2	3	0	0	9
Wear resistance	0	1	4	3	1	0	9
Resistance against dirt	0	0	0	3	3	3	9
Resistance against wetness	0	0	2	2	1	1	Only 6
Vibration damping	**0**	**0**	**1**	**0**	**4**	**4**	9
Total impressions	0	0	1	1	7	0	9
How is the glove compared to the one you usually use.	0	0	1	2	5	1	9
Previously used hand protection:	5 yes	2 no					Only 7

Measured vibration levels

There were large differences between the various machines, with hand-arm weighted levels being between 0.8 and 8.3 m/s^2 (Table 2). High-speed machines, with a rotational speed of 55 000 rpm or more, had the lowest weighted vibration levels.

For the low-speed machines, the unweighted vibrations were between eight and 16 times greater than the weighted vibrations; for most high-speed machines, the equivalent figures were 109–124 times greater.

Table 2. Measured hand-arm weighted and unweighted vibration levels for the seven different machines, listed in descending order of rotational speed (revolutions per minute (rpm)). The three dominant frequencies in the vibration spectra are also reported.

Brand of machine	**Model**	**Rotational speed, rpm (frequency, Hz)**	**Hand-arm weighted level, m/s^2**	**Unweighted level, 0.1–1000 Hz, m/s^2**	**Dominant frequencies**, unweighted, Hz**
Biax [1)]	TVD 3-100/2	100 000 (1 667 Hz)*	1.2	149	620, 0.2, 2
Dotco [2)]	MDL 10 R 9000-03	100 000 (1 667 Hz)*	0.8 on machine body 1.0 on air hose	87 117	600, 200, 2
Biax [1)]	SRD 3-55/2	55 000 (917 Hz)*	1.4	44	800, 500, 300
Ingersoll Rand [3)]	PS 16/6.2 W 107 F 212545	5 400 (90 Hz)	6.3 brushing 7.0 idle	90 102	300, 95, 80 90, 300, 380
Ingersoll Rand [3)]	PS 16/6.2 W 106 C 183008	5 400 (90 Hz)	8.3 idle	117	80, 250, 300
Ingersoll Rand [3)]	Size 5 LJ 1	4 900 (82 Hz)	2.3	36	0.8, 400, 200
Atlas Copco [4)]	LBB 24 S 04 5 B	4 500 (75 Hz)	3.6 brushing 3.9 idle	46 30	350, 80, 70 80, 180, 250

* The glove can be expected to provide some vibration damping at this high frequency.
** In order of descending acceleration magnitude. Only frequencies up to 1000 Hz have been measured.
[1)] BIAX Schmid & Wezel GmbH & Co, Maulbronn, Germany.
[2)] Dotco, Apex Tool Group, Sparks, MD, USA.
[3)] Ingersoll Rand, Dublin, Ireland.
[4)] Atlas Cocpo Tools, Nacka, Sweden.

Measured vibration frequency spectra

Dominant vibration frequencies are shown in Table 2. Rotational frequency turned out to be a dominant part of the vibration spectrum (Annex 3). For the highest-speed machines (100 000 rpm), the rotational frequency was 1 667 Hz, which is above the vibration analyser's measuring frequency range.

Because of the hand-arm weighting (Figure 1), vibration levels for low and high-speed machines are assessed differently. The higher the frequency, the smaller the contribution to the vibration level. The ratio between unweighted vibration and hand-arm weighted vibration for the highest-speed machines was over 100 but could have been higher considering the fact that their rotational frequency exceeded the measuring frequency range.

Assumption of the glove's damping

In the absence of data on the glove's damping at individual frequencies, it can be assumed that in the medium-frequency range (16–400 Hz, the M spectra in Annex 1) there is no damping at all while in the high-frequency range (100–1 600 Hz, the H spectra in Annex 1) no more than 60% of the vibrations are transferred (Annex 1).

For a high-speed tool such as the Biax SRD with a rotational speed of 55 000 rpm and a rotational frequency of 917 Hz, a cautious assessment can be made of the damping effect: for the frequency range M in the standard, we can, with fair approximation, put the hand-arm weighted acceleration at the measured value 1.4 m/s^2. As evidenced by the unweighted frequency spectrum (Annex 3: Figure 2B), the majority of the vibrations are in the frequency range H in the standard. Within the frequency range H, the hand-arm weighting attenuates approximately fifty-fold and when the transmission ratio is assumed to be 0.6 the damping provided by the gloves can be expected to lower the hand-arm weighted level by about 0.03 m/s^2. This corresponds to about 2% damping of the hand-arm weighted acceleration. The hand-arm weighting-filter attenuation is so high that the frequency range H hardly contributes to the hand-arm weighted level.

For the machine Ingersoll Rand PS (5 400 rpm), the situation is different: in this case, the rotational frequency (90 Hz) strongly contributes to the hand-arm weighted level, as shown in Annex 3: Figure 1A. However, only vibrations >100 Hz will be damped by the glove, so the damping of frequency peaks around 300 Hz only has little influence on the hand-arm weighted value because the hand-arm weighting filter strongly attenuates vibrations in this frequency range. This result, at best, shows a 5–10% reduction of the hand-arm weighted exposure transmitted to the hand.

Thermal insulation – protection against convective cooling

The glove insulation was 0.079±0.000 m^2K/W when measured according to standard methods with 4 m/s air velocity (EN 511:2006). In windless conditions, the insulation was 0.158±0.000 m^2K/W.

Thermal insulation – protection against contact cooling

The results differed quite a bit from test to test, most probably because of uneven insulation and compression over the palm area. The thermal resistance against contact cooling was 0.066±0.013 m^2K/W.

Discussion

Parallel with the execution of this study, AV gloves has been carefully examined and reported in a commentary (Hewitt et al, 2015) and these authors have mainly the same topics and conclusions as told here. "*… one should balance the benefits of AV gloves and their potential adverse effects if their use is considered.*".

Methodological considerations

The number of persons included in the study was relatively small. All subjects were using the same type of equipment, with extensive use of very high-speed machines. This may have affected their perception of the glove's AV ability because this increases with frequency. It is possible that the glove would have been experienced differently in a different manufacturing industry.

An important aspect of vibration damping is the frequency ranges in which the risk of vibration damage arises. The Swedish Work Environment Authority regulation (AFS 2005:15) sets out the exposure limit value and action value for levels measured with a filter that strongly reduces vibrations at higher frequencies. Therefore, the glove's VR effect (in our case 40%) in the high-frequency range will only be a few per cent on the hand-arm weighted vibration level.

However, as noted in the vibration regulation (AFS 2005:15, comment on point 12), the risk of injury will be underestimated when working with high-frequency machines.

We would also point out that the vibration meters we used only register frequencies up to 1 000 Hz and, therefore, the measurements of the unweighted levels of the tested machines give only limited guidance in assessing the glove's advantage when using machines with high speed. Probably frequencies higher than 1 000 Hz were present and then the glove's damping ability may have been better than shown by the measurement.

It should also be noted that the vibration damping of the glove is only given as "meets the requirements of the standard". Information related to the damping of the individual frequencies is missing and would require sophisticated laboratory facilities. Such information would be necessary to do a more careful calculation of the expected vibration reduction. It has previously been shown that there are significant differences between different gloves with respect to vibration damping (Annex 4, Laszlo et al., 2011; McDowell et al., 2013). In addition, the feed force has a major impact; vibration transmission may increase from 60% at forces <10 N to 80% at 50 N (Laszlo et al., 2011).

The rotating speed

The vibrations caused by the rotating speed generally dominate the weighted frequency spectrum and, therefore, the measured weighted vibration level (Annex 3: Figure 1A). The exception is machines with high rotating speed, as shown in Annex 3: Figure 2A. Above 20 000 rpm, the rotation frequency will usually no longer dominate.

Self-rated damping and the vibration sense of the hand

When assessing self-rated vibration damping (question 9 of the questionnaire) it must be noted that the hand's ability to perceive vibration acceleration varies with frequency and is at its best around 125 Hz (Lundström et al., 1992). A diagram of the hand's perception threshold is shown in Annex 5. The ability to self-estimate whether a glove is vibration damping or not therefore largely depends on how well the person can perceive the specific vibration frequencies of the machine used.

Concerning the glove's vibration damping ability, eight out of nine subjects selected the second highest response option (5 or 6 = "Very good"). Certainly the machines used during the day emit frequencies >150 Hz (Table 2) where significant damping is achieved, but the hand's sense of vibration drops sharply after 300 Hz, as shown in Annex 5. For a high-revving machine of, say, 50 000 rpm corresponding to a rotation frequency of 800 Hz, the vibration sense is pretty bad. The ability to perceive differences in vibration level, and thus the ability to self-estimate a glove's damping properties, will, therefore, be severely limited for most high-speed machines.

Frequency weighting, according to the vibration regulations (Figure 1), is of great importance for calculation of vibration level. Frequencies >16 Hz are increasingly suppressed and consequently the hand's sense of vibration does not reflect the frequency-weighted value (Compare Annex 5 and Figure 1). Many gloves have a considerable damping effect at high frequencies but this can neither be sensed nor can it be measured according to vibration measurement standards.

The "Halo" and Hawthorne effects

When using questionnaires there should be awareness of the so-called "Halo effect": if for some reason the subject is either positive or negative to the glove this could spill over to the self-reporting on the vibration damping. Similarly, the so-called "Hawthorne effect" can affect the answer: those who participate in a survey are possibly more positive because they have been given attention and have been shown respect. However, there was some degree of independence between the various responses to the questions; we saw positive judgments of vibration damping but also negative judgments regarding comfort and function.

Could the studied machines' vibrations be damped by the glove?

Half of the machines had a rotational frequency >150 Hz and some vibration damping can be expected. The remaining machines had lower frequencies and for them, vibrations will not decrease to a noteworthy extent (Annex 2). However, when a CE-certified glove is used, the user will be assured that amplification will not take place; unfortunately, amplification can occur with some other common work gloves.

For example, take the Ingersoll Rand PS machine with 5 400 rpm (rotational frequency 90 Hz) (Annex 3). Despite the assumption that the glove dampens the vibration as the standard requires, a vibration reduction of only a few per cent can be expected. In our results, the hand-arm weighted vibration level, measured in accordance with regulations, was 6.3 m/s^2. A reduction of 10% would give 5.7 m/s^2, which is still high.

For high-speed machines (Annex 2), the damping becomes considerable at frequencies >150 Hz. But according to vibration regulations, the reduction of the weighted level of a machine such as the Biax SRD (Annex 3) with 55 000 rpm (rotational frequency 917 Hz) is not remarkable, as the measured 1.4 m/s^2 will be reduced by only 2%.

The Swedish regulation of vibrations (AFS 2005:15) does not allow any reduction of the daily dose when protection is used. For noise exposure, however, where similar requirements exist, the noise damping hearing protection shall be taken into account before evaluation according to the noise exposure limit (AFS 2005:16).

Other anti-vibration gloves

In this report, only one glove brand has been examined that can serve as a model of AVG. There are other brands of CE-certified AVGs such as CORSAIR and MAKITA. Self-reported data and thermal insulation might have been different but the AV promise of vibration protection is the same. ErgoAir® (ErgoAir, Inc., Las Vegas, NV, USA) have developed an AVG according to a partially new principle based on sophisticated damping elements. This new principle is not evaluated in this report.

Why do anti-vibration gloves give so little protection?

As highlighted in this report, the hand-arm weighted vibration exposure mainly takes into account frequencies between 5 and 30 Hz. Higher frequencies are gradually attenuated out by the weighting. With these frequencies, the importance of the vibrations wanes rapidly. For damping at low frequencies, the gloves would need to be heavy and thick and would therefore not be practical.

Another aspect is that the requirement regarding vibration damping applies only to the palm of the hand. Nothing is said about the fingers, where the damage usually occurs. There are even fingerless gloves that meet the requirements to be called “anti-vibration”! Therefore, we do not know what protection factor the gloves have for the transmission of vibrations to fingers. In some situations, contact with the vibrating object is limited to the fingers. The uncertainty of the glove’s protection further increases by stating an average over a large range of frequencies (100–1 600 Hz). As shown in Annex 4, there are large differences in the transfer of vibrations at these frequencies, meaning that the real protection can be both higher and lower than promised by the glove standard, depending on the particular combination of the selected glove and rpm (vibration frequencies) of the machine.

Thermal insulation – protection against convective cooling

According to standard test methods, the AVG is not approved for use in cold conditions. This is most probably due to the very thin textile layer on the back of hand. According to Annex B of the standard (EN 511:2006), the glove would allow cold protection of the hands at temperatures above +5°C under heavy workloads in windy weather. If the workplace is shielded against wind the gloves may protect against cold at -15°C if the workload is heavy, that is if body heat production is high. If the workload is light or medium the surrounding temperature should be +8°C or more depending on the wind at the site.

Thermal insulation – protection against contact cooling

In total, there are four classes of protective gloves, with the highest class requiring contact thermal resistance >0.150 m^2 K/W. Assuming that the modified test gives the same answer as the standard test, the tested vibration protective glove may be classified as class 2 (0.050–0.100 m^2K/W) protective glove against contact cooling. This means the glove provides reasonable protection in most common contact exposure cases – however, not in extremely cold conditions.

Conclusion

Self-rated vibrations indicated that the glove offers good vibration damping but self-rated comfort, usability and function were often affected negatively.

AV gloves don’t give a general protection against vibration damage. Only high frequencies, > 150 Hz, will be damped to some extent but the medical benefit is not obvious. Amplification of vibrations is avoided which is a risk with regular gloves and the hand will be kept warmer which is believed to be beneficial. But the AV gloves might give the user a false feeling of safety. Other measures in the working environment have to be taken to reduce the harm of vibrations.

Recommendations

The most effective measure to reduce vibration in the working environment is to change the process and not use vibrating tools at all. Thereafter should low vibrating machines or processes be chosen and the exposure time minimized for every worker in the process. Generally, all protective equipment disrupts work to a greater or lesser degree. Working without a helmet, protective mask, hearing protection, and protective clothing is preferred in most situations. Furthermore, personal protective equipment is always the last measure.

Despite the limitations of the protection against vibration provided by the CE-marked protective glove, we still recommend the glove in some rare cases since it dampens supposedly harmful high-frequency vibrations, ensures that amplification of vibrations is less than in some regular gloves and keeps the hands warm, which is believed to reduce vibration-induced suffering. But compared to regular gloves, AV-gloves are usually thicker and may introduce adverse effects, such as increasing grip force and reducing manual dexterity.

Vibrations with frequencies <150 Hz, corresponding to machines with a rotating speed <9 000 rpm, are hardly damped at all. Commonly used machines such as angle grinders emit these frequencies. Frequencies >150 Hz are damped to some extent; these are machines with higher speed, such as many straight grinders.

Low-frequency percussive machines, such as chisel hammers and impact wrenches, also emit high-frequency vibrations. The glove is effective for use with these machines because high-frequency vibrations are considered harmful and hence, gloves may be appropriate for this type of work. However, the knowledge in this field is still limited. But gloves do not significantly reduce the measured vibration levels: frequencies >150 Hz are suppressed, according to the ISO standard of vibration measurements. It is also worth noting that the hand’s ability to sense vibrations is low at the frequencies at which the glove’s damping is high.

It would have been desirable if the CE certification of “AVGs” had been more detailed and damping at specific frequencies had been reported – this would have facilitated a prudent selection of the right glove for a certain work situation where the rpm or vibration frequencies are known. It would also have been desirable for the CE certification to have included vibration protection for the fingers because these are exposed in many work situations.

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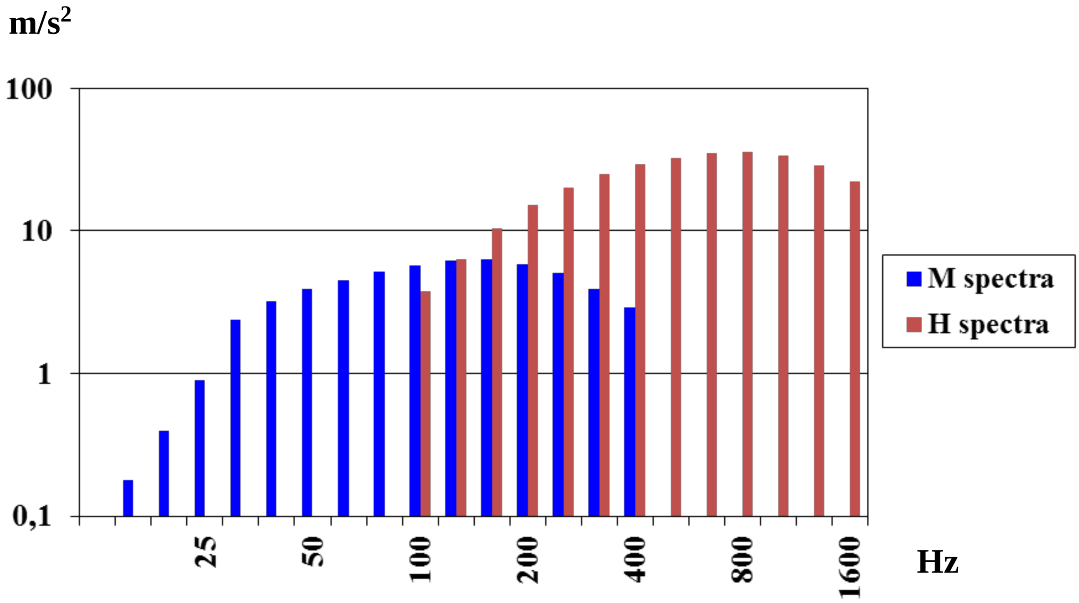
Annexes

Annex 1.
Measurement standard for glove vibration transmissibility

ISO 10819:1996: “Mechanical vibration and shock – Hand-arm vibration – Method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand”.



Vibration levels in the third-octave band for test frequencies in the medium and high-frequency (M and H) ranges. Total vibration levels are equivalent to 3.4, respectively 3.3 m/s^2 hand-arm weighted (16.7 and 92.2 m/s^2 unweighted).

The transmission ratio (TR) between the “hand inside glove” and the “hand without a glove” represents the attenuation. The feed force shall be 50 N. The criteria for a work glove to be called “AVG” are, according to ISO 10819:1996:

> *A glove shall not be considered as “antivibration glove” according to this Standard if it does not fulfil both of the following criteria: $TR_M < 1.0$, and $TR_H < 0.6$.*
>
> *NOTE: The fulfilment of these criteria does not imply that the use of such gloves removes the hazard of vibration exposure.*

Annex 2.
Machines used at the factory where this study was conducted

Rotary milling and grinding machines, and operating times during typical work, in order of operating time.

Brand	**Model**	**Shape and tool**	**Rotational frequency, rpm**	**Typical operating time**
Biax*	TVD 3-100/2	Straight, milling cutter	100 000 (1 667 Hz)**	2–4 hours
Dotco*	MDL 10 R 9000-03	Straight, milling cutter	100 000 (1 667 Hz)**	2–4 hours
Uryu	UG 25 NA	Straight, disc ø 40 mm	25 000 (417 Hz)**	1–2 hours
Ingersoll Rand*	Size 5 LJ 1	Straight, plastic brush	4 900 (82 Hz)	1–2 hours
Ingersoll Rand*	PS 16/6.2 W 107 F 212545	Straight, plastic brush	5 400 (90 Hz)	1–2 hours
Ingersoll Rand*	PS 16/6.2 W 106 C 183008	Straight, plastic brush	5 400 (90 Hz)	1–2 hours
Atlas Copco*	LBB 24 S 04 5 B	Straight, plastic brush	4 500 (75 Hz)	1–2 hours
Ingersoll Rand	Cyclone CD 200	Straight, disc ø 15 mm	18 000 (300 Hz)**	1–2 hours
Biax*	SRD 3-55/2	Straight	55 000 (917 Hz)**	0.5–1 hours
UHT	Mag-121 n	Straight	55 000 (917 Hz)**	0.5–1 hours
Atlas Copco	LSF 12	Straight, disc ø 15 mm	27 000 (450 Hz)**	0.5–1 hours
Ushio	–	Straight	65 000 (1 083 Hz)**	0.5–1 hours
Atlas Copco	–	Pistol-shaped	500 (8 Hz)	0.5 hours
Ingersoll Rand	–	Pistol-shaped	500 (8 Hz)	0.5 hours
Atlas Copco	–	Angled	1 000 (17 Hz)	0.5 hours
Biax	–	Angled	500 (8 Hz)	0.5 hours

* Machine subject to vibration measurements in this report.
** Some vibration damping can be expected from the gloves at this high frequency.

Annex 3. Measured frequency spectra

Figure 1A & B: Machine with lower revolutions per minute (rpm). The graphs show frequency spectra of Ingersoll Rand PS 16/6.2, W 107 F, 5 400 rpm (90 Hz), during brushing. Hand-arm weighting using the standard ISO 5349 (A), and the unweighted spectrum (B). As can be seen, the rotation rate (around 90 Hz) dominates the weighted spectrum. Note the different scales on the y-axis.

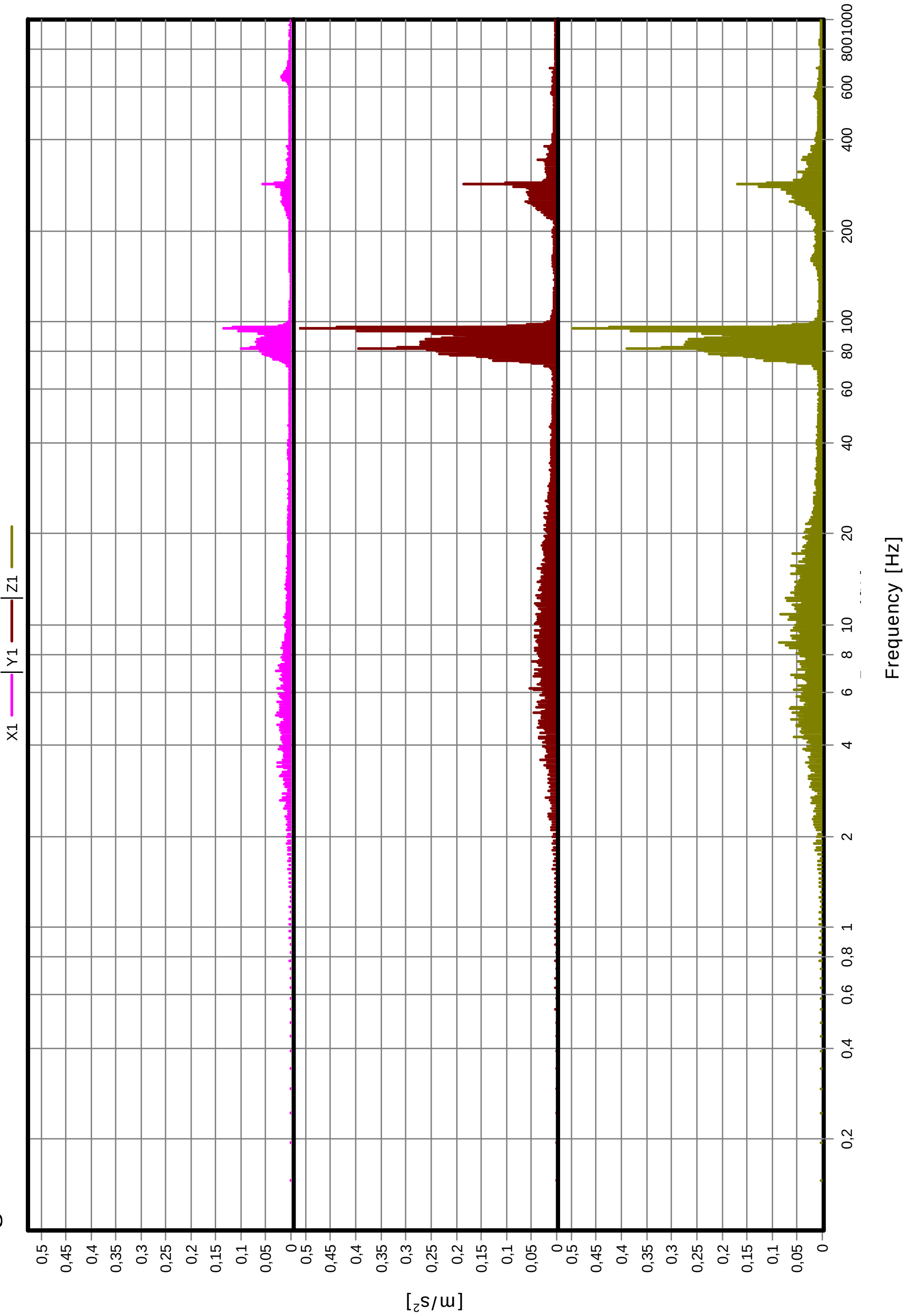
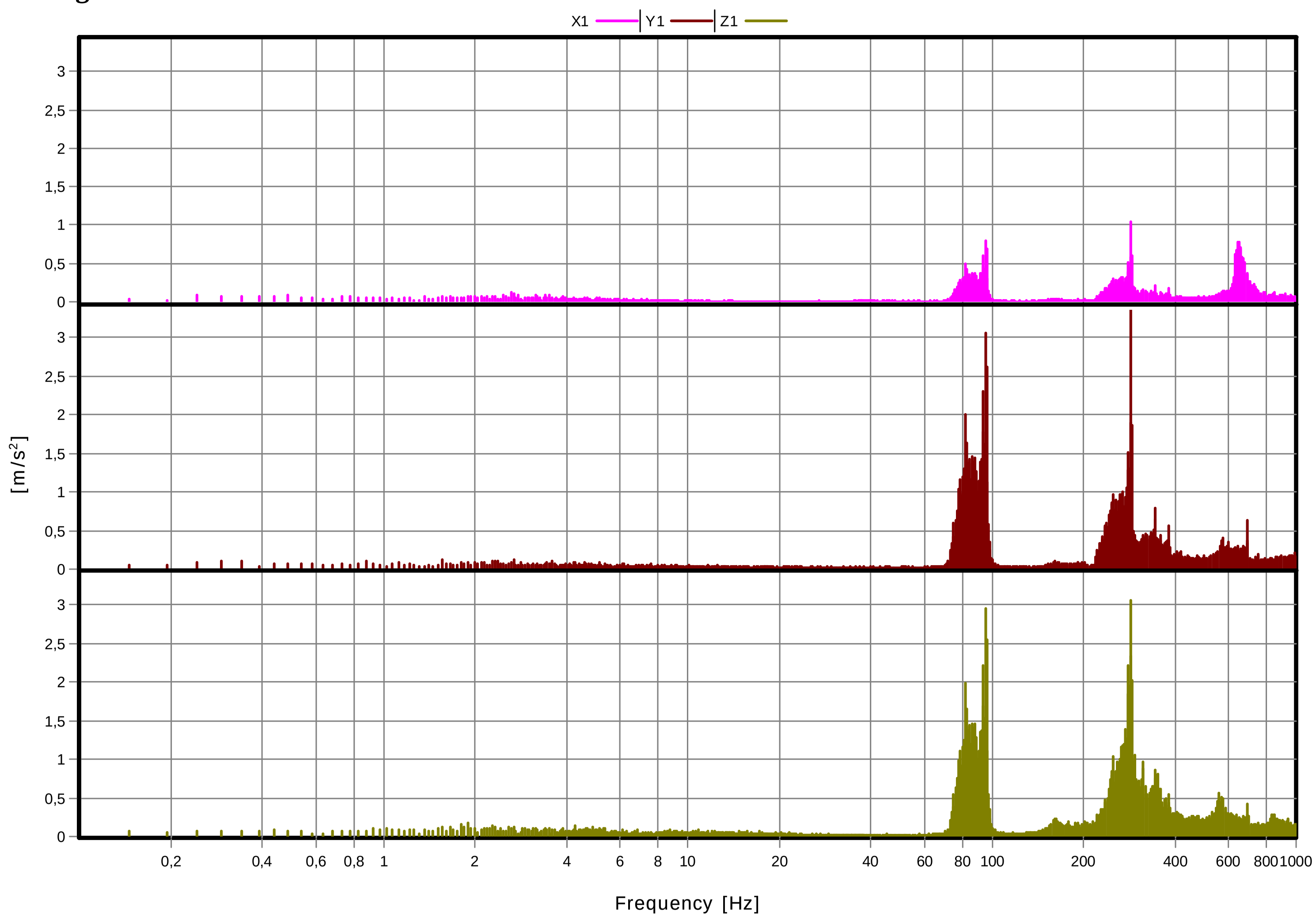


Figure 1A

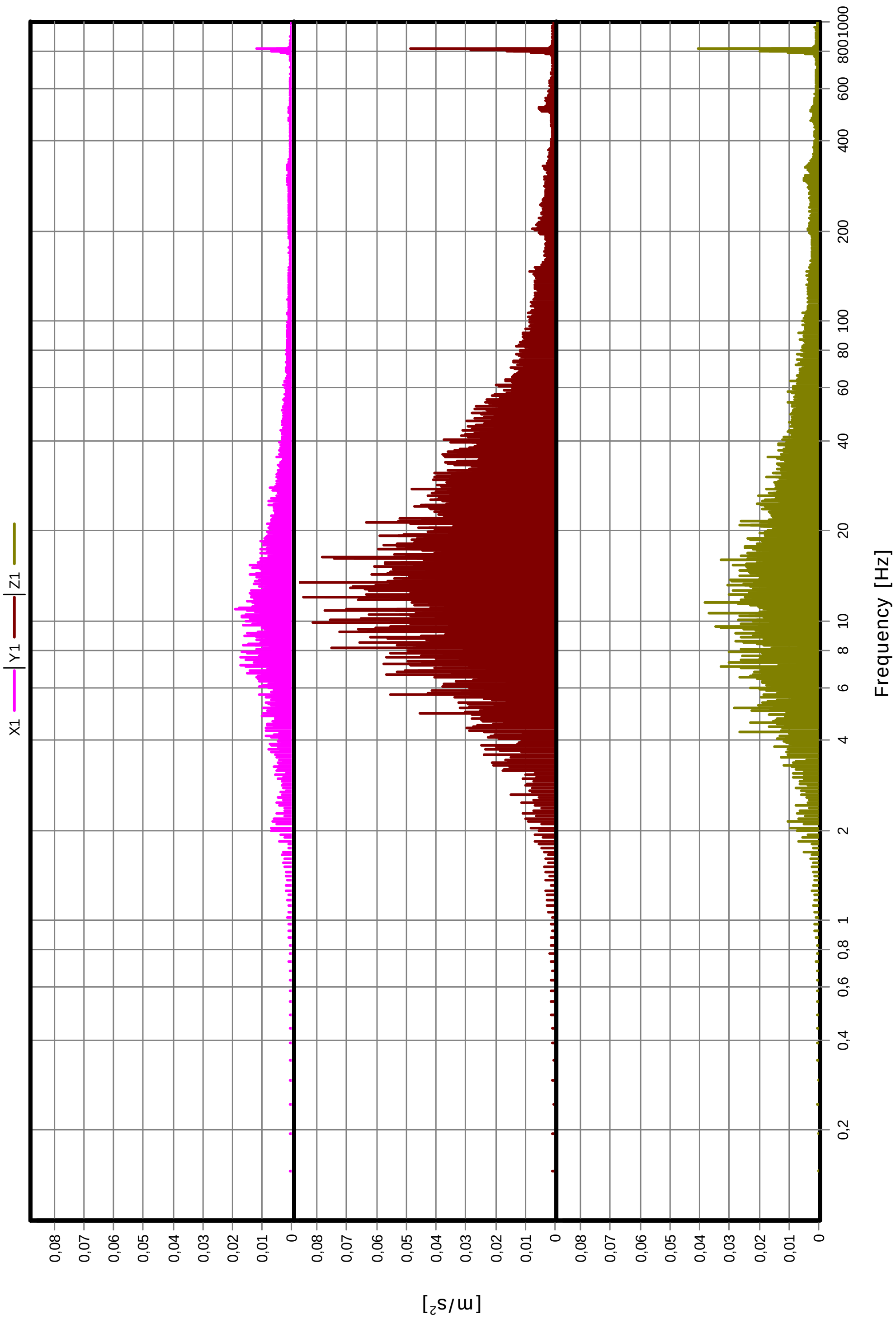
Figure 1B



X1
Y1
Z1
[m/s²]
3
2,5
2
1,5
1
0,5
0
0,2
0,4
0,6
0,8
1
2
4
6
8
10
20
40
60
80
100
200
400
600
800
1000
Frequency [Hz]

Figure 2A & B: Machine with a higher speed, Biax SRD 3-55/2, 55 000 rpm (917 Hz). Differences in the frequency spectra between hand-arm weighted (A) and unweighted (B) level. We see that the rotation frequency (just below 917 Hz) dominates the unweighted spectrum while lower frequencies emerge in the weighted spectrum. Note the different scales on the y-axis.

Figure 2A



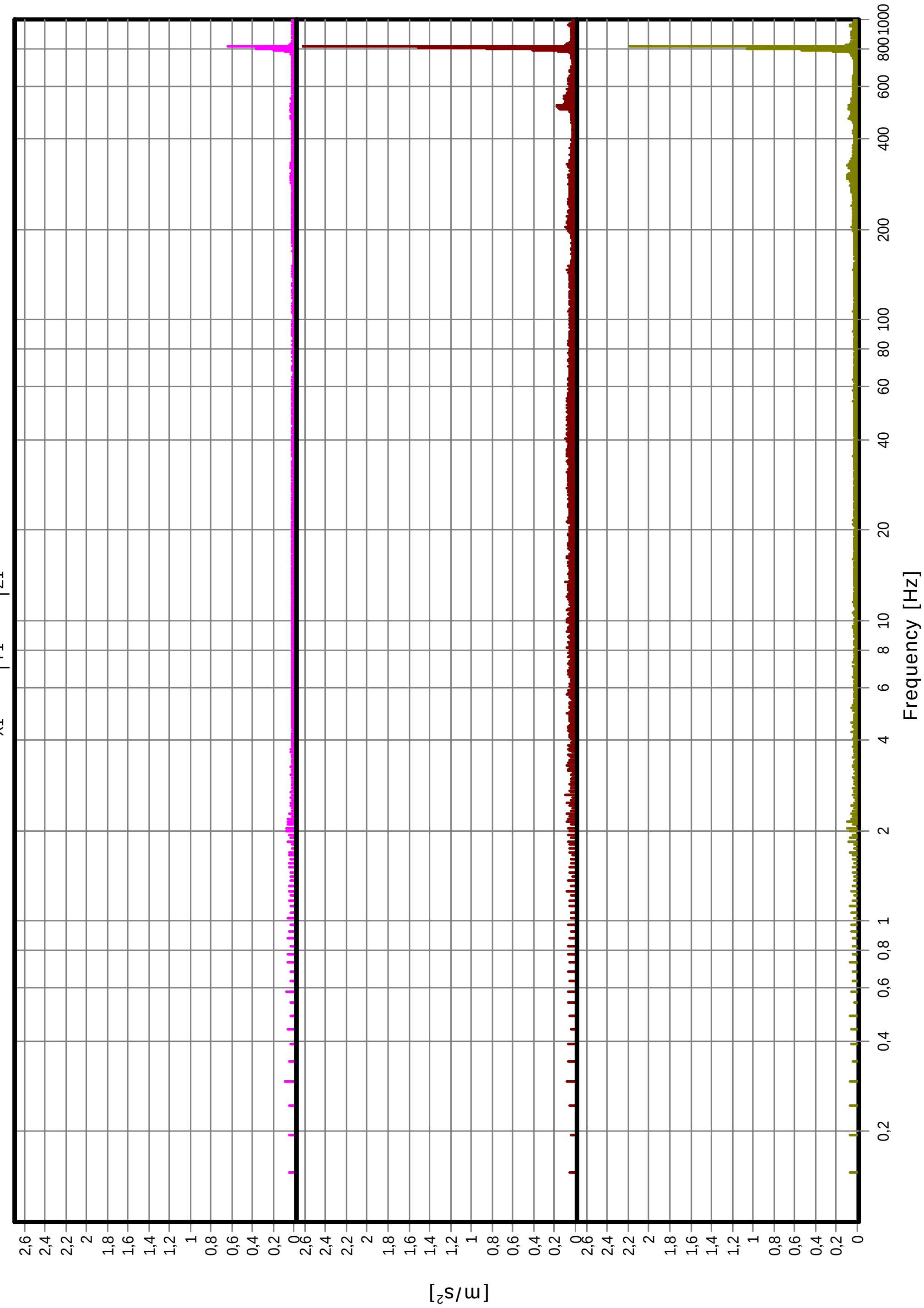
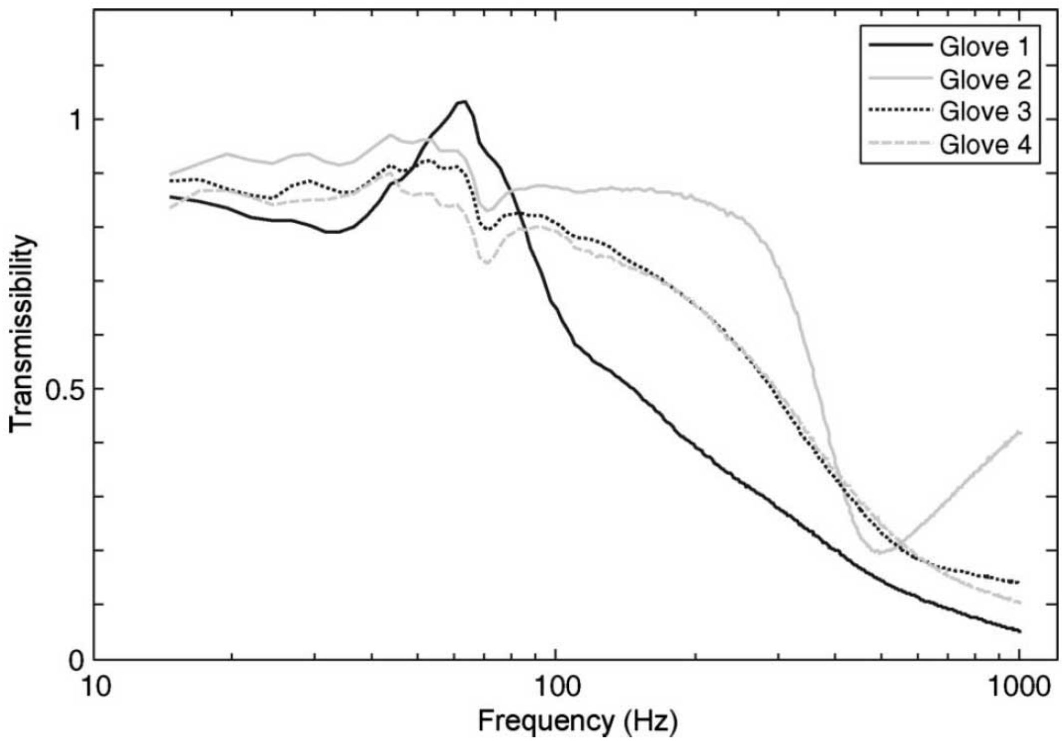

X1
Y1
Z1
Frequency [Hz]
[m/s²]
0,2
0,4
0,6
0,8
1
2
4
6
8
10
20
40
60
80
100
200
400
600
800
1000
2,6
2,4
2,2
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0

Figure 2B

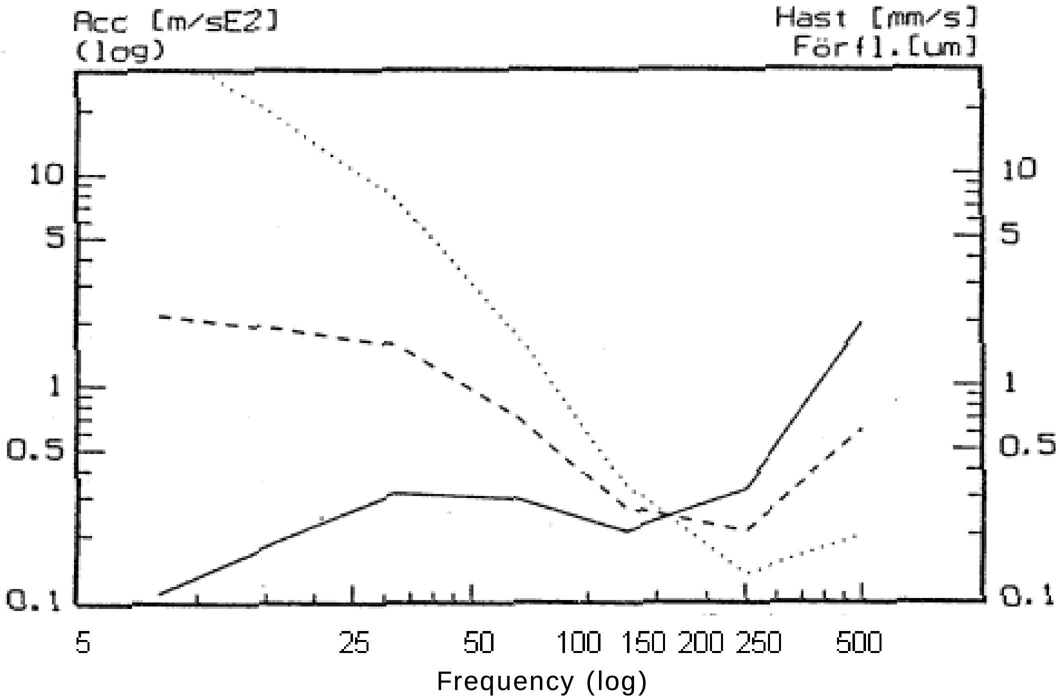
Annex 4.
The vibration transmissibility for four anti-vibration gloves

The vibration transmissibility for four different “full-finger” gloves when the feeding force = 50 N depending on the frequency (Source: Laszlo et al., 2011). Damping of vibrations exists when the vibration transmissibility is <1.0. The transmissibility usually decreases with higher frequencies.



Annex 5.
The hand's perception threshold

The frequency chart below shows that the hand's ability to perceive vibration varies with frequency. Vibration amplitude can be described as acceleration (m/s^2), velocity (mm/s) or displacement (µm). It's here obvious that the threshold of perception depends on how vibration amplitude is described because the curves slopes are shifting. So the answer to the question at which frequency the hand is most sensitive depends, therefore, on whether acceleration, velocity or displacement is given because the minima of the curves shift in frequency. Sensitivity to acceleration is high around 125 Hz; however, for vibrations expressed as displacement, the sensitivity is best at 250 Hz.



The hand's perception threshold at different frequencies, shown as:
- ——— acceleration (m/s^2),
- - - - - velocity (mm/s) and,
- .... displacement (µm)

(Data: Lundström et al., 1992).

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