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Measurement of isolated shocks in accordance with ISO/TS 15694

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Abstract

The ISO/TS 15694 technical specification [1] sets out procedures for the measurement of discrete vibration shocks acting upon the hand-arm system at repetition frequencies below 5 Hz. The TS thus supplements ISO 5349 [2], the scope of which is limited to periodic and random/non-periodic vibration. However, the TS does not set out any method for assessment of the health risk. This paper explains the relevant terms and variables, and presents and discusses them for typical shock exposure such as that caused by a nail gun, pistol, cattle stunning apparatus and hand-powered hammer.

1. Introduction

Exposure of the hand-arm system to vibration with periodic and non-periodic excitation generated by machinery and tools is measured and assessed in accordance with ISO 5349. Since the effects of discrete shocks or repeated discrete shocks are as yet not fully known, the scope of ISO 5349 is extended to discrete shocks only provisionally and with a caution. In order for the declared emissions (vibration characteristics of machinery) to be uniform and comparable and for assessment methods to be developed, the ISO/TS 15694 technical specification describes formation of a range of shock-specific measured values and methods for their interpretation. With reference to the frequency range stated in ISO 5349 (6.3 Hz to 1,250 Hz), the scope is limited to series of shocks with a frequency of < 5 Hz. Shocks constitute a particular form of vibration. However, the ISO 118/SC 3 committee [3] responsible for the emission standards determined that series of shocks with a frequency of < 5 Hz are not to be treated as vibration, and that the machines concerned are not therefore subject to mandatory declaration in accordance with the EU Machinery Directive [4]. In the research project conducted jointly by the KSZ engineering consultancy and the IFA, SCHENK [5] [6] was unable in his studies into the subjective perception to confirm the threshold of 5 Hz stated in the ISO standard. He determined a limit of 15 s^{-1}, which is comparable to the primary excitation frequency of demolition hammers and tampers.

2. Interpretation methods and variables

Modern digital measurement technology enables the "acceleration" measured value to be interpreted in both the frequency range and the time range. The ISO/TS 15694 technical specification contains a number of provisions concerning the measurement and description of excitation with a shock component. The various frequency and time weightings can be combined in the formation of the characteristic values. The frequency weightings relevant to the hand-arm system produce the following accelerations:

- $Flat_F$ -weighted acceleration: corresponds to the unweighted acceleration in the frequency range from 6.3 to 1,250 Hz
- W_h -weighted acceleration: corresponds to the frequency weighting defined in ISO 5349-1
- W_p hand-arm vascular weighting: corresponds to the new additional weighting to ISO/TR 18570

The time weighting is produced by the fixed integration times of T = 1 s and 3 s and by the time constant for the running root-mean-square value τ = 0.125 s. Only by use of the uniform integration times are the variables of the mean weighting comparable.

In the interests of clearer presentation, the variables for the $flat_F$ weighting are shown below. They can however be shown for any time and frequency weighting:

- The *root-mean-square value* corresponds to the variables usually used to date for non-periodic vibration.

$$a_{hF,RMS,T} = \sqrt{\frac{1}{T}\int_0^T a_{hF}^2(t)\,\mathrm{d}t}$$

- The same applies to the *running root-mean-square value*, which to date has been used only as an auxiliary variable for the signal characteristic.

$$a_{hF,RRMS,\tau}(t) = \sqrt{\frac{1}{\tau}\int_0^t a_{hF}^2(\xi)\,\mathrm{d}\xi}$$

- The *root-mean-quad* value constitutes a cycle maximum average of the value.

$$a_{hF,RMQ,T} = \sqrt[4]{\frac{1}{T}\int_0^T a_{hF}^4(t)\,\mathrm{d}t}$$

- The *maximum transient vibration value* is the highest running root-mean-square value.

$$a_{hF,MTVV,\tau} = \max_{0 \le t \le T}\left\{a_{hF,RRMS,\tau}(t)\right\}$$

- The peak value is the highest absolute value of the instantaneous measured value.

$$a_{hF,PV} = \max_{0 \le t \le T}\left\{\left|a_{hF}(t)\right|\right\}$$

- The *crest factor* is the quotient of the peak value and the root-mean-square value.

$$CF_h = \frac{a_{hF,PV}}{a_{hF,RMS,T}}$$

- The *shock content quotient* is the ratio of the cycle maximum average to the root-mean-square value.

$$SC_h = \frac{a_{hF,RMQ,T}}{a_{hF,RMS,T}}$$

- The jerk is a further physical variable used to date primarily in vehicle dynamics. This variable is not found in ISO/TS 15694 at present.

$$\vec{j}(t) = \dot{\vec{a}}(t) = \ddot{\vec{v}}(t) = \frac{\mathrm{d}^3\vec{x}(t)}{\mathrm{d}t^3}$$

3. Measurement results

The sources of shock studied comprise exposure situations in the trades and the metalworking sector (peen hammer), materials testing (firearm), construction (nail gun) and the meat industry (cattle stunning apparatus). During the measurements, a high-speed camera was used to record the movement at a rate of 500 images per second. For technical reasons, all measurements were performed in a single direction of measurement only, namely parallel to the direction of shock.

3.1 Nail gun

The measurements were performed during a typical work process in which a nail was driven into a steel plate. Figure 1 shows the nail gun and the test arrangement. Figure 2 shows the time characteristic of the flat$_h$-weighted acceleration with a peak value of 5,000 m/s². The maximum value of the running root mean square of the frequency-weighted acceleration with the time constant τ = 0.125 s was 30 m/s² (see Figure 3). Table 1 shows a selection of the different variables for the same signals. In the interests of clarity, not all possible combinations are shown. The values marked in grey are comparable with those of the weighting method used in ISO 5349-1. The mean and the standard deviation are shown.

Figure 1: Performance of the test involving the nail gun

Selected indikators	Mean value	Standard deviation	Unit
$a_{hF\ RMS\ (T=3s)}$	79	± 4.2	m/s²
$a_{hF\ RMS\ (T=1s)}$	176	± 9.8	m/s²
$a_{hw\ RMS\ (T=3s)}$	9.2	± 0.2	m/s²
$a_{hw\ RMS\ (T=1s)}$	21	± 0.6	m/s²
$a_{hwp\ RMS\ (T=3s)}$	71	± 7,5	m/s²
$a_{hwp\ RMS\ (T=1s)}$	134	± 7.8	m/s²
$a_{hF\ RMQ\ (T=3s)}$	461	± 15.1	m/s²
$a_{hF\ MTVV}$	336	± 19	m/s²
$a_{hw\ MTVV}$	33	± 0.4	m/s²
$a_{hF\ PV}$	4417	± 356	m/s²
$a_{hw\ PV}$	270	± 13	m/s²
CF_h	57	± 7.1	
SC_h	5.9	± 0.18	
$J_{hF\ RMS\ (T=3s)}$	354 733	± 7031	m/s³

Table 1: Measurement results for the nail gun

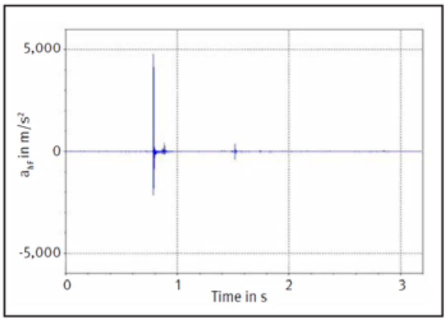

Figure 2: Time characteristic of the flat$_h$-weighted acceleration

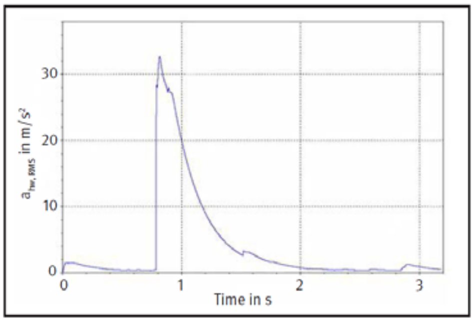

Figure 3: Time characteristic of the flat$_h$-weighted running root-mean-square value

3.2 Pistol

During weapons testing, up to 20,000 shots must be fired manually. At such stress levels, cases of occupational disease are already being reported. Measurements were performed during firing of discrete shots with 9 mm ammunition (see Figure 4). Figure 5 shows the time characteristic of the flat$_h$ -weighted acceleration with a peak value of 6,000 m/s². The maximum value of the running root mean square of the frequency-weighted acceleration is 35 m/s² (see Figure 6). The exposure values compiled in Table 2 are comparable in their order of magnitude with those for the nail gun. The images produced with the high-speed camera however revealed a rotational pulse on the wrist that suggests a shock component in the y axis (direction of gripping by the hand).

Figure 4: Pistol with sensor

$a_{hF\ RMS\ (T=3s)}$	143	± 4	m/s²
$a_{hF\ RMS\ (T=1s)}$	281	± 35	m/s²
$a_{hw\ RMS\ (T=3s)}$	8.2	± 1	m/s²
$a_{hw\ RMS\ (T=1s)}$	16.4	± 3.8	m/s²
$a_{hwp\ RMS\ (T=3s)}$	49	± 0.9	m/s²
$a_{hwp\ RMS\ (T=1s)}$	88	± 14	m/s²
$a_{hF\ RMQ\ (T=3s)}$	691	± 123	m/s²
$a_{hF\ MTVV}$	559	± 23	m/s²
$a_{hw\ MTVV}$	31	± 3.8	m/s²
$a_{hF\ PV}$	4 104	± 212	m/s²
$a_{hw\ PV}$	89	± 10.7	m/s²
CF_h	29	± 1.9	
SC_h	4.8	± 0.7	
$J_{hF\ RMS\ (T=3s)}$	1 038 023	± 266 668	m/s³

Table 2: Measurement results for the pistol

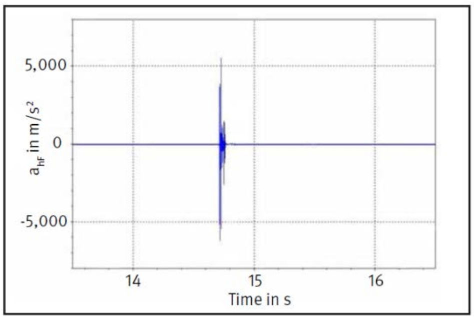

Figure 5: Time characteristic of the flat$_h$-weighted acceleration

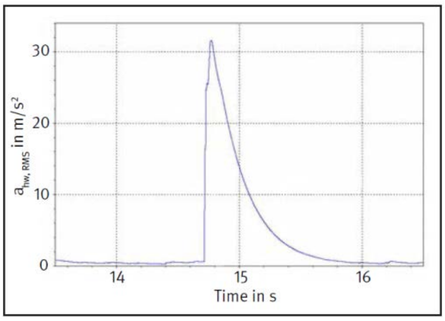

Figure 6: Time characteristic of the flat$_h$-weighted running root-mean-square value

3.3 Cattle stunning apparatus

The measurements were performed by means of a substitute method [8] that is comparable to the emissions measurement method specified in ISO 8662 [9] for fastener driving tools. Figure 7 shows that the direction of shock is not in the axis of the forearm, but in the y axis. Figure 8 shows the time characteristic of the $flat_h$-weighted acceleration with a peak value of 10,000 m/s². The maximum value of the running root mean square of the frequency-weighted acceleration is 75 m/s² (see Figure 9). Table 3 shows the different variables.

Figure 7: Performance of testing with cattle stunning apparatus

$a_{hF\ RMS\ (T=3s)}$	146	± 3.0	m/s²
$a_{hF\ RMS\ (T=1s)}$	250	± 6.5	m/s²
$a_{hw\ RMS\ (T=3s)}$	18.7	± 0.7	m/s²
$a_{hw\ RMS\ (T=1s)}$	31.5	± 0,4	m/s²
$a_{hwp\ RMS\ (T=3s)}$	108.8	± 1.6	m/s²
$a_{hwp\ RMS\ (T=1s)}$	187	± 4.6	m/s²
$a_{hF\ RMQ\ (T=3s)}$	1040	± 8.7	m/s²
$a_{hF\ MTVV}$	688	± 16	m/s²
$a_{hw\ MTVV}$	71	± 10.6	m/s²
$a_{hF\ PV}$	9504	± 241	m/s²
$a_{hw\ PV}$	599	± 11	m/s²
CF_h	65	± 2,8	
SC_h	7.1	± 0.1	
$J_{hf\ RMS\ (T=3s)}$	566 605	± 36 069	m/s³

Table 3: Measurement results for the cattle stunning apparatus

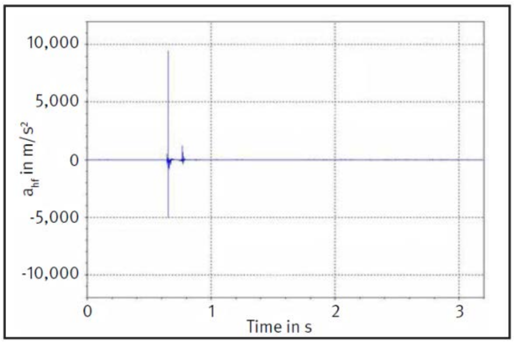

Figure 8: Time characteristic of the $flat_h$-weighted acceleration

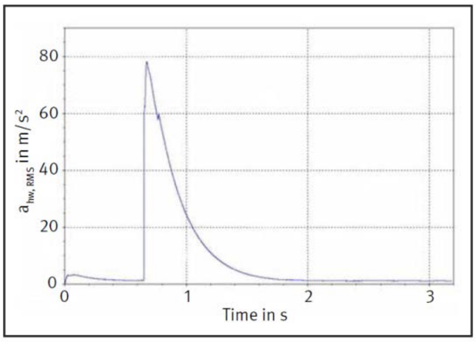

Figure 9: Time characteristic of the $flat_h$-weighted running root-mean-square value

3.4 Hand-powered hammers

Hand-powered hammers have a very wide range of uses. Very heavy impacts may be required in order to form metal, for example during straightening work. Measurements were performed with a peen hammer with a weight of 500 g under the most reproducible conditions possible with reference to RIEDEL [10] (see Figure 10). Figure 11 shows the time characteristic of the $flat_h$-weighted acceleration with a peak value of 10,000 m/s². The maximum value of the running root mean square of the frequency-weighted acceleration is 80 m/s² (see Figure 12). Table 4 shows the different variables.

$a_{hF\ RMS\ (T=3s)}$	184	± 5.4	m/s²
$a_{hF\ RMS\ (T=1s)}$	415	± 35	m/s²
$a_{hw\ RMS\ (T=3s)}$	40	± 15	m/s²
$a_{hw\ RMS\ (T=1s)}$	67	± 21	m/s²
$a_{hwp\ RMS\ (T=3s)}$	47	± 6.6	m/s²
$a_{hwp\ RMS\ (T=1s)}$	106	± 21	m/s²
$a_{hF\ RMQ\ (T=3s)}$	1004	± 21	m/s²
$a_{hF\ MTVV}$	790	±14,9	m/s²
$a_{hw\ MTVV}$	144	± 54	m/s²
$a_{hF\ PV}$	9 479	± 552	m/s²
$a_{hw\ PV}$	369	± 104	m/s²
CF_h	51	± 1.5	
SC_h	5.6	± 0.12	
$J_{hF\ RMS\ (T=3s)}$	1 187 383	± 34 736	m/s³

Figure 10: Performance of the test involving the peen hammer

Table 4: Measurement results for the peen hammer

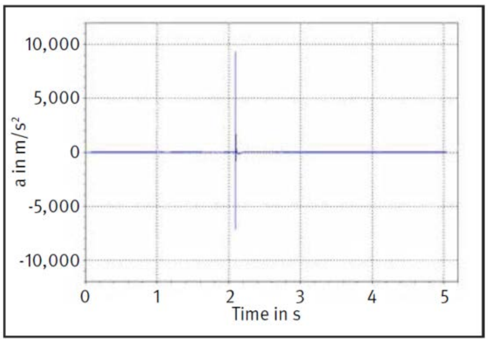

Figure 11: Time characteristic of the flat$_h$-weighted acceleration

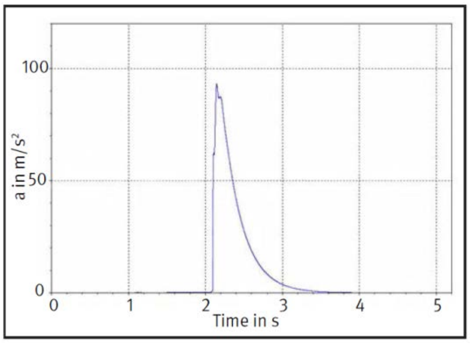

Figure 12: Time characteristic of the flat$_h$-weighted running root-mean-square value

4. Comparison of the results and summary

Figure 13 shows the measured values in the form of RMS values and the scatter with flat$_h$ weighting, frequency weighting to ISO 5349, and the additional frequency weighting a_{hwP} to ISO/TS 18570 [11] for comparison. The different relative deviations in the frequency weightings indicate differences in risk assessment. If for example the assessment method to ISO 5349 is applied to the value for the nail gun, calculation yields a violation of the action value A(8) = 2.5 m/s² in accordance with the EU directive [12] after an exposure of 922 driving operations per day. Whether this provisional assessment to ISO 5349 can be confirmed, or other frequency weightings and variables are more suitable for assessment of the health risk presented by shock exposure, must be determined by physiological and medical studies. The digital measurement technology currently available and the available defined variables provide adequate means of describing the discrete shocks (repetition frequency under 5 Hz) to the hand-arm system.

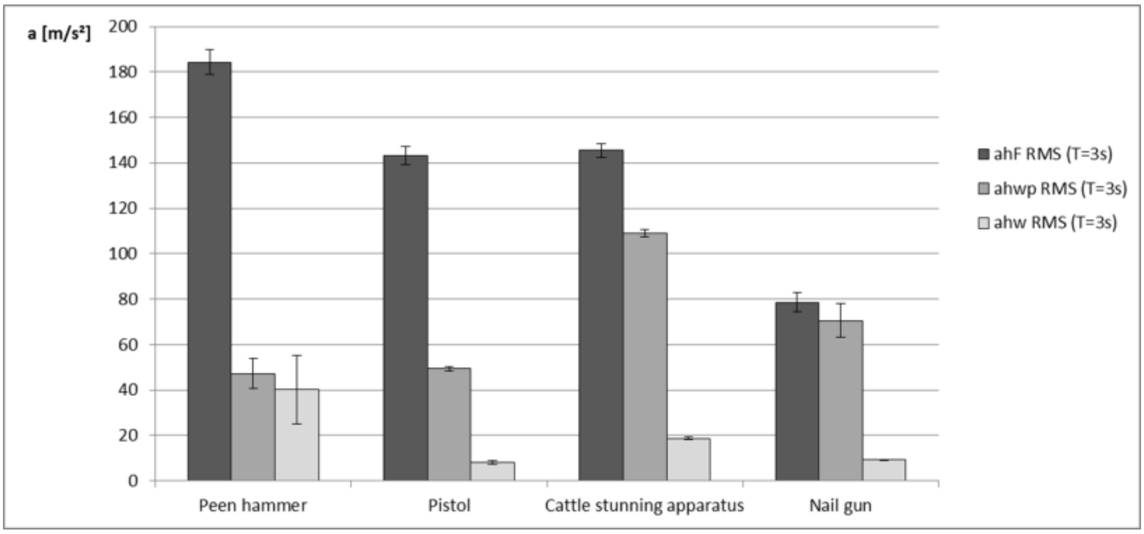

Figure 13: Comparison of the objects under measurement with the different frequency weightings

4. References

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