

Hand-Arm Vibration Measurement

CASE STUDY: The Impact of Contact Force on the Accuracy of Hand-Arm Vibration Measurement Using SV 106

Measurement Equipment:

- SV 106 - Human Vibration Meter
- SV 105AF - Hand-Arm Adapter with Traxial Accelerometer

Measurement Operator:

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Department of Vibroacoustic Hazards

Challenge:

Accurate hand-arm vibration measurement is difficult because grip force influences results and introduces uncertainty. To ensure reliable assessment of vibration exposure, it is necessary to define a minimum force threshold at the tool-hand contact point.



1.1. Micro Electro-Mechanical Systems

In recent years accelerometers based on MEMS technology (Micro Electro-Mechanical Systems) became an alternative to piezoelectric sensors. MEMS transducers are widely used in micro-mechanical systems in the automotive, computer and audio-visual industries. Construction of MEMS consists in a moving mass of resistant boards placed on a mechanical suspension system frame of reference. As a result of movement (such as vibration) there is a change in the capacitance between the moving and the fixed plates (which form capacitors).

The advantage of MEMS is their dimensions that can vary from only a few microns to millimetres, which makes them a milestone in miniaturization. The list of the advantages of MEMS-based sensors is long and includes low cost, low power consumption, small size, resistance to mechanical shocks, full electromagnetic compatibility and no DC-shift effect.



Introduction of MEMS accelerometers broke the barrier created by piezoelectric accelerometers in handarm vibration measurements. First of all, it reduced the cost of the complete system. Secondly, their small size allowed for being attached to human hands without any distraction to the performance of everyday activities even underneath anti-vibration gloves, therefore giving the true results of vibration exposure. Additionally, their size gave the opportunity to install a force sensor next to the accelerometer, thus enabling measurement of the contact force simultaneously to tri-axial acceleration assessment. This constituted a strong basis for the creation of improved methods of hand-arm vibration assessment and new hand-arm vibration measurement standards.

SV 105AF Hand-arm vibration adapter with tri-axial MEMS accelerometer and contact force sensor installed.

1.2. Use of hand-arm vibration adapters in accordance to ISO 5349

Before MEMS sensors were introduced to the market, hand-arm vibration measurements were performed with piezo-electric sensors typically mounted on tools. The location of sensors was chosen not as recommended by the ISO – at the point of contact with hand, but, in order to avoid damages, at the point most convenient and safe for the sensor itself. The introduction of MEMS hand-arm vibration adapters with force measurement capabilities solved that problem, and enabled measurement exactly at the point of contact between the hand and the vibrating surface.

At the same time the use of hand-arm vibration adapters raised a question on the accuracy of vibration measurements in function of the contact force. To answer this question 240 measurements were performed at the Polish National Research Institute at the Central Institute for Labour Protection. The impact of the coupling force on the vibration magnitudes has been assessed with Svantek's **SV 106** human vibration meters and **SV 105AF** hand-arm adapters (push force thresholds in tests were: 0 N, 20 N, 50 N, 100 N).

2.1. Measurement instrumentation and localisation of measurement points

Instrumentation used to generate and control test signals:

vibration accelerometer

Brüel & Kjaer 4374,
nr id. NA2/11,

power amplifier

Ling Dynamic Systems PA
2000, nr id. NA2/26,

vibration exciter

Ling Dynamic Systems
V721, nr id. NA2/30/31,

amplifier

NEXUS, Brüel & Kjaer
2692, nr id. NA2/62,

signal generator

Brüel & Kjaer 1054,
nr id. NA2/25,

computer

nr id. NA2/63,

analyser PULSE

Brüel & Kjaer 3560C,
nr id. NA2/84.

Instrumentation used for force measurements:

force meter

PI-W Movir MSZN-1, Nr id. NA2/32,

push force platform

CIOP PIB, Nr id. NA2/34,

testing handle

CIOP PIB, Nr id. NA2/33,

optic sensor

Sensor, CW 18/80, Nr id. NA2/43,

The study has been performed with two **SV 106** (Svantek Sp. z o.o., 2017), SVANTEK's human vibration level meters meeting the ISO 8041:2005 requirements, and designed to perform measurements in accordance with ISO 5349-1 and ISO 5349-2 standards, with special **SV 105AF** hand-arm adapters mounted on handles of vibration excitors. During the measurement, the instrument was battery powered.

Two **SV 105AF** units, marked as A and B hand-arm adapters, have been attached with a tape and beeswax to ensure the repeatability of measurements. One of the adapters (A) has been used for measurement with the operator, while the second one (B) as the reference. Both measurement points were located on testing handle. During measurements, point A was located at the point of contact of operator's hand with the handle.

Point B has been located below the zone of contact of hand with the testing handle. As the reference the accelerometer Brüel & Kjaer 4374, nr id. NA2/11 and PULSE Brüel & Kjaer 3560C, Nr id. NA2/84 analyzer have been used. The reference accelerometer has been also attached to the handle.

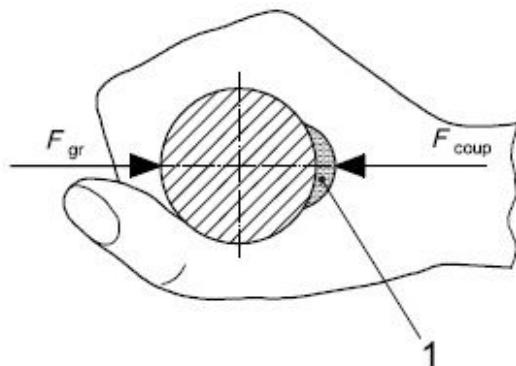
SV 106 meters with sensors and the reference accelerometer installed on the vibration exciter handle.



2.2. Contact force

Contact forces between the hand and the vibrating surface are: the push/pull force and the gripping force. The need of simultaneous assessment of contact forces and vibration magnitudes has been universally recognized and reflected in ISO 15230 standard.

During the experiment the push force has been measured with the use of special platform at the Polish National Research Institute at the Central Institute for Labour Protection, using PI-W Movir MSZN-1 meter and CW 18/80 sensor. Push force thresholds in tests were: 0 N, 20 N, 50 N, 100 N.



Example of contact forces measurement given by ISO 15230.

2.3. The measurement goal and method

Position of the operator on platform during the measurements.



The goal of the experiment was to perform measurements of vibration acceleration on a testing handle with the use of **SV 106** meters described in p. 2.1 with the presence of the different push forces applied by the operator and evaluation of these forces on the vibration results.

The method of the study was to measure the weighted vibration acceleration in the direction parallel to vibration generated on a testing handle with the simultaneous use of two measurement sets described in p. 2.1. The vibration generated on a handle was compliant to ISO 10819:2013 standard.

Adapter A was tested under defined push forces applied by 10 different operators, whereas adapter B was used as the reference without use of push forces.

Two testing signals were used in the study:

Vibration signal 1 - simulated signal of vibration accelerations generated by the vibration hammer,

Vibration signal 2 - simulated signal of vibration accelerations generated by the angle grinder.

Measurements of hand-arm vibration were performed in accordance to standards ISO 5349-1:2001 Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration:

Part 1: General requirements and ISO 5349-2:2001 Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration

Part 2: Practical guidance for measurement at the workplace.

3.1. Differences between vibration values measured with applied forces and the reference values

Tables below presents measurement results of the weighted vibration acceleration in accordance to the method described in p.2.3 measured for the selected force thresholds: 0 N, 20 N, 50 N, 100 N.

Table 1. Measurement results of the weighted vibration acceleration at push force: 0 N

PUSH FORCE 0 N							
Operator No	Test No	Test Signal 1			Test Signal 2		
		Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]	Ratio of the value of vibration acceleration measured with meter A against meter B	Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]	Ratio of the value of vibration acceleration measured with meter A against meter B
1	1	10,20	10,30	0,990	6,71	6,81	0,985
	2	10,60	10,50	1,010	6,61	6,69	0,988
	3	10,60	10,50	1,010	6,65	6,72	0,990
2	1	10,70	10,60	1,009	6,74	6,88	0,980
	2	10,40	10,40	1,000	6,63	6,73	0,985
	3	11,00	10,90	1,009	6,68	6,70	0,997
3	1	10,40	10,40	1,000	6,60	6,55	1,008
	2	10,80	10,70	1,009	6,71	6,62	1,014
	3	10,70	10,60	1,009	6,58	6,52	1,009
4	1	10,60	10,60	1,000	6,66	6,75	0,987
	2	10,20	10,20	1,000	6,75	6,85	0,985
	3	10,50	10,40	1,010	6,66	6,78	0,982
5	1	10,90	10,80	1,009	6,75	6,86	0,984
	2	10,90	10,80	1,009	6,69	6,78	0,987
	3	10,40	10,80	0,963	6,73	6,86	0,981
6	1	10,50	10,40	1,010	6,75	6,79	0,994
	2	10,80	10,70	1,009	6,78	6,78	1,000
	3	10,80	10,70	1,009	6,78	6,78	1,000
7	1	10,20	10,20	1,000	6,72	6,60	1,018
	2	10,40	10,50	0,990	6,79	6,69	1,015
	3	10,20	10,30	0,990	6,68	6,59	1,014
8	1	10,90	10,80	1,009	6,78	6,73	1,007
	2	10,80	10,70	1,009	6,85	6,78	1,010
	3	11,00	10,90	1,009	6,77	6,71	1,009
9	1	11,00	11,00	1,000	6,79	6,75	1,006
	2	11,00	10,90	1,009	6,82	6,77	1,007
	3	11,00	10,90	1,009	6,89	6,83	1,009
10	1	11,10	11,00	1,009	6,82	6,71	1,016
	2	11,10	11,00	1,009	6,85	6,75	1,015
	3	11,20	11,10	1,009	6,82	6,75	1,010
Average Value		10,70	10,65	1,004	6,73	6,74	1,000
Standard Deviation		0,30	0,26	0,010	0,08	0,09	0,013

Table 2. Measurement results of the weighted vibration acceleration at push force: 20 N

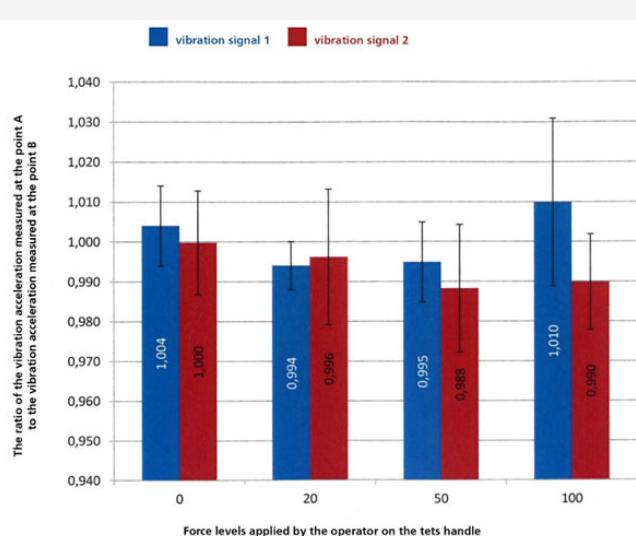
PUSH FORCE 20 N							
Operator No	Test No	Test Signal 1			Test Signal 2		
		Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]	Ratio of the value of vibration acceleration measured with meter A against meter B	Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]	Ratio of the value of vibration acceleration measured with meter A against meter B
1	1	10,40	10,40	1,000	6,61	6,60	1,002
	2	10,20	10,20	1,000	6,66	6,64	1,003
	3	9,95	10,10	0,985	6,58	6,57	1,002
2	1	10,30	10,40	0,990	6,70	6,71	0,999
	2	10,40	10,60	0,981	6,69	6,68	1,001
	3	10,30	10,40	0,990	6,76	6,78	0,997
3	1	10,10	10,10	1,000	6,58	6,71	0,981
	2	10,20	10,30	0,990	6,64	6,77	0,981
	3	10,10	10,20	0,990	6,56	6,69	0,981
4	1	10,20	10,20	1,000	6,60	6,77	0,975
	2	10,20	10,30	0,990	6,66	6,87	0,969
	3	10,30	10,30	1,000	6,55	6,71	0,976
5	1	10,00	10,20	0,980	6,55	6,76	0,969
	2	10,20	10,30	0,990	6,57	6,77	0,970
	3	10,10	10,20	0,990	6,63	6,82	0,972
6	1	10,30	10,40	0,990	6,69	6,76	0,990
	2	10,10	10,10	1,000	6,80	6,81	0,999
	3	10,30	10,40	0,990	6,78	6,75	1,004
7	1	10,40	10,40	1,000	6,78	6,61	1,026
	2	10,60	10,70	0,991	6,85	6,68	1,025
	3	10,40	10,50	0,990	6,74	6,58	1,024
8	1	10,50	10,50	1,000	6,68	6,74	0,991
	2	10,80	10,80	1,000	6,68	6,74	0,991
	3	10,60	10,60	1,000	6,71	6,76	0,993
9	1	10,50	10,60	0,991	6,72	6,63	1,014
	2	10,40	10,40	1,000	6,78	6,67	1,016
	3	10,30	10,40	0,990	6,85	6,71	1,021
10	1	10,60	10,60	1,000	6,80	6,72	1,012
	2	10,70	10,70	1,000	6,72	6,72	1,000
	3	10,70	10,70	1,000	6,75	6,73	1,003
Average Value		10,34	10,40	0,994	6,69	6,72	0,996
Standard Deviation		0,22	0,20	0,006	0,09	0,07	0,017

Table 3. Measurement results of the weighted vibration acceleration at push force: 50 N

PUSH FORCE 50 N							
Operator No	Test No	Test Signal 1			Test Signal 2		
		Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]			Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]
1	1	9,99	9,89	1,010	6,55	6,58	0,995
	2	10,10	10,10	1,000	6,58	6,65	0,989
	3	9,92	9,91	1,001	6,65	6,68	0,996
2	1	10,10	10,30	0,981	6,65	6,68	0,996
	2	9,85	10,00	0,985	6,70	6,75	0,993
	3	9,87	10,00	0,987	6,63	6,67	0,994
3	1	10,00	10,00	1,000	6,55	6,69	0,979
	2	9,78	9,87	0,991	6,65	6,72	0,990
	3	9,85	10,10	0,975	6,58	6,75	0,975
4	1	10,20	10,30	0,990	6,48	6,73	0,963
	2	10,20	10,40	0,981	6,54	6,75	0,969
	3	9,93	10,00	0,993	6,56	6,78	0,968
5	1	10,10	10,20	0,990	6,50	6,76	0,962
	2	9,79	9,94	0,985	6,59	6,80	0,969
	3	10,20	10,40	0,981	6,53	6,78	0,963
6	1	9,87	9,97	0,990	6,66	6,77	0,984
	2	10,10	10,00	1,010	6,63	6,75	0,982
	3	9,83	9,78	1,005	6,63	6,82	0,972
7	1	10,50	10,50	1,000	6,75	6,65	1,015
	2	9,98	9,98	1,000	6,62	6,60	1,003
	3	9,97	9,87	1,010	6,65	6,61	1,006
8	1	10,30	10,30	1,000	6,58	6,65	0,989
	2	10,60	10,70	0,991	6,61	6,69	0,988
	3	10,30	10,30	1,000	6,52	6,61	0,986
9	1	10,40	10,50	0,990	6,74	6,63	1,017
	2	10,40	10,50	0,990	6,69	6,62	1,011
	3	10,40	10,40	1,000	6,75	6,63	1,018
10	1	10,60	10,60	1,000	6,61	6,65	0,994
	2	10,40	10,40	1,000	6,65	6,69	0,994
	3	10,500	10,40	1,010	6,65	6,72	0,990
Average Value		10,13	10,19	0,995	6,62	6,70	0,988
Standard Deviation		0,25	0,25	0,010	0,07	0,07	0,016

Table 4. Measurement results of the weighted vibration acceleration at push force: 100 N

PUSH FORCE 100 N							
Operator No	Test No	Test Signal 1			Test Signal 2		
		Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]		Value of vibration acceleration measured with meter A [m/s ²]	Value of vibration acceleration measured with meter B [m/s ²]	
1	1	10,20	10,10	1,010	6,64	6,58	1,009
	2	10,20	10,20	1,000	6,52	6,60	0,988
	3	10,20	10,20	1,000	6,46	6,65	0,971
2	1	10,40	10,40	1,000	6,63	6,65	0,997
	2	10,10	10,10	1,000	6,68	6,68	1,000
	3	10,20	10,20	1,000	6,61	6,58	1,005
3	1	9,95	9,93	1,002	6,55	6,61	0,991
	2	9,74	9,75	0,999	6,54	6,78	0,965
	3	9,72	9,67	1,005	6,55	6,65	0,985
4	1	9,93	9,95	0,998	6,48	6,61	0,980
	2	9,89	8,89	1,112	6,52	6,65	0,980
	3	9,92	9,87	1,005	6,57	6,69	0,982
5	1	10,40	10,20	1,020	6,43	6,61	0,973
	2	10,20	10,10	1,010	6,49	6,68	0,972
	3	10,40	10,30	1,010	6,53	6,61	0,988
6	1	10,10	9,93	1,017	6,52	6,68	0,976
	2	10,20	10,10	1,010	6,46	6,63	0,974
	3	10,10	9,99	1,011	6,51	6,67	0,976
7	1	10,30	10,30	1,000	6,61	6,64	0,995
	2	9,82	9,74	1,008	6,49	6,52	0,995
	3	10,30	10,10	1,020	6,52	6,54	0,997
8	1	10,20	10,10	1,010	6,56	6,58	0,997
	2	10,40	10,30	1,010	6,55	6,58	0,995
	3	10,20	10,20	1,000	6,47	6,50	0,995
9	1	10,30	10,20	1,010	6,61	6,59	1,003
	2	10,20	10,00	1,020	6,70	6,67	1,004
	3	10,30	10,20	1,010	6,56	6,53	1,005
10	1	10,40	10,40	1,000	6,58	6,58	1,000
	2	10,30	10,30	1,000	6,57	6,58	0,998
	3	10,10	10,10	1,000	6,58	6,59	0,998
Average Value		10,16	10,06	1,010	6,55	6,62	0,990
Standard Deviation		0,20	0,29	0,021	0,06	0,06	0,012



The ratio of vibration values measured with the applied force against to the reference values with no force applied.

The graph presents the ratio of averaged results for 30 measurements for each force threshold at point A against the results at point B together with the standard deviation. The results from vibration signal 1 are marked in blue and vibration signal 2 in red.

3.2. The impact of contact force on measured vibration values

On the basis of the conducted study it has been defined that differences between measured vibration accelerations in points A and B for push forces in the range of 0 – 100 N do not exceed 1.2% which means that the effect of the push force applied is irrelevant to the measured vibration values.

3.3. The minimum contact force threshold required for the accurate vibration acceleration measurements.

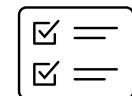
Additional measurements with hand-arm adapters without the use of beeswax nor mounting tape were performed to evaluate the effect of changes of the coupling of the adapter to the testing handle. It has been

noted that for force thresholds below 20 N it was necessary to ensure that the coupling between adapter and testing handle was sufficient to prevent the breaks in a continuous contact during the measurements.



Conclusion

The conducted study proves that the effect of changes of the force thresholds applied by the operator are irrelevant to the measured vibration acceleration values. This assumption is valid for the forces above threshold of 20 N, below which it is necessary to ensure the correct coupling between hand-arm adapter and vibrating surface. Together with the force level drop below 20 N, the uncertainty related to the coupling increases rapidly. However it is necessary to note that in practise, for tools generating high vibration amplitudes, the threshold of 20 N may not guarantee the perfect coupling, therefore higher threshold levels should be established.



Summary

At the time the ISO 5349 standard was introduced it was practically impossible to perform force measurements together with tri-axial vibration measurements due to limitations in hardware.

At the moment very small force transducers can be fitted right next to the MEMS-technology-based vibration accelerometer in a form of hand-arm adapter as specified by ISO 5349-2 and ISO 10819 standards. In comparison to the technique of mounting sensor on a tool, the use of contact force allows defining the actual vibration exposure, whereas mounting on a tool bears the uncertainty of including into tests the periods when there was no contact with the operator's hand.

As it has been proven, the use of hand-arm adapters provides the same accuracy of vibration amplitudes as in case of standard piezoelectric vibration sensors mounted on a tool, but additionally offers the advantage of the best possible location of the measurement point – exactly at the point of transmission of the vibration signal to the hand of an operator and provides information on the actual exposure to the vibration.

References

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