PD CEN/TR 16391:2012

BSI Standards Publication

Mechanical vibration and shock — Hand-transmitted vibration — Influence of coupling forces at the hand-machine interface on exposure evaluation

bsi.

...making excellence a habit.™

National foreword

This Published Document is the UK implementation of CEN/TR 16391:2012.

The UK participation in its preparation was entrusted to Technical Committee GME/21/6, Mechanical vibration, shock and condition monitoring - Human exposure to mechanical vibration and shock.

This Technical Report addresses the influence of coupling forces between the hand and a hand-guided or hand-fed machine on the transmission of vibration into the hand and arm. It also seeks to encourage further research to improve the current state of knowledge.

The UK committee advises that it is not appropriate to use coupling forces to modify workplace assessments of vibration exposure in relation to the EU Physical Agents (vibration) Directive (implemented in the UK as the Control of Vibration at Work Regulations 2005) or the measures of vibration emission as required by the EU Machinery Safety Directive (implemented in the UK as the Supply of Machinery (Safety) Regulations 2008).

A list of organizations represented on this committee can be obtained on request to its secretary.

Published by BSI Standards Limited 2012

ISBN 978 0 580 77055 5

ICS 13.160

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 November 2012.

Amendments issued since publication

Date	Text affected

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 16391

October 2012

ICS 13.160

English Version

Mechanical vibration and shock - Hand-transmitted vibration - Influence of coupling forces at the hand-machine interface on exposure evaluation

Chocs et vibrations mécaniques - Vibrations transmises à la main - Evaluation de l'exposition aux effets des forces de couplage à l'interface entre la main et la machine

Mechanische Schwingungen und Stöße - Hand-Arm-Schwingungen - Einfluss der Ankopplungskräfte an der Schnittstelle zwischen Hand und Maschine auf die Bewertung der Schwingungseinwirkung

This Technical Report was approved by CEN on 24 June 2012. It has been drawn up by the Technical Committee CEN/TC 231.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. CEN/TR 16391:2012: E

Contents

Page

Foreword

This document (CEN/TR 16391:2012) has been prepared by Technical Committee CEN/TC 231 “Mechanical vibration and shock”, the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

Introduction

The coupling force between the hand-arm system and a hand-held, hand-guided or hand-fed machine during its use is an important factor in the transfer of damaging vibration energy to the hand and arm. There is evidence that reducing coupling forces is likely to decrease the damaging effects of exposure to hand-transmitted vibration. However, the relationship between vibration exposure, coupling forces and damage to the hand-arm system is still the subject of research studies. There is a need for practical advice for users on how to minimise and control contact forces and guidance on how to account for those reduced contact forces when assessing vibration exposures. Machine manufacturers of hand-held and hand-guided machines need advice on how to achieve the best compromise between the requirements for both low coupling forces and low vibration magnitudes.

The aims of this Technical Report are to:

— provide guidance on good-practice for both workplace control of exposure and machine design and

— encourage further research to improve the current state of knowledge.

This Technical Report provides an overview of the current state of knowledge on the relationship between vibration exposures, coupling forces and damage to the hand-arm system. It provides general guidance on how to build the reduction of coupling forces into workplace action plans to control vibration exposures and how the reduction of coupling forces may be incorporated into machine design. An example of an empirical relationship for accounting the coupling force in assessments of vibration magnitudes is also provided.

Technical Reports have no effect on the regulations specified by European Directives. That means that at present coupling forces should not be used to modify workplace assessments of vibration exposure according to the EU Physical Agents Directive (vibration) 2002/44/EC or the measurement of vibration emission declared according to the EU Machinery Directive 2006/42/EC.

1 Scope

This Technical Report provides an overview of the current state of knowledge on the relationship between vibration exposures, coupling forces and damage to the hand-arm system. It provides general guidance on how to build the reduction of coupling forces into workplace action plans to control vibration exposures and how the reduction of coupling forces may be incorporated into machine design. An example of an empirical relationship that accounts for the coupling force in assessments of vibration magnitudes is also provided.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1005-2, *Safety of machinery — Human physical performance — Part 2: Manual handling of machinery and component parts of machinery*

EN 1005-3, *Safety of machinery — Human physical performance — Part 3: Recommended force limits for machinery operation*

EN ISO 5349-1, *Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 1: General requirements (ISO 5349-1)*

EN ISO 5349-2, *Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 2: Practical guidance for measurement at the workplace (ISO 5349-2)*

ISO 15230:2007, *Mechanical vibration and shock — Coupling forces at the man-machine interface for hand-transmitted vibration*

3 Symbols and abbreviations

For the purposes of this document, the symbols and abbreviations given in ISO 15230:2007 apply.

4 Contact force and hand-transmitted vibration

EN ISO 5349-1 recognises that, although characterisation of the vibration exposure currently uses the acceleration of the surface in contact with the hand as the primary quantity, it is reasonable to assume that the biological effects depend largely on the coupling of the hand to the vibration source. It further notes that the coupling of the hand to the vibrating surface can affect considerably the vibration magnitudes measured.

The importance of coupling force on measurement is also emphasised in EN ISO 5349-2, which advises that different measurement ought to be made if there are changes in the feed forces applied to machines.

EN ISO 5349-1 states that coupling forces should be measured, and notes that a standard on measurement of coupling forces was (in 2001) in preparation. ISO 15230 was published in 2007 and defines parameters relating to the measurement of coupling forces (feed-force, grip force, contact pressures, etc.).

ISO 15230 defines the coupling force as the combination of compressive push/pull and grip forces. It provides a basis for obtaining good-quality information on the forces between the vibrating surface and the hand. However, workplace measurement of coupling force is a complex process that requires specialised equipment and knowledge.

NOTE Coupling force does not include forces acting tangentially to the vibrating surface, such as the force required to twist a handle. It is the (compressive) coupling force that is assumed to influence the transmission of damaging vibration energy into the hand.

5 Influence of coupling force on vibration exposure evaluation

The method for assessing workplace exposure to hand-arm vibration is standardised in EN ISO 5349-1. This standard evaluates the risk of harm from vibration based on two factors:

— the vibration at the surface in contact with the hand and

— the exposure time over the working day.

However, EN ISO 5349-1 also recognises that the biological effects of vibration are likely to depend on the coupling of the hand to the vibration source.

Annex A summarises the state of current knowledge on the relationship between vibration exposure, coupling force and damage to the hand-arm system. The relationship between vibration exposure, coupling forces and damage to the hand-arm system is still the subject of research studies. However, there is evidence that reducing coupling forces is likely to decrease the damaging effects of exposure to hand-transmitted vibration.

Methods for compensating data on vibration magnitude according to the coupling force have been developed. Annex B provides an example of one such system. The method shown in Annex B requires information on coupling forces, based on measurements according to ISO 15230. Currently there is limited data available on typical coupling forces for normal workplace tasks. Annex C shows some examples of the coupling forces used for a range of hand-held and hand-guided machines.

This Technical Report provides a bibliography of papers that contribute to the evidence linking coupling forces associated with the use of hand-held and hand-guided machinery and vibration injury.

6 Control of coupling forces in the workplace

6.1 General

In general, workplaces and work tasks should be designed as far as possible to provide workers with ergonomically good postures for both the body and the hand and arm. Awkward and strained postures will tend to result in higher than necessary coupling-forces between the hand and the handle of the machine.

The work tasks should be generally designed to promote minimum coupling forces. This should begin with selection of the most appropriate machines for the task; it may also include adapting the workstations to reduce contact forces and will include the provision of information for and instruction and training of the machine operators.

Some actions to reduce coupling forces may increase the magnitude vibration, when evaluated according to EN ISO 5349-1. Understanding how and why the vibration increases may help to identify solutions that will lead to both reduced coupling force and reduced vibration exposure.

6.2 Machine selection

Hand-held machines (power tools) should be selected based on their capability to do the job. In general, smaller, more compact, machines tend to require lower supporting and twisting forces to hold and manoeuvre them and should be used where they are an option. However, smaller, low-weight, machines may not be suitable if they need higher feed and gripping forces to compensate for the reduced mass. Sometimes, larger and heavier machines are simply more capable of doing the job being asked of them. For this reason, good ergonomic design of machines may be more important than simply reducing the mass and making the machine smaller.

Things to consider when selecting machines for the workplace:

a) Is it able to the job?

b) Does it perform the task efficiently?

c) Is it designed ergonomically such that it:

   1) is easy to operate,

   2) is comfortable to use and

   3) requires low coupling forces?

d) Is it low-vibration?

6.3 Workstations and work-tasks

Guidance on ergonomic design criteria and assessment of manual-handling risks related to work activities is given in EN 1005-2. While EN 1005-2 specifically excludes hand-guided (including hand-held) machines, the general good ergonomic practices may be employed, such as:

— Bringing work pieces up to the natural working level of the worker;

— Orienting work pieces so that the worker is not required to lift and apply force away from the body;

— Providing overhead-support for hand-operated machines.

Additional guidance is given in EN 1005-3 on the applied forces that can be applied by typical working populations under different work situations.

Overhead support for machines can provide an opportunity for introducing vibration controls that would not normally be possible because of the additional weight. Effective vibration reductions have been achieved by fitting the hand-held machine into a frame with vibration-isolated handles. With the weight of the machine supported, the worker is only guiding the machine and the additional weight of the frame does not add to the load that the worker has to support.

Adding mass can have an additional advantage; it will act to reduce the amount of motion in the body of the machine, reducing the vibration magnitude.

6.4 Information and training

Users of machines need to understand how to get the best out of the machines they use. It is important that workers understand how a machine needs to be operated, why certain operating methods are recommended and why others are not desirable.

Instruction and training provided to users should be based on information provided by machine manufacturers on the safe use of their machinery.

When excessively high push forces are applied the magnitude of hand-arm vibration on machines often increases. This increase in vibration is not usually indicating more effective machine operation and may be an indicator that the machine is no longer operating efficiently. Unfortunately, the machine operator can misinterpret this increase in vibration (and noise) as an indication that the machine is working more effectively and will apply forces much higher than those that are necessary for the task being performed.

Many machines are designed with anti-vibration systems that isolate the worker from the vibration of the machine. Poorly trained operators often relate low vibration with low work-rates of the machine, and push harder until they can feel the vibration. This overloads the anti-vibration systems, giving the worker a high vibration exposure but makes little difference to the real work rate.

It is generally important that the workers allow the machine to do the job and that they do not put in excessive effort themselves. The feeling that there is a need to push hard can be a result of the machine accessories being inappropriate for the job, or poorly maintained. Examples of conditions that lead to excessive force being applied include:

a) Blunt drill bits, moil-points or chisels – Workers feel the need to push if the machine is not operating as quickly as it normally does. This may be due to blunt accessories. In addition, excessive push forces will cause drill bits and chisel to become blunt more quickly than they should.

b) The wrong accessory for the job – Using an abrasive that is too hard for the task can result in the abrasive surface becoming smooth rather than wearing properly. Abrasives that are too soft will quickly wear, without being able to adequately abrade the surface. In both situations, the worker will feel that it is necessary to push harder to get the work done.

c) Poorly maintained machines – For most machines with a rotary action, any out-of-balance in the machine can both increase vibration and increase the forces required to properly control the machine.

Reduced machine performance is one indicator that a machine is in need of maintenance or inspection. Workers need to be trained to recognise the changes in machine characteristics that indicate the need for inspection and maintenance. These signs may include:

- more time required to do the job,
- greater forces required (increased strain and coupling forces),
- increase vibration,
- increase noise,
- overheating.

7 Design of machinery

7.1 General

Machines designed using the guidance and recommendation provided in EN 1005-2 and EN 1005-3 will improve general ergonomic handling of machines, and lead to optimised coupling forces between the hand and machine handles.

EN 1005-2 provides ergonomic recommendations for the design of machinery involving manual handling. While EN 1005-2 specifically excludes hand-guided (including hand-held) machines, the general good ergonomic practices are applicable to all hand-machines. This standard gives guidance on factors such as mass, mass-distribution, size, grips and handles and working postures.

EN 1005-3 provides guidance to the manufacturers of machinery on controlling health risks due to machine-related muscular force exertion. It provides recommended force limits for machinery, based on the actions being carried out and the capability of the working population to provide the necessary force. It considers speed, frequency and duration of the operation that will be carried out with the machine.

7.2 Applied force and machine efficiency

Machines should be designed such that the coupling forces required for the most efficient operation of the machine are considered when designing the machine for good ergonomic handling.

7.3 Indicators for operators on applied force

Machines can be designed to make it clear to the user when excessive push forces are being applied, for example:

— Road breakers with suspended handles or bodies indicate the correct applied force by being in the centre of their suspension range;

— Some large electric drills are designed to stall if excessive feed forces are applied.

7.4 Handle characteristics

Machine handles should be designed to encourage the machine with minimum required operating forces. Triggers should be designed and positioned so that minimal force is required while the machine is operating (consistent with other safety considerations) and should not encourage operation of the machine when it is not normally required (e.g. when pulling a road-breaker out of a hole).

Annex A
(informative)

Evidence for dependence on contact forces

A.1 Biodynamics

The extent to which vibration energy transmitted into the hand is dependent upon both the force applied between the vibrating surface on the hand (the coupling force) and the dynamic mass of the fingers, hand or hand-and-arm.

The biodynamic studies show that force affects the apparent mass of the hand, the absorbed power in the hand and the transmission of vibration through glove materials. In summary:

— The primary resonance of the apparent mass of the palm of the hand increased with increasing force applied at the palm;

— The absorbed power at the palm reduced as the push force increased.

Different coupling forces are likely to change the vibration-energy absorption characteristics of the hand and arm. Biodynamic models have been developed that illustrate that the current EN ISO 5349-1 frequency weighting W_h can be said to represent the energy absorption by the hand-and-arm system when a specific coupling forces are applied. These same models suggest alternative frequency weightings for individual elements of the hand-arm system, such as the fingers.

A.2 Physiological effects

Vasoconstriction in the finger caused by vibration depends on the applied force. The greater the applied force, the greater the reduction in finger blood-flow (this applies both with and without exposure to vibration). In addition to these reductions caused by the applied forces, vibration exposure itself causes reductions in finger blood-flow that are not limited to just the finger experiencing force and vibration. In all fingers, the greater the magnitude of vibration, the greater the reduction in finger blood-flow.

Carpal Tunnel Syndrome is also associated with vibration exposure. It is also associated with poor hand-arm postures, regular repetitive processes and high operating forces. Control of coupling forces, improvement of hand-arm postures and control of vibration exposures are all likely to reduce the risks of developing this condition.

A.3 Studies on the influence of coupling forces

Since it is virtually impossible to study the influence of the coupling forces under practical working conditions, research results are based primarily upon studies conducted under laboratory conditions. The following parameters have therefore frequently been specified as loading criteria:

— Biodynamic characteristics of the hand-arm system (transmission to the finger, wrist, elbow and shoulder joints),

— Muscle activity (surface electromyography),

— Subjective level of perception,

— Skin temperature at the fingertips,

— Threshold of perception (of vibration).

Annex B
(informative)

Evaluation of vibration exposure as function of the coupling force

B.1 Background

This annex provides a method for weighting vibration magnitude data according to the coupling force. This method might be used when investigating the effect of coupling force on risks from vibration exposure. It is designed to be a simple and practical method and is based on a review of a wide range of literature [29] including studies on biodynamic characteristics of the hand-arm system (transmission to the wrist, elbow and shoulder joints), muscle activity (surface electromyography), subjective level of perception, skin temperature at the fingertips and threshold of perception (of vibration).

B.2 Terms and definitions

In addition to ISO 15230:2007, the following terms and definitions apply.

B.2.1
coupling factor
c_{cp}
weighting factor for adjusting the frequency-weighted acceleration a_{hw} as a function of the coupling force F_{cp}

B.2.2
coupling-force- and frequency-weighted acceleration
a_{hwc}
frequency-weighted acceleration a_{hw} after weighting by the coupling factor c_{cp}

B.2.3
coupling-force-weighted total vibration
a_{hvc}
total vibration value a_{hv} calculated from the frequency-weighted acceleration after weighting by the coupling factor c_{cp}

B.2.4
coupling-force-weighted daily vibration exposure
$A(8)_c$
daily vibration exposure calculated from the coupling-force-weighted total vibration values a_{hvc}

B.3 Calculation of parameters

B.3.1 Coupling-force-weighted factor

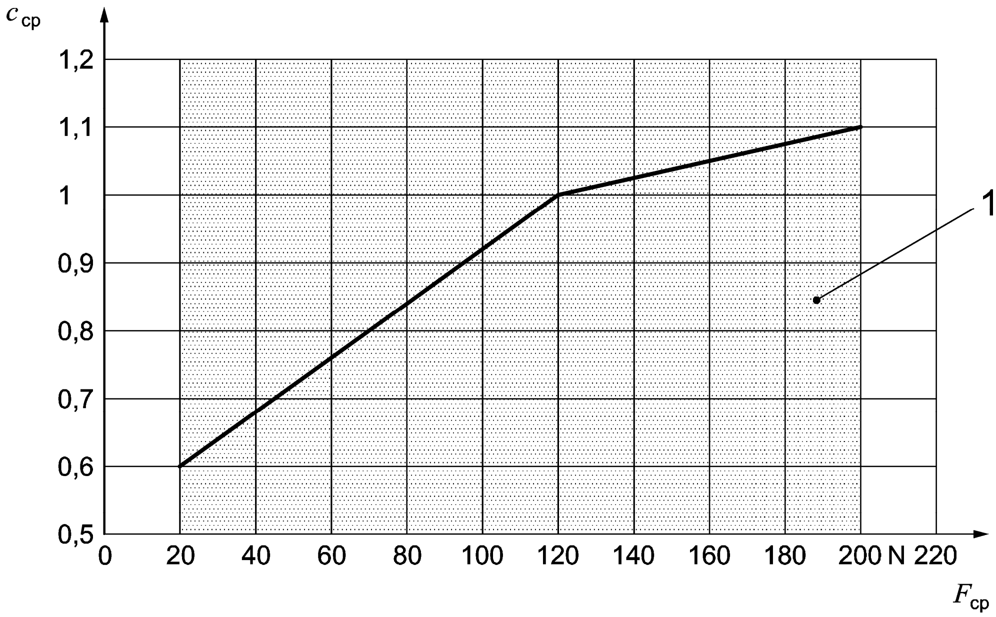
Coupling factor, c_{cp}, is valid over the coupling force range from 20 N to 200 N. It is shown in Figure B.1 and is defined by:

$$c_{cp} = 4\frac{F_{cp}}{F_0} + 0,52 \qquad \text{for } 20\text{ N} \le F_{cp} \le 120\text{ N} \qquad \text{(B.1)}$$

$$c_{cp} = 1{,}25\frac{F_{cp}}{F_0} + 0{,}85 \quad \text{for } 120\ \text{N} < F_{cp} \leq 200\ \text{N} \qquad \text{(B.2)}$$

where

F_0 = 1 000 N.



Key

1 shadowed area is the range of validity

Figure B.1 — Coupling factor c_{cp} as a function of coupling force F_{cp}

B.3.2 Coupling-force- and frequency-weighted acceleration

The coupling-force-weighted frequency-weighted acceleration, a_{hwc}, is calculated from the frequency-weighted acceleration a_{hw} using:

$$a_{hwc} = a_{hw}\ c_{cp} \qquad \text{(B.3)}$$

It is assumed that the coupling factor is applied equally to all the x-, y- and z-axes of vibration. Therefore the coupling factor may be applied individually to the three axes before calculating the coupling-force-weighted vibration total value a_{hvc}, or applied directly to the vibration total value, i.e.:

$$a_{hvc} = a_{hv}\ c_{cp} \qquad \text{(B.4)}$$

B.3.3 Coupling-force-weighted daily vibration exposure

The coupling-force-weighted total vibration a_{hvc} can be used in place of a_{hv} calculations for coupling-force-weighted partial vibration exposure values and coupling-force-weighted daily vibration exposures $A(8)_c$.

Annex C
(informative)

Examples of coupling forces

C.1 Definition of coupling forces

The coupling forces involved in the operation of holding a vibrating machine consist of two different components: the push/pull force and the gripping force.

According to ISO 15230, the coupling force F_{cp} is calculated as follows:

$$F_{cp} = F_{pu} + F_{gr} \quad \text{(C.1)}$$

where

F_{pu} is the push force is the in-plane force exerted by the operator onto the handle of the machine;

F_{gr} is the gripping force is the clamp-like force exerted by the hand of the operator when enclosing the handle.

C.2 Examples of machines measured in the laboratory and workplace

C.2.1 General

Experience in measuring coupling forces is still limited. These examples are given to provide some information on the importance of coupling forces under practical conditions.

Measurements were made with a pressure sensor matrix wrapped around the handle so that pressure integration results are comparable to direct force measurements. The whole matrix was composed of 156 sensor elements (area of each element: 1,05 cm × 1,05 cm).

NOTE 1 The coupling force in Tables C.1, C.2 and C.3 is not in all cases the summation of minimum or maximum of the grip and push forces. That means the minimum coupling force does not necessarily result from a combination of both the minimum grip and minimum push forces. Similarly, the maximum coupling force does not in all cases result from maximum grip and push forces. For this reason, the coupling force range is not simply an arithmetic sum of the minima or maxima of the push and grip force ranges.

NOTE 2 The ranges of values given in Tables C.1, C.2 and C.3 are not representative for all clusters of these types of machines.

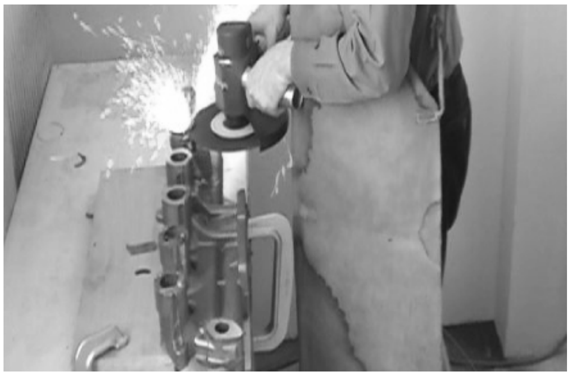
C.2.2 Vertical grinder (laboratory test)

Using a vertical grinder, the operator carried out two typical working operations: surfacing a horizontal bar and cutting a roughcast workpiece (a tractor casing), see Figure C.1. Measurements were performed over 8 s acquisition periods. The coupling forces depend on task and are summarised in Table C.1.

Table C.1 — Vertical grinder: Push, gripping and coupling forces with two models of grinding disks

Task	Disk no.	Push force N	Gripping force N	Coupling force N
Surface grinding	1	27 to 61	25 to 168	53 to 229
	2	32 to 39	41 to 106	80 to 138
Cutting	1	2 to 28	12 to 69	20 to 80
	2	15 to 32	50 to 72	75 to 95

a) Surface grinding



b) Cutting

Figure C.1 — Vertical grinder work operations

C.2.3 Pavement breaker with and without suspension handle (laboratory test)

Two pavement breakers were tested in a steel-ball energy absorber designed for the measurements of vibration emission at the handle of breakers (see EN ISO 28927-10). Measurements were performed over 8 s periods. One breaker was a low-vibration machine with suspended handles, the other an older machine with no suspension.

Push and grip force results are summarised in Table C.2. Both push and grip forces were significantly higher with the ordinary breaker than with the anti-vibration machine.

Table C.2 — Breakers: Push, gripping and coupling forces with two types of suspension

Breaker	Push force N	Gripping force N	Coupling force N
No suspension	102 to 147	69 to 82	180 to 218
With suspension	85 to 90	54 to 64	143 to 149

C.2.4 Machines measured in the work place

Measurements made in the workplace, under real operating conditions were made using the pressure sensor matrix. Table C.3 summarises the results from the four machines investigated.

Table C.3 — Various machines in the workplace: Push, gripping and coupling forces

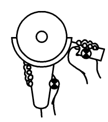
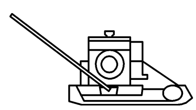
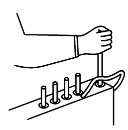
Machine (main handle)	**Push force** N	**Gripping force** N	**Coupling force** N
Pavement breaker	58 to 111	97 to 134	178 to 229
Pavement hammer	66 to 166	158 to 219	246 to 370
Rammer	13 to 58	77 to 128	90 to 180
Angle grinder (surfacing)	49 to 65	79 to 105	128 to 170

C.3 Likely coupling force ranges

Table C.4 shows the coupling force ranges expected for hand-held and hand-guided machines and for control levers.

NOTE The ranges of coupling forces given in Table C.4 do not apply for all clusters of grinders and compactors. These machines are only taken as examples to show the difference between hand-held and hand-guided machines.

Table C.4 — Likely coupling force ranges for hand-held machines, hand-guided machines and control levers

Machine type (Example)	**Coupling force range**	**Likely coupling force**	**Example**
Hand-held (Grinder)	Low	80 N to 100 N	
	Medium	> 100 N to 140 N	
	High	> 140 N to 200 N	
Hand-guided (Compactor)	Low	40 N to 60 N	
	Medium	> 60 N to 80 N	
	High	> 80 N to 100 N	
Control levers	Low	≤ 20 N	
	Medium	> 20 N to 40 N	
	High	> 40 N to 60 N	

Bibliography

[1] EN ISO 14738, *Safety of machinery — Anthropometric requirements for the design of workstations at machinery (ISO 14738)*

[2] EN ISO 28927 (all parts), *Hand-held portable power tools — Test methods for evaluation of vibration emission (ISO 28927, all parts)*

[3] ISO 5805, *Mechanical vibration and shock — Human exposure — Vocabulary*

[4] ISO 8727, *Mechanical vibration and shock — Human exposure — Biodynamic coordinate systems*

[5] DIN 45679, *Mechanical vibration — Measurement and evaluation of the grip and feed forces for assessing the exposure of the hand-arm system to vibration* (in German)

[6] Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration)

[7] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery

[8] Bovenzi M, Welsh AJL, Della Vedova A, Griffin MJ. Acute effects of force and vibration on finger blood flow. Occup Environ Med 63, 2005, pp. 84-91

[9] Cronjäger, L., et al.: Auswirkung der Ankopplungsintensität zwischen Hand und Handgriff vibrierender Arbeitsgeräte auf die Schwingungsbelastung und -beanspruchung des Hand-Arm-Systems. Endbericht zum Forschungsvorhaben BMFT/AuT 01 HK 595 8, 1990

[10] Dantigny, F.: Caractérisation de capteurs de pression pour la mesure des forces de poussée et de préhension exercées sur une poignée d'outil. INRS Document de Travail MAV – DT-374/FD, 1998

[11] Dantigny, F.: Mesures des forces de poussée et de préhension exercées sur une poignée d'outil. INRS Document de Travail MAV – DT-375/FD, 1998

[12] Dong, R. G., Welcome, D. W., Wu, J. Z.: Estimation of the biodynamic force acting at the interface between hand and vibrating surface. Ind. Health 43, pp. 516-526

[13] Dong, R. G., Wu, J. Z., McDowell, T. W., Welcome, D. E., Schopper, A. W.: Distribution of mechanical impedance at the fingers and the palm of human hand. Journal of Biomechanics 38 (5), pp. 1165-1175

[14] Dupuis, H., Scheffer, M.: Wirkung von Greif- und Andruckkraft unter Schwingungsbelastung – Teilprojekt II. Forschungsbericht Hand-Arm-Schwingungen III, Schriftenreihe des Hauptverbandes der gewerblichen Berufsgenossenschaften, Sankt Augustin, 1992

[15] Edgren CS, Redwin RG, Irwin CB. Gripping force vectors for varying handle diameters and hand sizes. HUM FACTORS 46 (2), 2004, pp. 244-251

[16] Engel Z., Kowalski P., Evaluation indices of exposure to vibration, Machine Dynamics Problems, pp. 21-33, vol. 24, No. 3, Warszawa 2000

[17] Engel Z., Kowalski P., Zawieska W., Proposal for an Indexical Method of Evaluating Risk of Hand Tool Operators' Exposure to Mechanical Vibrations, International Journal of Occupational Safety and Ergonomics (JOSE), vol. 8, No. 2, Central Institute for Labour Protection, Warszawa 2002, pp.183-194

[18] Gillmeister, F., Schenk, T.: Simultaneous measurement of the hand-arm vibration and coupling force at the workplace with a measurement adapter. VDI-Berichte 1821, Düsseldorf, 2004, pp. 215-230

[19] Griffin MJ, Welsh AJL, Bovenzi M. Acute response of finger circulation to force and vibration applied to the palm of the hand. Scand J Work Environ Health 32, 2006, pp. 383-391

[20] Harazin, B., Szlapa, P.: Measurement of coupling forces applied to vibration tools in industry. Proceedings of the 34th Meeting of the UK Group of Human Response to Vibration, Dunton, Essex, England, 1999, pp. 111-117

[21] Hartung E, Dupuis H, Scheffer M. Effects of grip and push forces on the acute response of the hand-arm system under vibrating conditions. Int Arch Occup Environ Health 64, 1993, pp. 463-467

[22] Kaulbars, U.: Measurement and evaluation of coupling forces when using hand-held power tools. Central European Journal of Public Health, No. 1, vol. 4 (JHEMI vol. 40), 1996, pp. 57-58

[23] Kaulbars, U.; Lemerle, P. Messung der Ankopplungskräfte zur Beurteilung der Hand-Arm-Schwingungen – Weiterentwicklung eines Messsystems, 3. Nationale Tagung Humanschwingungen, 2007, Dresden. VDI-Berichte Nr. 2002, pp. 99-111

[24] Kaulbars, U.; Concettoni, E. Industrial trials of a system for measurement of coupling forces. Proceedings of the 11th International Conference on Hand-Arm Vibration, 2007, Bologna, pp. 481-488

[25] Kaulbars, U.; Raffler, N. Study of vibration transmission on a paver's hand hammer. Proceedings of the 12th International Conference on Hand-Arm Vibration, 2011, Ottawa. In: Canadian Acoustics 39 No. 2, pp. 52-53

[26] Kowalski P.,The influence of feed force on vibration transmissibility in the hand-tool system, International Conference NOISE CONTROL '98, 1998, Krynica

[27] Lemerle P, Klingler A, Trompette N, Cristalli A, Geuder M. Development and validation of an accurate testing procedure to measure coupling forces and characterize the man/machine interaction. Proceedings of the 11th International Conference on Hand-Arm Vibration, 2007, Bologna, pp. 497-506

[28] Lemerle P, Klinger A, Cristalli A, Geuder M. Application of pressure mapping techniques to measure push and gripping forces with precision. Ergonomics vol 51, n° 2, 2008, pp 168-191

[29] Marcotte, P., Aldien, Y., Boileau, P.-É., Rakheja, S., Boutin, J.: Effect of handle size and hand-handle contact force on the biodynamic response of the hand-arm system under z_h-axis vibration. Journal of Sound and Vibration, 283(3), 2005, pp. 1071-1092

[30] Marcotte, P.; Adewusi, S.; Rakheja, S., Development of a Low-Cost System to Evaluate Coupling Forces on Real Power Tool Handles, Proceedings of the 12th International Conference on Hand-Arm Vibration, 2011, Ottawa. In: Canadian Acoustics 39 No. 2, pp. 36-37

[31] Miyakita T, Miura H, Futatsuka M. Hand-arm vibration, noise, temperature and static load – An experimental study of peripheral circulation while operating chain-saws. Kurume Medical Journal 37 (suppl), 1990, pp. 73-78

[32] Riedel, S.: Consideration of grip and push forces for the assessment of vibration exposure. Central European Journal of Public Health, vol. 3 (JHEMI vol. 39), 1995, pp. 139-141

[33] Sandover J, Louw J. Acute effects of grip force and vibration on finger temperature. Proceedings of the 6th International Conference on Hand-Arm Vibration, 1992, Bonn. Published: HVBG, Sankt Augustin

[34] Scalise L, Paone N, Concettoni E, Cristalli A, Geuder M. Design and development of a pressure sensor matrix for the indirect measurement of feed and grip forces on real tools. Proceedings of the 11th International Conference on Hand-Arm Vibration, 2007, Bologna, pp. 489-496

[35] Scalise L, Concettoni E, Deboli R, Calvo A, Rapisarda V. Simultaneous measurement of acceleration, grip and push orce on chain saw for forestry:correlation with hemodynamic parameters. Proceedings of the 11th International Conference on Hand-Arm Vibration, 2007, Bologna, pp. 465-472

[36] Tomasini EP. A grip force mapping for characterisation of hand-held vibrating tools: an overview of the European project VIBTOOL. Proceedings of the 11th International Conference on Hand-Arm Vibration, 2007, Bologna, pp. 473-480

[37] VIBTOOL, Grip force mapping for characterisation of hand-held vibrating tools. Final technical report, 2005: www.dguv.de/ifa/en/fac/vibration/vibtool/Publishable_Final_Technical_Report.pdf

[38] Wasserman, J., Logston, D., Wasserman, D.: The use of a resistive pressure sensor to assess glove effects on tool transmitted vibration. Proceedings of the 10th International Conference on Hand-Arm Vibration, 2004, Las Vegas, USA

[39] Welcome, D. E., Rakheja, S., Dong, R. G., Wu, J. Z., Schopper, A. W. Relationship between the grip, push and contact forces between the hand and a tool handle. International Journal of Industrial Ergonomics 34(6), 2004, pp. 507-518

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK