BRITISH STANDARD

BS ISO 15230:2007

Mechanical vibration and shock — Coupling forces at the man-machine interface for hand-transmitted vibration

ICS 17.160

British Standards

National foreword

This British Standard is the UK implementation of ISO 15230:2007.

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

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

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Mechanical vibration and shock — Coupling forces at the man-machine interface for hand-transmitted vibration

Vibrations et chocs mécaniques — Forces de couplage à l'interface homme-machine en cas de vibrations transmises par les mains

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Contents

Page

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 15230 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

Introduction

The coupling forces between the hand-arm system and a hand-held or hand-guided machine during its use are very important factors. Although these forces are of interest for both vibrating and non-vibrating machines, the primary focus of this International Standard is to provide a set of descriptions of the forces at the man-machine interface that are primarily for the hand-arm system in contact with a vibrating surface of a machine.

The coupling forces involved in the operation of a vibrating machine generally consist of two different components. The first component is the force applied by the hand-arm system, which is used to provide necessary control and guidance of the machine and to achieve desired productivity. This quasi-static force (frequency below 5 Hz) is the focus of this International Standard. The second component is the biodynamic force which results from the biodynamic response of the hand-arm system to a vibration.

Different couplings of the hand to a vibrating surface can affect the human body in two different ways.

- The relationship between the measured handle vibration and the resultant transmission of vibration to the hand-arm system might be altered. This alteration modifies the exposure and the vibration effect to the hand-arm system.

- The coupling can result in a synergistic effect with vibration exposure which affects anatomical structures, such as the vascular system, nerves, joints, tendons.

Currently, many machine situations have been modelled by numerous basic physiological studies investigating the effect of vibration on the human body, which use push force and gripping force to describe the coupling force between the hand and the machine handle.

This International Standard can assist in the reporting of coupling data in epidemiological or laboratory research.

In the future, the measurements taken at the workplace for the determination and evaluation of mechanical vibration affecting human beings could need to take into account the influence of the contact of the hand-arm system in the vibrating surface. The measurements of relevant coupling forces and the vibration acceleration will need to be taken simultaneously to account for the potential interactions.

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Mechanical vibration and shock — Coupling forces at the man-machine interface for hand-transmitted vibration

1 Scope

This International Standard describes the coupling parameters between the hands of a machine operator and a vibrating surface of the machine.

The coupling between the hand and the vibrating surface can be described using different parameters and component parts of these parameters:

— force parameters, such as push, pull and grip;

— parameters such as pressure exerted on skin.

In addition, informative annexes provide guidelines for measuring procedures, the measurement of the force and pressure parameters, and information on the requirements for measuring instrumentation, as well as a calibration method.

This International Standard does not deal with forces which act tangentially to the hand.

2 Symbols and abbreviated terms

2.1 Symbols

F force

i integer for summation

n total number of elements to be summed

p_i local pressure at surface element i

S surface

t time

T duration of operation

α hand-oriented angle of the dividing plane

β machine-oriented angle of the dividing plane

δ coefficient of the proportionality for the gripping force

γ coefficient of the proportionality for the push force

2.2 Subscripts

BD	biodynamic force
c	contact
coup	coupling
f	feed
g	guiding
gr	gripping
l	lifting
m	mean value
max	maximum
n	normal
pu	push or pull
x, y, z	Cartesian coordinates

3 Parameters at man-machine interface

3.1 Pressure exerted on skin

3.1.1 Area element of surface

The area element of the surface, S_i, is given using Equation (1):

$$\vec{S}_i = S_i \cdot \vec{S}_{\mathrm{n},i} \tag{1}$$

with the unit vector, $\vec{S}_{\mathrm{n},i}$, in the normal direction to the area element. (See Figure 1.)

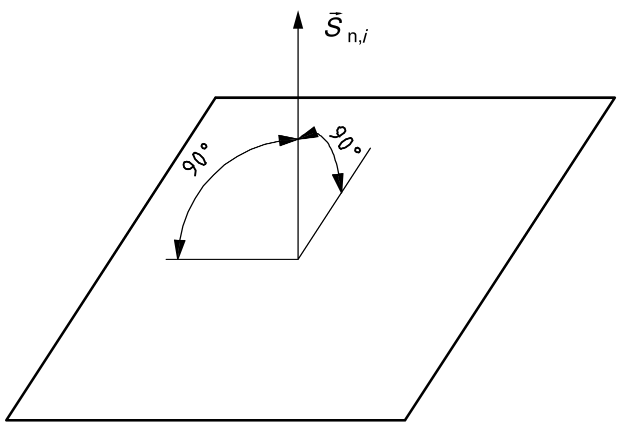


Figure 1 — Direction of the area elements, S_i

3.1.2 Local pressure

The local pressure, p_i, exerted on an area element of the surface, S_i, of the hand skin is given as the ratio between the perpendicular component of the area element contact force, $F_{c,i}$ (see 3.1.5), applied in the middle of this area element and the area of this surface, as given by Equation (2):

$$p_i = \frac{F_{c,i}}{S_i} \quad (2)$$

When reporting local pressure values, the area element surface area should be reported.

NOTE Depending on the operator, hand location, tool and task, local pressure p_i usually ranges between zero and 0,8 N/mm^2. Values above this pressure range can be perceived as painful.

3.1.3 Mean pressure

The mean pressure, p_m, exerted on the surface of the hand in contact with the machine or a part of the machine is calculated as average pressure using Equation (3):

$$p_m = \frac{\sum_{i=1}^{n} p_i \cdot S_i}{\sum_{i=1}^{n} S_i} \quad (3)$$

3.1.4 Maximum local pressure

The maximum local pressure, p_{max}, is the highest pressure value measured on the hand surface in contact with the machine, calculated using Equation (4):

$$p_{max} = \max\{p_i\} \quad (4)$$

3.1.5 Elemental contact force

The elemental contact force, $F_{c,i}$, is given by Equation (5):

$$F_{c,i} = p_i \cdot S_i \quad (5)$$

where

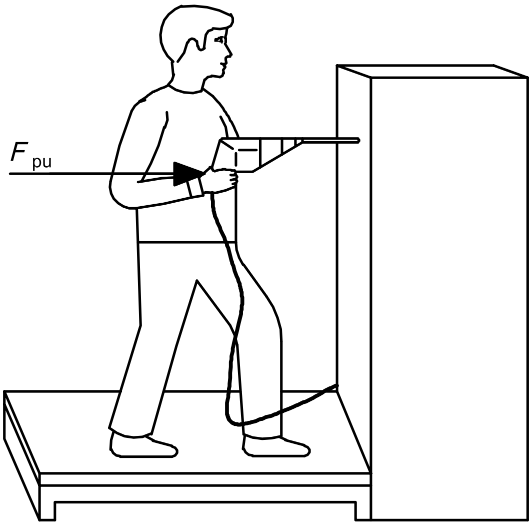
p_i is the pressure over the ith surface element;

S_i is the elemental surface area of the hand skin.

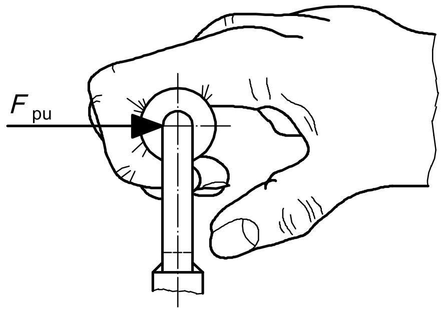
The direction of $F_{c,i}$ is normal to the vibrating surface.

3.2 Push/pull force

The push force, F_{pu}, is the force exerted by the operator away from his shoulder on the vibrating surface via each hand and not compensated within the coupling surface of the hand. The pull force, F_{pu}, is the force exerted by the operator towards his shoulder via each hand. (See Figure 2.)



a) Push force



b) Pull force

Figure 2 — Example of push force, F_{pu}, and pull force, F_{pu}

NOTE 1 In some cases, the operation involves both push and pull forces. The push and pull forces can act at different positions on the hand. However, both forces are denoted by F_{pu}.

NOTE 2 Push force F_{pu} can be a very significant force, such as the required pushing of a drill, and needs always to be considered.

3.3 Guiding force

The guiding force, F_g, is the force exerted by the operator on the vibrating surface via either hand in a horizontal or nearly horizontal plane tangentially to the push and/or pull force and not compensated within the coupling surface of the hand. This force is mostly necessary to hold or to move the machine, workpiece or control lever. (See Figure 3.)

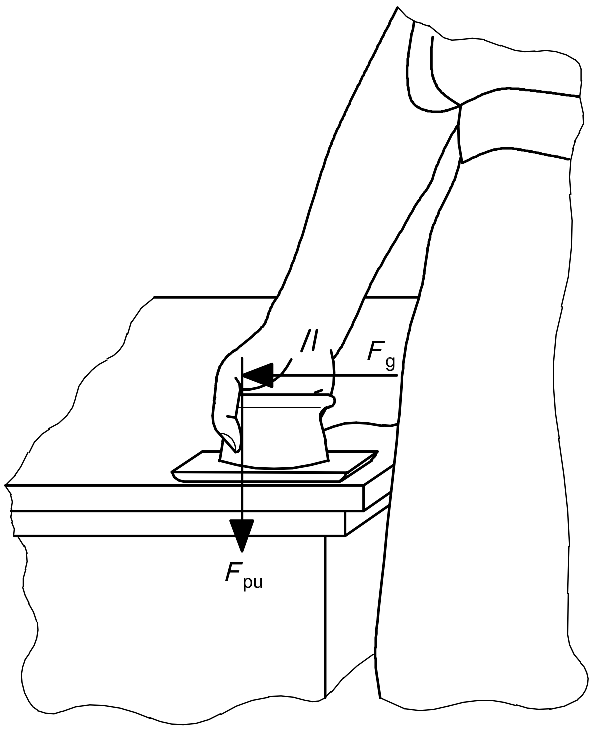


Figure 3 — Example of guiding force, F_g, with indication of push force, F_{pu}

NOTE F_g has the potential to be a low magnitude force when the surface is horizontal.

3.4 Lifting force

The lifting force, F_l, is the force which is necessary to counteract the machine weight. (See Figure 4.)

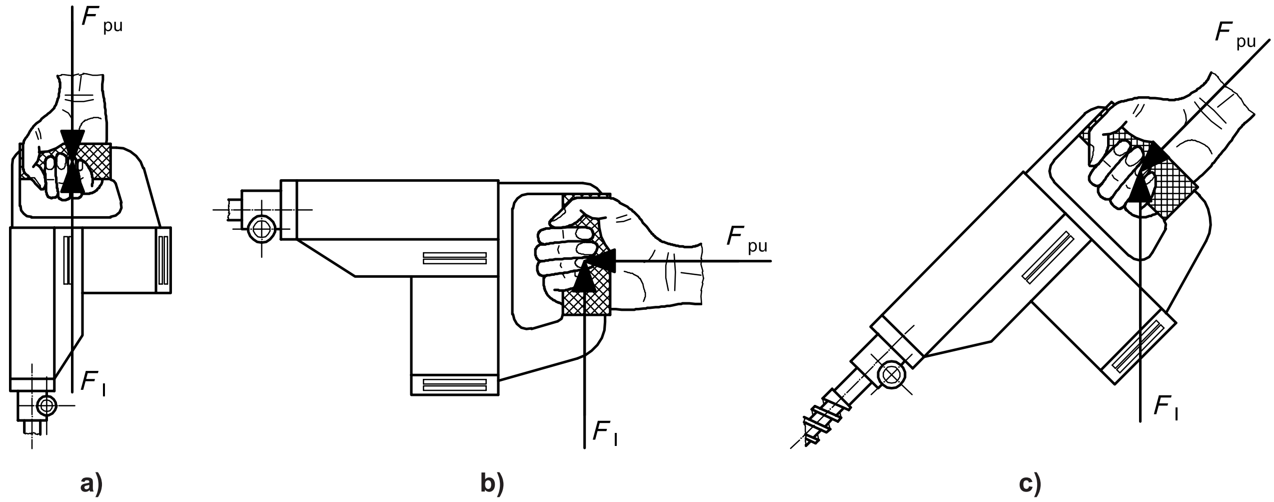
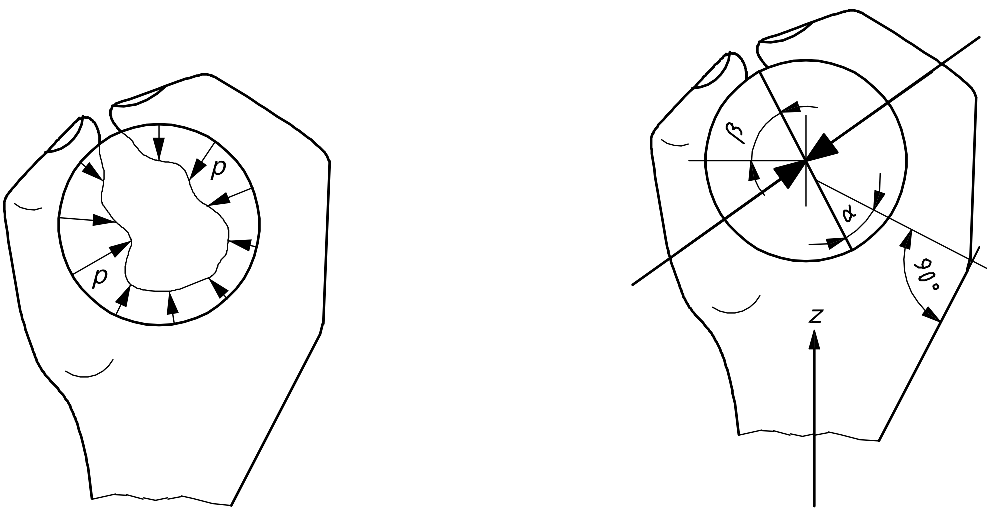


Figure 4 — Example of lifting force, F_l, with indication of push force, F_{pu}

NOTE In some cases, it is possible for lifting force, F_l, to equal push/pull force, F_{pu} [see Figure 4 a)].

3.5 Gripping force

The gripping force, F_{gr}, is half the sum of the force components acting towards an axis inside the handle without push, pull or lifting forces. Simplified, the gripping force is the clamp-like force exerted by the hand of the operator when enclosing the handle. The force is compensated within the hand by a gripping force acting in the opposite direction towards a dividing plane. (See Figure 5.)



a) Pressure field, p b) Clamp-like force

Key

α hand-oriented angle of the dividing plane

β machine-oriented angle of the dividing plane

NOTE The z axis is along the forearm.

Figure 5 — Example of gripping force, F_{gr}, as clamp-like force

NOTE 1 When the operator is gripping a cylindrical handle, the direction of the main gripping force is generally parallel to the z axis as defined in ISO 8727.

NOTE 2 Because the grip contact pressure is usually unevenly distributed around the handle, the magnitude of the gripping force is generally a function of the reference axis or dividing plane. The orientation of the maximum or minimum gripping force generally depends on handle dimensions, hand sizes and hand-grip posture. For simplicity's sake, the gripping force in the forearm-based z axis shown in Figure 5 b) is conventionally used in the measurement and/or control of the gripping force in laboratory studies.

3.6 Feed force

The feed force, F_f, is the external force acting on the machine. (See Figure 6.)

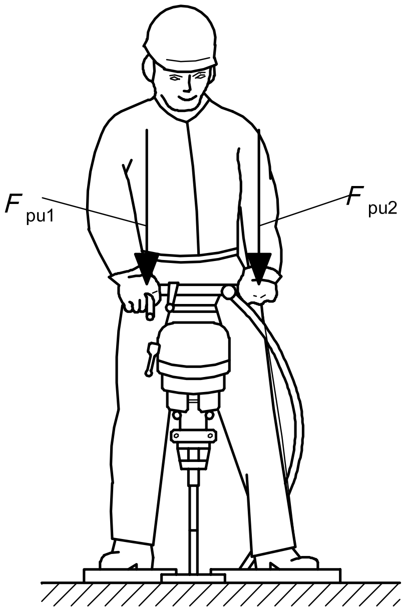


Figure 6 — Example of feed force, F_f

NOTE In Figure 6, the feed force, F_f, is equal to the sum of the push force, F_{pu1}, F_{pu2}. Whereas, in Figure 2 a), the feed force, F_f, is equal to the push force, F_{pu}.

3.7 Contact forces

In general, the contact forces, F_c, are those forces which act between the hand and the vibrating surface. They are the elemental forces integrated over the contact area (see 3.1.5). These are vector forces which act both perpendicularly and tangentially to the vibrating surface. The tangential force is not considered at this time because of the difficulty of measurement. The contact force can represent the average values of pressures but might not provide information on distributions resulting in moments that can balance external moments, which can be described as torques around specific axes (see 3.9). The moments or torques can be calculated when the pressure distribution is available.

This International Standard concentrates on the perpendicular component of these contact forces, F_c, which, for many vibrating surfaces, are those which primarily effect the transmission of vibration into the hand (see Figure 7).

The contact forces can be determined through integration of the measured pressure distribution between the hand and the handle. Studies have shown that the total static contact forces can be related to the gripping and push forces, F_{gr} and F_{pu}, through a linear relationship, Equation (6):

$$F_c = \delta F_{gr} + \gamma F_{pu} \tag{6}$$

where δ and γ are proportionality coefficients and the gripping force F_{gr} is that in the forearm-based z axis shown in Figure 5 b).

NOTE 1 For cylindrical handles with a diameter ranging between 30 mm and 50 mm, the coefficient δ has been reported to be close to 3 and γ close to 1. The gripping force coefficient tends to be larger for smaller diameter handles.

NOTE 2 The above relationship can differ for handles with different geometry and size and when overlap of the fingers on the thumb occurs.

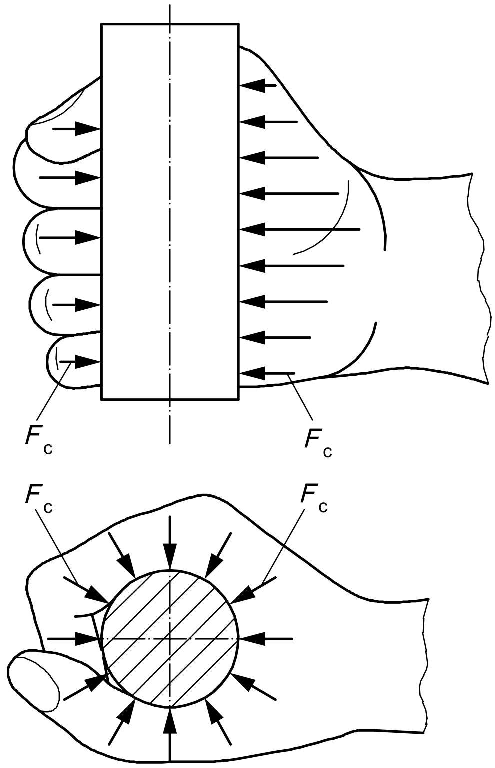


Figure 7 — Example of contact forces, F_c

3.8 Coupling force

The compressive coupling force, F_{coup}, is the sum of the gripping force and the push/pull force as given by Equation (7):

$$F_{coup} = F_{gr} + F_{pu} \quad (7)$$

NOTE 1 The coupling force of the hand-arm system to the machine or control lever is given in a simplified manner in this International Standard, in terms of two forces, the push/pull force and the gripping force, but would theoretically include also the biodynamic forces as described in Annex A.

NOTE 2 A few studies have found that the acute effects of the gripping and push/pull forces under exposure to vibration are not distinguishable. Hence, the two components are incorporated with equal weighting into the coupling force.

NOTE 3 The contact force is much more complex than the coupling force.

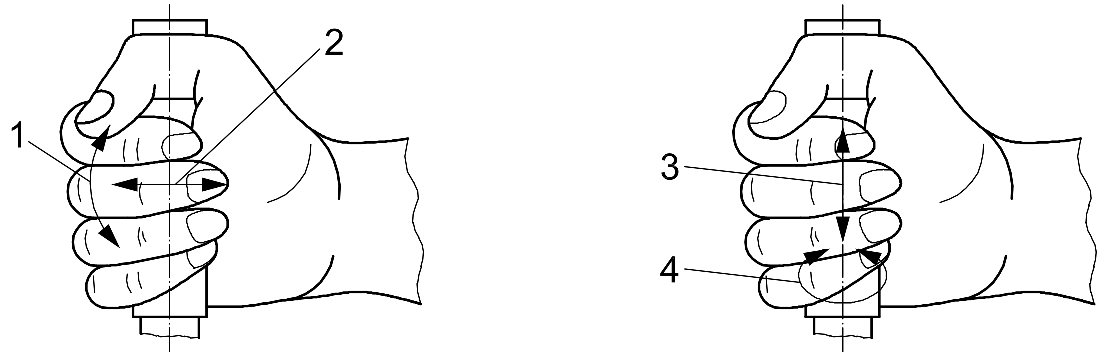
3.9 Torque and friction force

This International Standard does not deal with forces which act tangentially to the hand, such as surface forces that produce a moment due to torque from a friction force. However, two examples are given for explanation of these forces.

A moment or a torque such as that shown in Figure 8 a) and b) is not possible without a gripping force, a push/pull force or a lifting force.

A friction force such as that shown in Figure 8 b) is not possible without a gripping force, a push/pull force or a lifting force.

NOTE The current measurement systems for the distributed pressure are not able to provide this information.



a) b)

Key

1 moment

2 push or pull force

3 friction

4 torque

Figure 8 — Examples of torque and friction against the hand

Annex A
(informative)

Biodynamic effects on machine contact forces

A.1 Biodynamic forces

The biodynamic force, F_{BD}, acting at the interface between the human hand-arm system and a vibrating machine or workpiece, results from the dynamic response of the system to vibration. Hence, its magnitude depends primarily on the apparent mass of the system and the magnitude of the machine or workpiece vibration.

A.2 Measurement and estimation methods

Technically speaking, biodynamic force F_{BD} acting on the hand can be resolved in three orthogonal directions (x_h, y_h, and z_h). It can be directly measured using instrumented handles or gloves, or flexible transducers mounted on machine handles or the hand contact surface. It can also be measured together with the applied forces and then separated using a high-pass filter ($>$ 5 Hz). In an alternative approach, the magnitude of the biodynamic force in each direction can be estimated using the apparent mass or mechanical impedance of the system and the machine acceleration in the corresponding direction. As the first degree of approximation, the biodynamic force can be estimated using either Equation (A.1) or (A.2), as appropriate:

$$F_{BD}(\omega_i)_J \approx \left|M(\omega_i)\right|_J \cdot a(\omega_i)_J \tag{A.1}$$

$$F_{BD}(\omega_i)_J \approx \left|Z(\omega_i)\right|_J \cdot a(\omega_i)_J \big/ \omega_i \tag{A.2}$$

where

a is the root-mean-square (r.m.s.) value of the machine acceleration;

J is the hand coordinate;

M is the apparent mass;

Z is the point mechanical impedance;

ω_i is the angular frequency of the ith spectral component.

The r.m.s. value of the biodynamic force in each direction can thus be estimated using its corresponding component at each frequency using Equation (A.3):

$$F_{BD,J} = \sqrt{\sum_i F_{BD}^2(\omega_i)_J} \tag{A.3}$$

A.3 Fundamental characteristics of biodynamic force

Because the apparent mass generally decreases with the increase in frequency, the biodynamic force is generally much higher when working with a machine that generates dominant low-frequency vibration ($\leqslant$ 40 Hz) than those that produce high frequencies ($\geqslant$ 100 Hz). The low-frequency biodynamic force may be comparable with the applied forces on some machines. Because the apparent mass in the z_h direction (along the forearm direction) is generally the highest among those in the three orthogonal axes, the biodynamic force in this direction is also generally the highest one. The biodynamic force usually reaches its maximum value at the dominant frequency of the machine vibration. The fundamental resonance frequency of the hand-arm system is usually in the range of 10 Hz to 63 Hz. If the dominant frequency of a machine is in this range, the biodynamic force could become especially significant. At frequencies less than 100 Hz, the biodynamic force in a grip action or a combined grip and push action is primarily distributed on the palm of the hand. This is especially true for the biodynamic force in the z_h direction. At higher frequencies, however, the biodynamic force components distributed at these two parts of the hand are comparable.

Annex B
(informative)

Calculation of gripping force and push/pull force from measurement of pressure

B.1 General

The push/pull, gripping and coupling forces can be calculated from the mapping of local pressure and the geometry of the grip zone. It is essential to know, for each transducer, the relative angle between its surface and the main gripping force axis. The state of the art allows mapping pressure without interpolation.

When the number of transducers is insufficient to cover the whole surface of the hand in contact with the grip zone, it is necessary to make an interpolation between transducers.

B.2 Push/pull force

The push or pull force, F_{pu}, is calculated using Equation (B.1) (see Figure B.1):

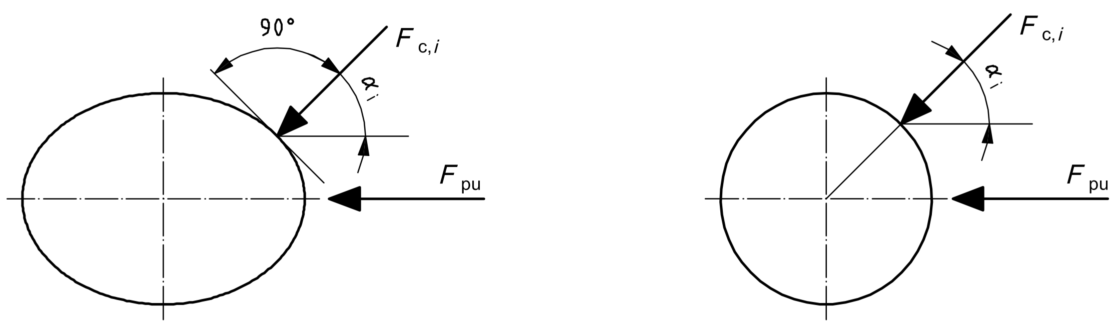
$$F_{\mathrm{pu}} = \sum_i F_{\mathrm{pu},i} = \sum_i F_{\mathrm{c},i} \cos\alpha_i = \sum_i p_i \cdot S_i \cos\alpha_i \tag{B.1}$$

When the feed force is not in the direction of the push or pull force, it can be useful to calculate also the resultant forces in this direction. In this case, the following definition of real push force, $\vec{F}_{\mathrm{RP}}$ should be used:

$$\vec{F}_{\mathrm{RP}} = \sum_i p_i \cdot S_i \left(\hat{i} \cos \alpha_i + \hat{j} \sin \alpha_\mathrm{i} \right)$$

where $\hat{i}$ and $\hat{j}$ are the coordinate axis definitions for the vector.

NOTE $\vec{F}_{\mathrm{RP}}$ is a vector quantity which can be measured in the plane orthogonal to the handle axis and would provide information on the posture of the operator during the test. Its direction can be time-dependent.



a) Elliptic handle b) Circular handle

Figure B.1 — Angle between local normal force and push/pull force axes

B.3 Gripping force

See Figure B.2.

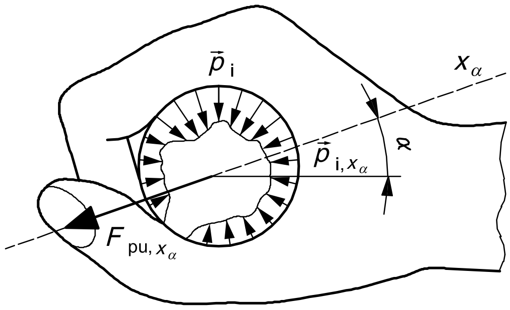


Figure B.2 — Grip orientation with information for calculation

The gripping force, F_{gr}, is calculated as follows. At first, a grip action $F_{gr\alpha}$, projected along all possible directions, x_α, around the handle is calculated using Equation (B.2):

$$F_{gr\alpha} = \frac{1}{2}\left(\sum_i \left|\vec{p}_{i,x_\alpha}\right| - F_{pu,x_\alpha}\right) \tag{B.2}$$

where

x_α is the projected direction;

$\vec{p}_{i,x_\alpha}$ is the force applied on the ith transducer, projected along x_α;

F_{pu,x_α} is the push force projected along x_α.

Based on this quantity, then:

a) The push-oriented gripping force, $F_{gr,pu}$, is defined as gripping force $F_{gr\alpha}$, calculated along the direction of the push vector $\vec{F}_{RP}$, which can vary during the test, depending on operator posture (see B.2). Its definition is given by Equation (B.3):

$$F_{gr,pu} = \frac{1}{2}\left(\sum_i \left|\vec{p}_{i,x_{\alpha,pu}}\right| - F_{pu,x_{\alpha,pu}}\right) \tag{B.3}$$

where $x_{\alpha,pu}$ is fixed as the direction of push vector $\vec{F}_{RP}$.

b) the maximum gripping force is defined by Equation (B.4):

$$F_{gr} = \max_{0 \leqslant \alpha \leqslant 2\pi}\left(F_{gr,\alpha}\right) \tag{B.4}$$

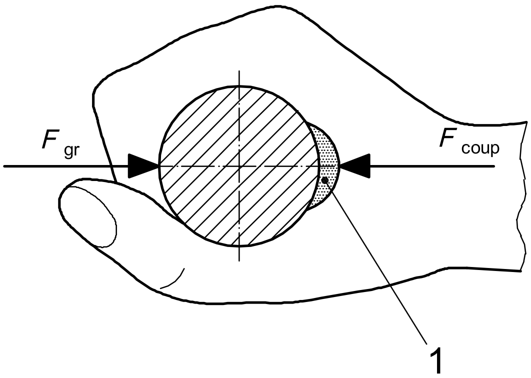
NOTE F_{pu,x_α} and $F_{pu,x_{\alpha,pu}}$ are positive quantities.

B.4 Coupling force

The coupling force, F_{coup}, is calculated as follows (see Figure B.3):

$$F_{\text{coup}} = F_{\text{pu}} + F_{\text{gr}} = \tfrac{1}{2}\left(F_{\text{c,pu}} + F_{\text{pu}}\right) = \frac{1}{2}\sum_i p_i \cdot S_i \cdot \left(\left|\cos\alpha_i\right| + \cos\alpha_i\right) \tag{B.5}$$

A possible scheme for measurement of the coupling force is shown in Figure B.3.



Key

1 transducer

Figure B.3 — Example for measurement of coupling force, F_{coup}

Annex C
(informative)

Measuring procedure and processing of measurement results

C.1 General

In practice, the contact force cannot be fully measured. Owing to measuring limitations, it is necessary to determine the most important components, such as push/pull force, gripping force and pressure.

The measuring instrumentation should fulfil the requirement of minimal ergonomic impairment and should not modify the dynamic response of the machine.

When assessing the vibration exposure, it is preferable to measure the vibration and the coupling parameters simultaneously. Due to the complexity of the measurement of these parameters, it is acceptable to make the two measurements at different times under the same conditions.

The measurement system should be calibrated (see Annex E).

The chain of measurement should be checked before and after the measurements are carried out.

Body posture, working conditions and operating conditions should, as far as possible, be recorded during the measurement.

C.2 Procedure for measuring push/pull force

For many machines, the main direction of the push or pull force is along the finger–forearm axis as shown in Figures 2 and 4.

There are two basic measurement techniques:

— the direct method, which uses transducers mounted between the hand and the vibrating surface (see, for example, Figure B.3);

— the indirect method, which measures the resultant forces on the operator or the machine [e.g. using a force platform, see Figure 2 a)].

The indirect method can only be used in cases where the operator is stationary and is either using one hand only or is applying equal forces with two hands.

C.3 Procedure for measuring gripping force

There are two basic measurement techniques:

— the direct method, which uses transducers mounted between the fingers and the vibrating surface;

— the indirect method, which measures, firstly, the coupling force between the palm of the hand and the vibrating surface and, secondly, the push or pull force, with the gripping force calculated as the resultant of these two forces.

C.4 Procedure for measuring pressure exerted on skin

The pressure transducers can be either fixed directly on the gripping zone, using double-sided adhesive tape or equivalent, or fixed on a surgical glove. In the latter case, it is essential to fix the transducers where peaks of pressure are expected.

C.5 Processing the measurement results — Time history

Reporting of the force or pressure time history in the frequency range up to 5 Hz is recommended. These forces or pressures are those imposed by the operator.

When dynamic forces and/or pressures are considered, the amplitude description of the force or pressure measurement should be presented in the frequency range up to at least three times the dominant frequency of the vibration.

C.6 Processing the measurement results — Averaging method

Where it is useful to report a time varying force or pressure as a single value, the mean value of the absolute force or pressure measured during the operation should be used. The operation is any period during which a machine is operating and the operator is exposed to hand-transmitted vibration. The duration of measurement should be as long as reasonably possible and normally not less than 8 s. The calculation of these means is carried out using Equations (C.1) and (C.2):

$$\overline{F} = \frac{1}{T}\int_0^T \left|F(t)\right| \, \mathrm{d}t \tag{C.1}$$

$$\overline{p} = \frac{1}{T}\int_0^T p(t) \, \mathrm{d}t \tag{C.2}$$

where T is the duration of operation.

NOTE In the case of gripping force, F(t) is always positive.

C.7 Information to be reported

The report should contain the following information (where possible).

a) General information:

- company and customer;
- purpose of the measurements;
- date of evaluation;
- subject of the individual expose evaluation;
- person carrying out the measurement and evaluation.

b) Environmental conditions in the work place:

- location of the measurement;
- temperature (e.g. environment, vibrating surface, measurement surface);
- humidity.

c) Description of the task:

- detailed, step-by-step description of the work process;
- direction of the measurement;
- movement directions of the handle, the vibration surface and the hand;
- gripping conditions;
- posture of the operator (e.g. photograph, video).

d) Anthropometry:

- dominant hand of the subject;
- dimensions of the hand (length, width, middle-finger length).

e) Vibration source:

- machine and inserted tool used;
- technical description of the machine;
- type and model number;
- age and maintenance condition of the machine;
- weight of the hand-held machine or hand-held workpiece or control lever;
- type of hand grip used;
- power of the machine;
- main frequencies of the power tool;
- models and types of inserted tools;
- materials or workpieces used.

f) Instrumentation:

- instrumentation detail;
- calibration traceability;
- date of the most recent verification test;
- results of functionality tests.

g) Force and/or pressure measurement conditions:

- description of the method of measurement;
- direction of the measurement;
- methods of attaching the transducers;
- operating conditions.

h) Measurement results:

- measured force and/or pressure;
- measurement durations;
- time history of the measured force or pressure;
- measurement uncertainty.

Annex D
(informative)

Recommended parameters for measuring instrumentation

D.1 Force-measuring instrumentation

The following are recommended in respect of measuring instrumentation used to detect push/pull force, F_{pu}:

- direction of measurement appropriate to force required;
- minimum range of measurement of up to 200 N, with adjustable calibration;
- minimum resolution of 2 % of the maximum value of the measurement range;
- working frequency range of up to 5 Hz;
- transducer thickness of less than 10 mm,
- minimal impairment of the ergonomic handling of the appliance;
- other measurement uncertainties equal to less than 10 % the maximum value of the measurement range,
- indicator of the mean value of the absolute force or pressure.

The following are recommended in respect of measuring instrumentation used to detect gripping force, F_{gr}:

- minimum range of measurement: up to 100 N,
- minimum resolution: 2 % of the maximum value of the measurement range,
- working frequency range: up to 5 Hz,
- thickness of transducers: less than 10 mm,
- minimal impairment of the ergonomic handling of the appliance,
- other measurement uncertainties: less than 10 % of the maximum value of the measurement range,
- indicator of the mean value of the absolute force or pressure.

NOTE In some cases the temperature influence of the transducers needs to be taken into consideration.

D.2 Local pressure-measuring instrumentation

The following are recommended in respect of the measuring system used to evaluate local pressure, p_i:

- minimal ergonomic impairment;
- surface of transducers not greater than 11 mm × 11 mm,
- thickness of transducers: less than 2 mm,
- range of measurement of up to 0,3 N/mm^2;
- minimum resolution of 2 % of the maximum measurement value;
- uncertainty (bias plus random) lower than 10 % of the measured values;

— hysteresis lower than 15 % of full scale when loaded and unloaded (over a complete cycle from zero to full scale and back);

— drift lower than 10 % for a constant load applied over a period of 5 min;

— minimum working frequency range of up to 5 Hz;

— sensitivity to tangential loads — deviation of less than 10 % when a tangential effort (30 % of normal force) is applied;

— sensitivity to partial loading of a sensor cell — deviation of less than 30 % when the force is applied on 25 % of the transducer surface.

D.3 Comparison of different measuring instruments

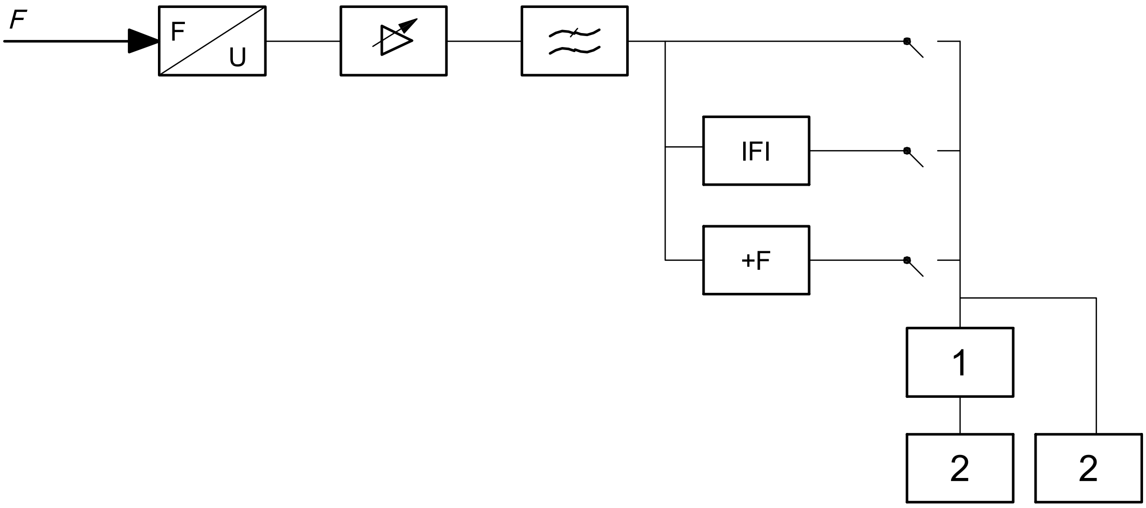
See Table D.1.

Table D.1 — Recommended parameters for measuring instrumentation

	Force-measuring instrumentation (see D.1)		**Pressure-measuring instrumentation** (see D.2)		
	Push/pull force	**Gripping force**	**Push/pull force**	**Gripping force**	**Pressure**
Min. range of measurement	Up to 200 N	Up to 100 N	Up to 200 N	Up to 100 N	Up to 0,3 N/mm^2
Min. resolution of maximum value of measurement range, %	2	2	2	2	2
Working frequency range, Hz	$\leqslant 5$	$\leqslant 5$	$\leqslant 5$	$\leqslant 5$	$\leqslant 5$
Measurement uncertainty, % of reading	± 10	± 10	± 20	± 20	± 10
Maximum thickness of transducer, mm	10	10	2	2	2
Minimum spatial resolution, mm	—	—	—	—	11 × 11
Maximum hysteresis, %	—	—	—	—	15

D.4 Examples of measuring instrumentation

A block diagram of a chain of measurement using a force or pressure transducer is shown in Figure D.1.



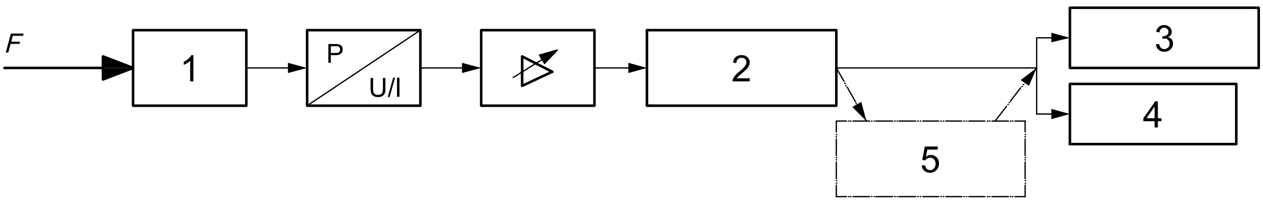
Key

1 average recorder
2 display

Figure D.1 — Example of measurement chain for registering push or gripping force using force transducer or pressure transducer (block diagram)

NOTE 1 The measurement of force can be done using a force transducer (e.g. based on a strain gauge deformation) or a pressure transducer (e.g. capacitive or resistive system).

A block diagram of a chain of measurement using a hydraulic system is shown in Figure D.2.



Key

1 ALP (active liquid pad)
2 average detector, r.m.s. detector
3 display
4 recorder
5 microprocessor

Figure D.2 — Example of measurement chain for registering push or gripping force using electro-hydraulic force meter

NOTE 2 The measurement chain for determination of coupling force is as follows. The coupling force, applied by the operator through his hands on the surface of the vibrating tool, is transformed into pressure changes of incompressible medium (i.e. oil) contained in an active liquid pad. Then pressure changes of liquid are transferred on the membrane of a pressure transducer. An instantaneous voltage or current signal from this transducer is proportional to pressure changes generated in the active liquid pad. DC voltage or a current signal is amplified, measured and displayed. The measurement results can be stored. The active liquid pad and the pressure transducer constitute a two-stage force transducer.

D.5 Application of transducer calibration

Studies have shown that some pressure transducers change their sensitivity during applications. This finding indicates that it is beneficial if both a pre-application and a post-application calibration are performed.

Annex E
(informative)

Calibration and reference method

E.1 Calibration of force transducers

Previous force measurement instrumentation found that calibration with a load of 100 N as a static reference force was effective. Since many different types of transducers are available for use, it is appropriate to also use a load that is 80 % to 90 % of the transducer maximum to establish appropriate transducer linearity. For gripping force, it was effective to calibrate with a load of 50 N in addition. The measurement point is the centre of the transducer.

NOTE In some cases, it is necessary to take into account the temperature deviation between the calibration and the measurement.

E.2 Calibration of pressure transducers

Pressure transducers may be calibrated using a press consisting of a rubber membrane and a flat solid surface, between which the transducers are laid. Compressed air is fed so as to exert a homogeneous pressure distribution on transducers via the rubber membrane. The press should be able to calibrate transducers up to 1 N/mm^2. The air pressure is measured by a manometer with a precision of 0,01 N/mm^2. Different pressure values within the range studied are applied so as to draw for each transducer a calibration curve (voltage over pressure).

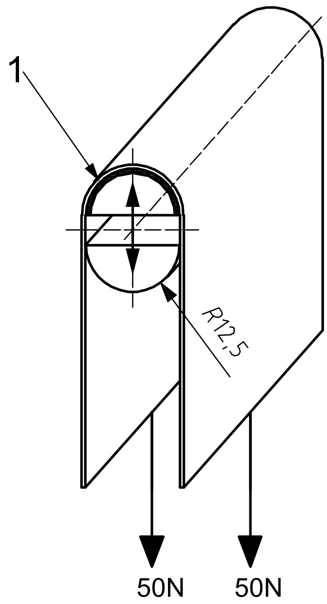
E.3 Reference method for comparing different force-measuring apparatus

Figure E.1 gives an example of a handle equipped with a force transducer. The different apparatus (strain gauge bar, pressure transducers, etc.) are fixed on one side of the handle. A piece of material which covers the instrumentation to be calibrated is fixed on one end to one edge of the reference handle and is weighted on the other end with masses of, e.g. 50 N. The width of the material shall correspond to the width of the instrumentation to be calibrated.

E.4 Alternative method for comparing different force-measuring apparatus

The primary location for force application may result in a non-uniform response to loading. If there is a question about the particular design, it is recommended that three loading locations be checked. The use of loading at the centre and half way between the measurement edge and the centre on both sides should provide the needed information on system sensitivity to the loading location.

Dimensions in millimetres



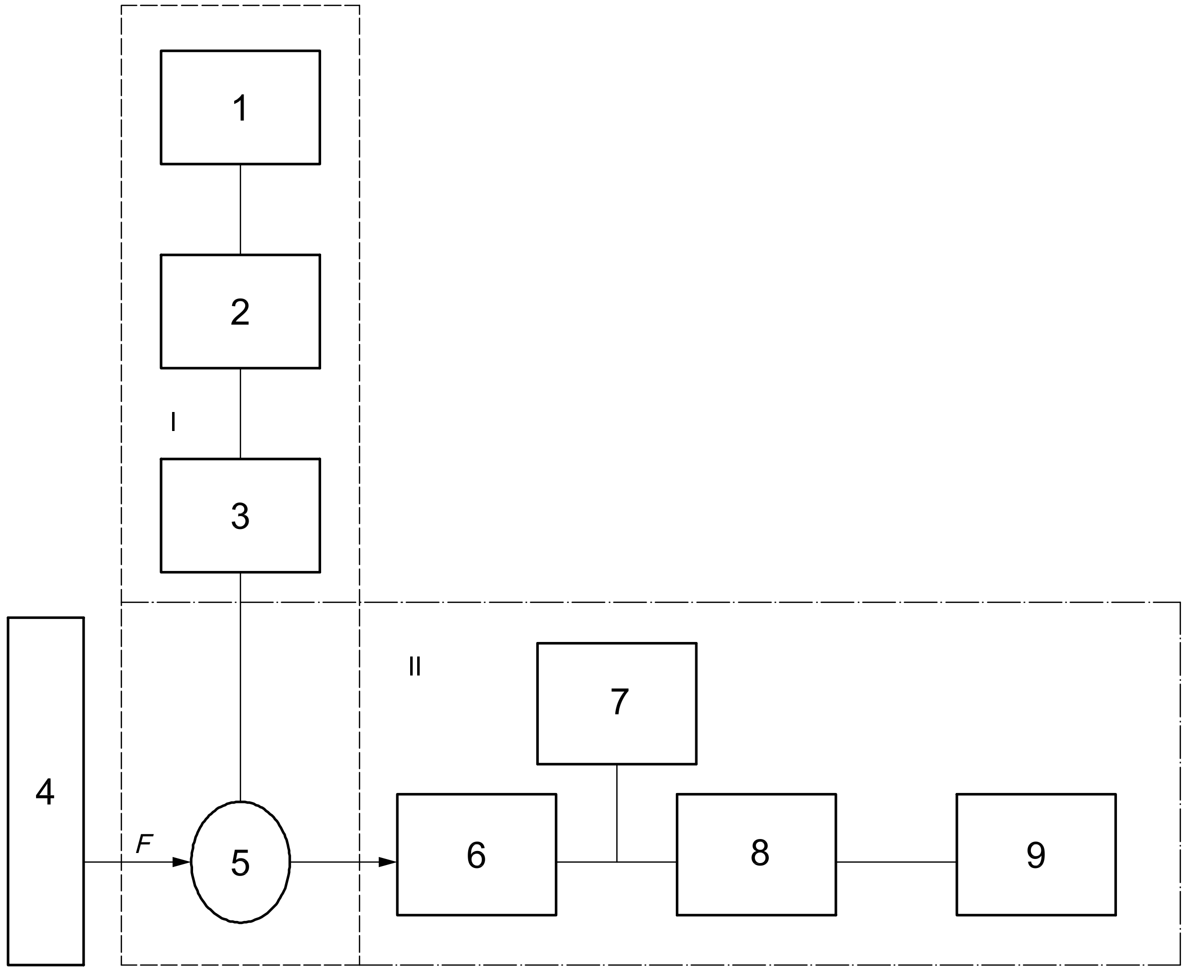
Key

1 transducer

Figure E.1 — Example of reference handle used to compare different instrumentation systems for measuring forces applied to handle

E.5 Calibration of an electro-hydraulic force meter

The electro-hydraulic force meter may be calibrated using a system such as shown in Figure E.2. The calibration system consists of a load constituted source of force, tensometric load cell and digital weight indicator. The active liquid pad is laid between a flat solid surface of load and a surface of the tensometric load cell. Applied load causes pressure changes in the active liquid pad of the electro-hydraulic force meter. Pressure values, displayed on a digital manometer of force meter, can be compared to load values measured by the tensometric load cell and displayed on a digital weight indicator. Different load values within the range studied (from zero to 300 N) are applied so as to draw a calibration curve (pressure over load). Calibration is needed to establish the two stage force transducer linearity.



Key

I electro-hydraulic force meter
II calibration system

1 pressure, p, display
2 digital manometer
3 pressure transducer
4 source of force
5 ALP (active liquid pad)
6 tensometric load cell
7 power supply adaptor
8 digital weight indicator
9 force, F, display

Figure E.2 — Example of calibration system of electro-hydraulic force meter

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