Safety of machinery — Human physical performance —

Part 3: Recommended force limits for machinery operation

The European Standard EN 1005-3:2002 has the status of a British Standard

ICS 13.110

National foreword

This British Standard is the official English language version of EN 1005-3:2002.

The UK participation in its preparation was entrusted by Technical Committee PH/9, Applied ergonomics, to Subcommittee PH/9/4, Anthropometry and biomechanics, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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This British Standard, having been prepared under the direction of the Health and Environment Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 26 February 2002

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Sécurité des machines - Performance physique humaine - Partie 3: Limites des forces recommandées pour l'utilisation de machines

Sicherheit von Maschinen - Menschliche körperliche Leistung - Teil 3: Empfohlene Kraftgrenzen bei Maschinenbetätigung

This European Standard was approved by CEN on 8 November 2001.

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

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Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 122 "Ergonomics", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2002, and conflicting national standards shall be withdrawn at the latest by July 2002.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EC Directive(s).

For relationship with EC Directive(s), see informative annex ZA, which is an integral part of this document.

EN 1005 consists of the following parts, under the general title "Safety of machinery - Human physical performance":

- Part 1: Terms and definitions;
- Part 2[1)]: Manual handling of machinery and component parts of machinery;
- Part 3: Recommended force limits for machinery operation;
- Part 4[1)]: Evaluation of working postures and movements in relation to machinery;
- Part 5[1)]: Risk assessment for repetitive handling at high frequency.

Annexes A and B are for information only.

According to the CEN/CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

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1) This European Standard is under preparation by CEN/TC 122/WG 4 "Biomechanics".

Introduction

Within the life cycle of a machine from construction to dismantling, various machine-related actions require muscular force exertion. Muscular force exertion causes strain to the musculo-skeletal system. Unfavourable musculo-skeletal strain corresponds to the risk of fatigue, discomfort and musculo-skeletal disorders. The manufacturer of a machine is in a position to control these health risks by optimising the required forces, while taking into account the frequency, duration and variation of force exertion.

The calculation procedure and the recommended limits in this standard aim to reduce the health risk for the operator as well as to increase the flexibility and possibility for a larger population to operate the machines which increases efficiency and profitability.

This standard has been prepared to be harmonised standard in the sense of the Machinery Directive and associated EFTA regulations.

This standard is written in conformity with EN 1050 and gives the user hazard identification for harm through musculo-skeletal disorders and tools for qualitative and, to an extent, a quantitative risk assessment. The tools for the risk assessment also implicate how to do the risk reduction. This standard does not deal with risks connected to accidents.

The recommendations provided by this standard are based on available scientific evidence concerning the physiology and epidemiology of manual work. The knowledge is, however, scarce and the suggested limits are subject to changes according to future research. In accordance with the rules for CEN/CENELEC-standards Part 2, 4.9.3, European Standards are reviewed at intervals not exceeding five years.

This European Standard is a type B standard as stated in EN 1070.

The provisions of this document can be supplemented or modified by a type C standard.

NOTE For machines which are covered by the scope of a type C standard and which have been designed and built according to the provisions of that standard, the provisions of that type C standard take precedence over the provisions of this type B standard.

1 Scope

This European Standard presents guidance to the manufacturer of machinery or its component parts and the writer of C-standards in controlling health risks due to machine-related muscular force exertion.

This standard specifies recommended force limits for actions during machinery operation including construction, transport and commissioning (assembly, installation, adjustment), use (operation, cleaning, fault finding, maintenance, setting, teaching or process changeover) decommissioning, disposal and dismantling. The standard applies primarily to machines which are manufactured after the date of issue of the standard.

This standard applies on one hand to machinery for professional use operated by the adult working population, who are healthy workers with ordinary physical capacity, and on the other hand to machinery for domestic use operated by the whole population including youth and old people.

The recommendations are derived from research on European population.

This document is not applicable to specify the machinery which are manufactured before the date of publication of this document by CEN.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 614-1, *Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles.*

EN 1005-1:2001, *Safety of machinery - Human physical performance - Part 1: Terms and definitions.*

EN 1070, Safety of machinery – Terminology.

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 614-1, EN 1005-1:2001 and EN 1070 apply.

4 Recommendations

4.1 General recommendations and information

The manufacturer should first consider EN 292-2:1991, annex A and EN 614-1 and EN 614-2 and then use the procedure for determining force limits presented below.

It is crucially important that the operator is in control of the operation sequences and the pace of the machinery. Furthermore, machines shall be designed in a way so that actions demanding force exertion can be performed optimally with respect to the posture of body and limbs and the direction of force application. In addition machines shall be designed to allow for variations in movements and force exertions.

The risk assessment procedure conveyed by this standard should formally be carried out for each action occurring during handling of the machinery. It may be noted, however, that infrequently occurring actions with low force demands may be assessed on an overview base.

Actions related to the handling of control actuators are considered in EN 894-3, however the present standard provides additional important information related to physical capacity and safety of the operator.

4.2 Risk assessment of action forces

The risk assessment in the present standard is based on the force generating capacity of the intended users, and follows a three-step procedure as illustrated in Figure 1.

In step A, the maximal isometric force generating capacity is determined for relevant actions within specified intended user populations. Within the scope of this standard the determination of maximal forces can be carried out according to three alternative methods.

In step B, the force generating in step A capacity is reduced, according to the circumstances under which the force is to be generated (velocity, frequency and duration of action). The reduction is achieved by a set of multipliers. Basically, the output is a force that may be delivered without substantial fatigue.

In step C, the risk associated with the intended use of the machinery is assessed. The risk evaluation is accomplished using risk multipliers, reducing the maximal attainable force from step B to values associated with different levels of risk.

The risk assessment focuses on musculo-skeletal disorders, and is preferentially based on the assumption that decreasing fatigue during work is effective in reducing disorders.

The recommended force limits are applicable to most men and women in a general population in optimal action posture and under ideal circumstances. The limits are calculated for an optimal range of motion of the joints involved in the respective actions.

It is recommended to let force limits for professional users correspond to the 15^{th} percentile of the whole adult population, i.e. males and females between 20 years and 65 years of age. Force limits for machines intended for domestic use should correspond to the 1^{st} percentile of the same adult population. The adult population is used as reference since reliable force data are scarce or unavailable for youth and aged individuals. Limits established by the procedure in this standard will essentially reduce hazards for at least 85 % of the intended user population.

The manufacturer should be aware that the force evaluation presented by the standard may be used also as a guidance when making instructions for the use of the machinery.

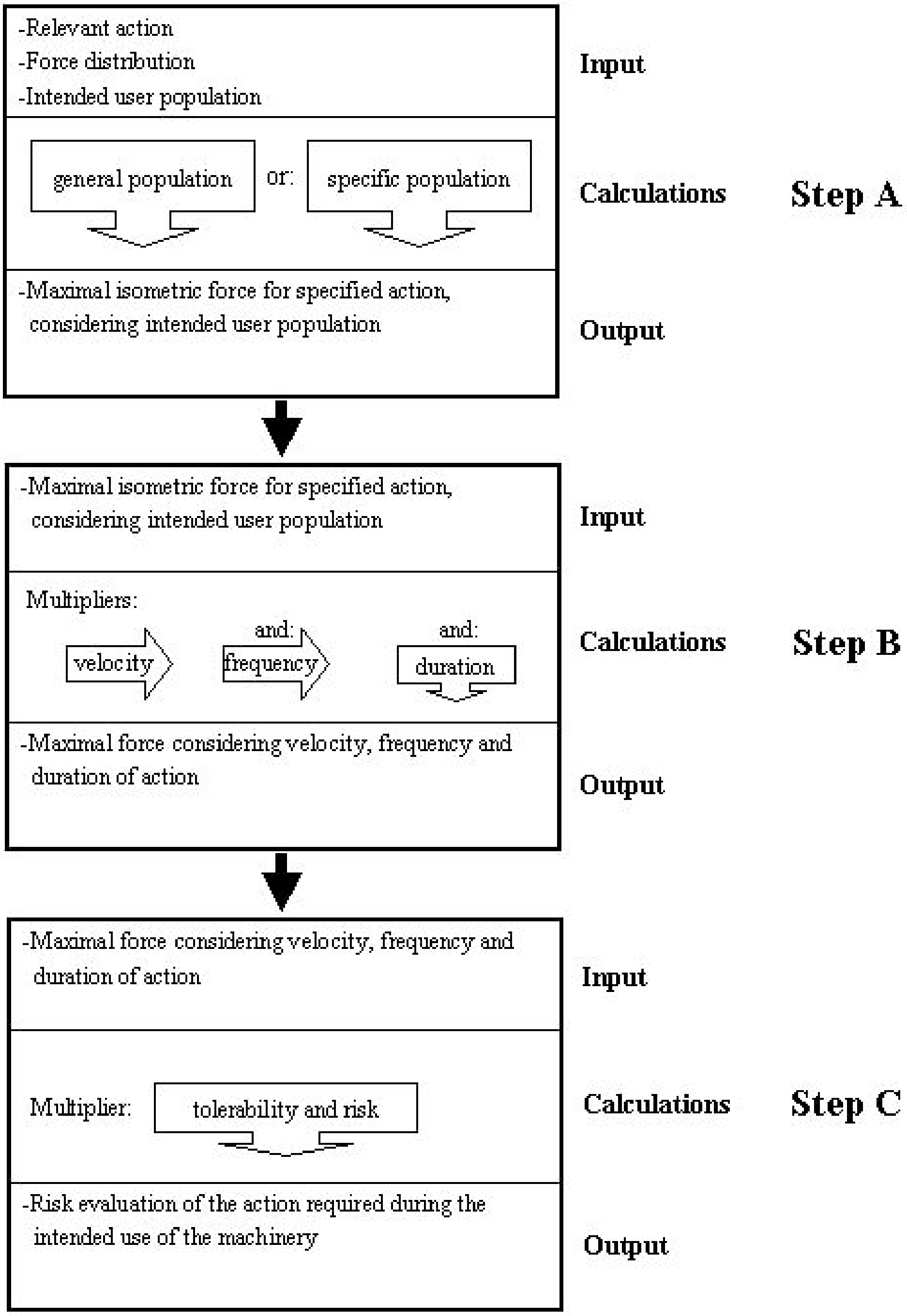


Figure 1 — Illustration of the step procedure leading to risk evaluation of action forces during machinery use for specified intended user populations

4.2.1 Step A: Determination of basic force generating capacity

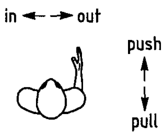
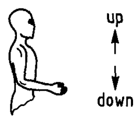
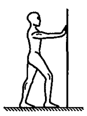
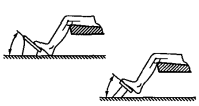
Output: maximal isometric force F_B, for specified actions, with consideration to intended user population.

Step A may be realised by one of three alternatives:

Alternative 1

Finding pre-calculated values of F_B in Table 1, if available. These limits represent the general European working population in the given mix in age and gender (Eur 12, 1993). Pre-calculations were done by alternative 3. These values are calculated for optimal working postures as illustrated in the table. The manufacturer shall be aware that physical strength, in particular at arm work, is strongly related to working postures and to the direction of force application.

Table 1 — Maximal isometric force F_B. Pre-calculated isometric force capacity limits for some common activity for professional and domestic use. The values apply to optimal working conditions.

Activity		Professional use F_B in N	Domestic use F_B in N
	Hand work (one hand):		
	Power grip	250	184
	Arm work (sitting posture, one arm):		
	- upwards	50	31
	- downwards	75	44
	- outwards	55	31
	- inwards	75	49
	- pushing		
	- with trunk support	275	186
	- without trunk support	62	30
	- pulling		
	- with trunk support	225	169
	- without trunk support	55	28
	Whole body work (standing posture):		
	- pushing	200	119
	- pulling	145	96
	Pedal work (sitting posture, with trunk support):		
	- ankle action	250	154
	- leg action	475	308

Alternative 2

Calculating F_B by an easy procedure as described in annex A. Alternative 2 is a rough approximation assuming equal representation of males and females and may be applied:

— if the intended user population is similar to the general European population, or

— if a specific demographic profile of the intended user population is not available.

Alternative 2 refers to strength data of the general female population.

Limits may be calculated realising the following basic steps:

— define relevant actions and force directions;

— obtain isometric strength distributions of the general adult and healthy European population at relevant actions;

— decide whether the machinery is intended for professional or domestic use;

— determine F_B, i.e. the 15th strength percentile for professional use or the 1st percentile for domestic use.

For further information and a suggested calculation procedure see annex A. Note that annex A is informative, not normative.

Alternative 3

Allowing precise calculation of F_B by an advanced procedure in annex B.

The amount of F_B exactly reflects the envisaged target population. Consequently alternative 3 applies:

— if the envisaged target population is known in its specific mix in age and gender.

Alternative 3 refers to strength data of a specified subgroup, females between 20 years and 30 years.

Limits may be calculated realising the following basic steps:

— define relevant actions and force directions;

— get strength distribution parameters (average and standard deviation) of a particular reference group (females between 20 years and 30 years);

— get distributions of age and gender of the intended user population as shaped by its demographic profile;

— determine F_B , i.e. the 15th force percentile for professional use of the 1st percentile for domestic use.

For further information and a suggested calculation procedure see annex B. Note that annex B is informative, not normative.

4.2.2 Step B: Determination of adjusted capacity

Output: maximal force for intended user population, taking into consideration velocity, frequency and duration of action.

4.2.2.1 Velocity multiplier m_V

The maximum force generating capacity is reduced in fast, contractive movements. This is covered by the velocity multiplier m_V determined in Table 2.

Table 2 — Velocity multiplier m_v, relating to movement speed

Velocity	no action implies no or a very slow movement	yes action implies an evident movement
m_V	1,0	0,8

4.2.2.2 Frequency multiplier m_f

Frequently repeated actions cause fatigue to develop, and thereby decreases the maximal force generating capacity. The fatigue effects depend on the relationship between the duration of each individual action (the 'action time') and the frequency with which the action occurs during machinery operation. The multiplier m_f intended to cover this is determined according to Table 3.

Table 3 — Frequency multiplier m_f, relating to the duration of individual actions ('action time') and their frequency of occurrence

Action time	**Frequency of actions** (min^{-1})			
min	≤ 0,2	> 0,2 - 2	> 2 - 20	> 20
≤ 0,05	1,0	0,8	0,5	0,3
> 0,05	0,6	0,4	0,2	not applicable

4.2.2.3 Duration multiplier m_d

Fatigue, i.e. a reduced force generating capacity develops gradually with time during ongoing work. Actions which are 'similar' may add up in causing fatigue, as they load the same body issues. Thus, not only the hours of work with the present action should be considered, but also the duration of similar actions. Below, 'similar' is defined as actions which are of the same character (i.e. pushing, pressing, or whatever) as the one under consideration, and which are executed close to the average hand/foot-position (whatever relevant) in this. The multiplier m_d in Table 4 captures the duration effect. 'Duration' in the table refers to working time including interruptions.

Table 4 — Duration multiplier m_d, relating to the cumulated duration (h) of similar actions

Duration (h)	≤ 1	> 1 - 2	> 2 – 8
$\boldsymbol{m_d}$	1,0	0,8	0,5

4.2.2.4 Calculation of reduced capacity, F_{Br}

Calculate the force generating capacity with consideration to velocity, frequency and duration of action by the following formula:

$$F_{Br} = F_B \times m_V \times m_f \times m_d$$

where

F_B is the maximal isometric force;
m_V is the velocity multiplier;
m_f is the frequency multiplier;
m_d is the duration multiplier.

4.2.3 Step C: Evaluation of tolerability and risk

Output: risk assessment of the force required while handling the machinery.

Both of the previous steps concern capability, starting from maximal isometric force. Thus, the value of F_{Br} shows the very limit of force exertion possible. Health risks are, however, present even at submaximal forces. The risk multiplier stated below takes this into consideration. It includes considerations to the tolerability of body tissues (in particular muscles, tendons and joints), as well as a safety margin addressing acceptability. The risk multiplier produces three risk zones which will guide the machinery manufacturer into a risk evaluation of the intended use of the machinery.

The evaluation of tolerability and risk is carried out as follows:

— the force value obtained in step B is multiplied by the values m_r given in Table 5, according to the formula:

$$F_R = m_r \times F_{Br}$$

where

F_R is the risk assessment force

— this leads to risk zones associated with action forces during machinery use. The evaluation of risk within each zone is provided below Table 5.

— by referring to the risk zones, the manufacturer may evaluate an intended machinery design and/or obtain quantitative guidance in formulating instructions for machinery use.

Table 5 — Risk multiplier m_r defining risk zones

Risk zone	m_r
recommended	≤ 0,5
not recommended	> 0,5 - 0,7
to be avoided	> 0,7

Recommended zone: The risk of disease or injury is negligible. No intervention is needed.

Not recommended zone: The risk of disease or injury cannot be neglected. The risk shall therefore be further estimated, and analysed with consideration to additional risk factors, including those presented in 4.3. This analysis may result in a risk multiplier value of 0,7 being considered acceptable. If, on the other hand, the analysis concludes that the intended use of the machinery is associated with risk, redesign or other measures may be needed which reduce the risk.

Zone to be avoided: The risk of disease or injury is obvious and cannot be accepted. Intervention to lower the risk is therefore necessary.

It should be emphasised that machinery which is intended to be operated at high action frequencies may imply a considerably increased risk for injury, irrespective of the required action force. For further information, it should be referred to prEN 1005-5[1)].

4.3 Factors affecting risk

4.3.1 Working posture

The machinery should allow for unrestricted, flexible and frequent changes of working postures during its handling and operation and extreme joint positions should be avoided. When considering working postures, reference should be made to prEN 1005-4[1)].

4.3.2 Acceleration and movement precision

It should be taken into consideration that actions demanding high accelerations imply large tissue forces and hence an increased risk for injuries and disorders. It should also be acknowledged that movements demanding high precision are performed at a slower rate, and may imply increased muscle efforts.

4.3.3 Vibration

The machinery should not infer any vibration to the arms or body of the operator. Vibration affects the force generating capacity and may in itself cause musculo-skeletal disorders.

4.3.4 Man-machine interaction

The individual should be allowed full control of his work pace. During machine operation, the operator should be able to activate and deactivate the machinery at any instant. The manufacturer should be aware of the risk for musculo-skeletal disorders due to monotonous repetitive work.

4.3.5 Personal protective equipment

Personal protective clothing and equipment may restrict the operators movements while handling the machinery. Typical PPE items may include gloves, aprons, overalls, flame-retardant trousers, gaiters, non-slip and toe-protected footwear, goggles, masks or respirators. This shall be recognised in the design of the machinery by allowing sufficient space, and by considering the decreased strength and mobility that may follow from the use of PPE.

4.3.6 External environment

The expected environmental conditions during intended machinery handling shall be taken into account. Care shall be taken if work has to be done at extremes of temperature. For example, high temperatures or humidity may cause rapid fatigue; work at low temperatures may cause numbness or require gloves with loss of manual dexterity. It is likewise important to consider the lighting conditions.

Annex A
(informative)

Calculation procedure for Alternative 2

A.1 General

Annex A specifies a fast approximation procedure to determine force limits. This procedure is realising an equal representation of males and females and applies

— when user populations of machinery are not reasonably well known, or

— when machinery is directly designed for the adult European working population.

In the second case annex A may be used to by-pass a more sophisticated method listed in annex B. Apply annex B if real manipulation forces are just missing limits as calculated below.

A.2 Input parameters

In a first step the intended operator's manipulations should be analysed to pinpoint most hazardous activities and forces required. Distribution parameters (average and standard deviation) of human strength will be found in the literature or in the table below. These strength data should generally represent the adult European working population. As an approximation it is recommended to start with distribution parameters taken exclusively from female reference groups. These parameters allow reasonably good predictions of force limits F_B integrating both genders:

— intended user population: adult European working population;

— reference group: adult female population;

— distribution parameters: average force $\overline{F}$ and standard deviation σ of reference group.

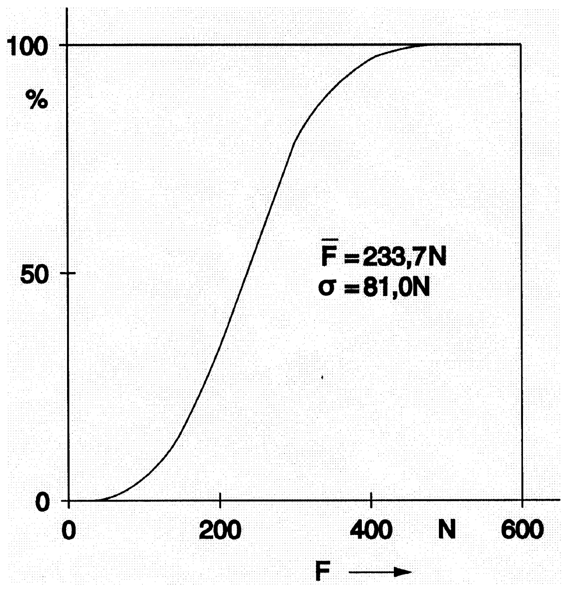
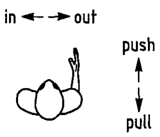
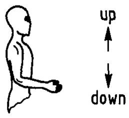
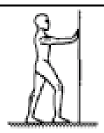
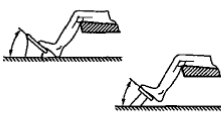


Figure A.1 — Example of distribution parameters

Table A.1 — Selection of distribution parameters $\overline{F}$ and σ
(Reference group: adult female population)

Activity		$\overline{F}$ [N]	σ [N]
	Hand work (one hand):		
	Power grip	278,0	62,2
	Arm work (sitting posture, one arm):		
	- upwards	58,0	18,4
	- downwards	88,6	33,2
	- outwards	65,5	26,2
	- inwards	85,6	24,6
	- pushing		
	- with trunk support	312,0	84,8
	- without trunk support	78,0	42,7
	- pulling		
	- with trunk support	246,0	45,7
	- without trunk support	67,9	33,5
	Whole body work (standing posture):		
	- pushing	233,7	81,0
	- pulling	164,6	44,9
	Pedal work (sitting posture, with trunk support):		
	- ankle action	293,4	104,7
	- leg action	542,5	156,2

NOTE Approximation. If no data of the reference group are available, distribution parameters of annex B - young females between 20 and 30 years - can be used as an approximation.

A.3 Procedure

A.3.1 Force distribution

Average and standard deviation define distribution functions *DF*(x) of all prospective forces. Such an approximation to normal allows an easy way to determine force limits in practical applications.

A.3.2 Logarithmic transformation

Limits are closer to reality by changing over to logarithmic normal distributions:

$$\overline{F}_{\ln} = \ln \overline{F} \qquad \sigma_{\ln} = \ln \frac{\overline{F} + \sigma}{\overline{F}}$$

Example: *pushing*

$$\overline{F}_{\ln} = \ln 233{,}7 = 5.45$$

$$\sigma_{\ln} = \ln \frac{233{,}7 + 81}{233{,}7} = 0{,}30$$

A.3.3 Calculation of force percentiles

Starting at above distribution parameters, $\overline{F}_{\ln}$ and $\sigma_{\ln}$, logarithmic force percentiles $\overline{F}_{\ln\%}$ may be calculated:

$$F_{\ln\%} = \overline{F}_{\ln} + z_{\%} \times \sigma_{\ln}$$

Referring to the 15th and 1st percentile of the target group, z% amounts to [2)]

$$z_{15\%} = -\ 0{,}5244$$

$$z_{1\ \%} = -\ 2{,}0537$$

Example:

$$F_{\ln 15\%} = 5{,}45 - 0{,}5244 \times 0{,}30 = 5{,}30$$

$$F_{\ln 1\%} = 5{,}45 - 2{,}0537 \times 0{,}30 = 4{,}84$$

A simple transformation back to the linear scale finally yields appropriate percentiles $F_{\%}$:

$$F_{\%} = e^{F_{\ln\%}} \qquad \text{N}$$

Example:

$$F_{15\%} = e^{5.3} = 200 \qquad \text{N}$$

$$F_{1\%} = e^{4.84} = 126 \qquad \text{N}$$

A.4 Results

Both percentiles $F_{15\%}$ and $F_{1\%}$ are defined as maximal isometric forces F_B:

$$F_B = \left\langle \begin{array}{ll} F_{15\%} & \text{for professional use} \\ F_{1\%} & \text{for domestic use} \end{array} \right.$$

Example:

F_B = 200 N for professional use

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2) Here we suppose:

$$z_{15\%}^{\text{gen. popul.}} = z_{30\%}^{\text{females}} = -0{,}5244$$

and

$$z_{1\%}^{\text{gen. popul.}} = z_{2\%}^{\text{females}} = -2{,}0537$$

These force limits allow work up to 85 % or 99 % of the adult European working population without exceeding their physical capacity.

Annex B
(informative)

Calculation procedure for Alternative 3

B.1 General

In 4.2 alternative 3 specifies a procedure to establish maximal isometric forces F_B for reasonably well known user populations of machinery. The calculation scheme includes two major steps that are described more detailed in the following:

B.2 Input parameters

B.2.1 Force

The procedure requires first distribution parameters of maximum isometric forces as observed at a particular reference group:

— reference group: females between 20 years and 30 years;

— distribution parameters: force average $\overline{F}$ and standard deviation σ of the reference group.

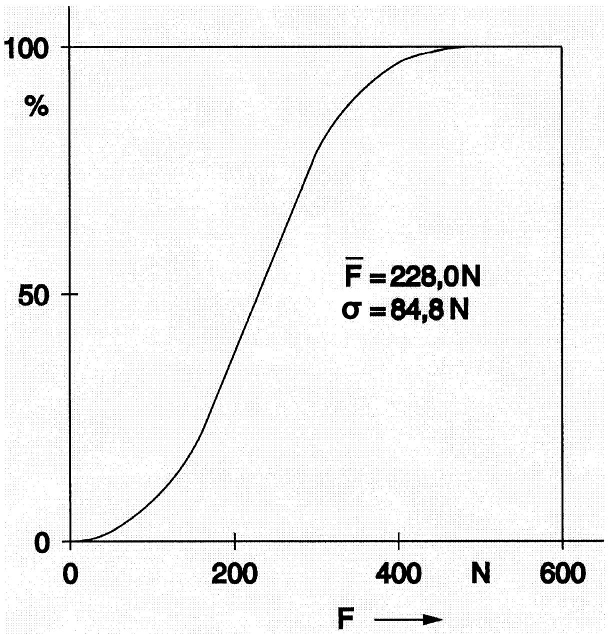
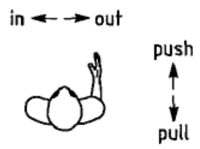
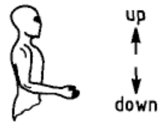
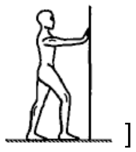
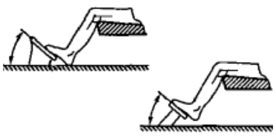


Figure B.1 — Example of distribution parameters

Reference forces can be found in the literature or in the table below.

Table B.1 — Selection of distribution parameters $\bar{F}$ and σ
(Reference group: females between 20 and 30 years)

Activity		$\bar{F}$ N	σ N
	Hand work (one hand): Power grip	 270,0	 54,1
	Arm work (sitting posture, one arm): - upwards - downwards - outwards - inwards - pushing - with trunk support - without trunk support - pulling - with trunk support - without trunk support	 56,0 88,0 63,5 83,4 303,0 75,5 242,0 65,7	 18,4 33,2 26,2 24,6 81,0 42,7 44,9 33,5
	Whole body work (standing posture): - pushing - pulling	 228,0 161,0	 84,8 45,7
	Pedal work (sitting posture with trunk support): - ankle action - leg action	 282,0 528,5	 96,5 157,6

NOTE Approximation. If no data of the reference group are available, distribution parameters of annex A - adult female population - can be used as an approximation.

B.2.2 User demography

Further the intended user population should be analysed. This analysis would have to concentrate on subgroups as specified by age and gender according to the following categories:

females

- n_{f1}: age < 20 years;
- n_{f2}: 20 years ≤ age ≤ 50 years;
- n_{f3}: age > 50 years.

males

- n_{m1}: age < 20 years;
- n_{m2}: 20 years ≤ age ≤ 50 years;
- n_{m3}: age > 50 years.

n_{fi}, n_{mi}: percentages of according subgroups as found in the intended user population

check: all n_{fi} and n_{mi} should sum up to 100 %

n_{f1} = 1,6 %
n_{f2} = 31,6 %
n_{f3} = 7,6 %

n_{m1} = 2,0 %
n_{m2} = 43,8 %
n_{m3} = 13,4 %

Example for the distribution in Europe of 12 states[3)]

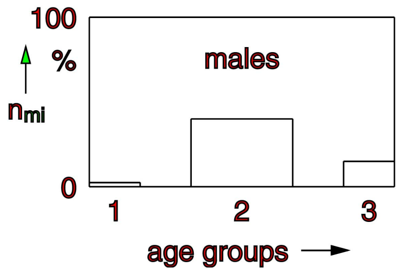


Figure B.2 — Example of user demography

B.3 Procedure

In a second step a special procedure calculates force limits made for user populations as specified above. The procedure works as follows:

B.3.1 Synthetical distribution parameters of subgroups

Force averages and standard deviations of all subgroups i are simply calculated by above reference parameters ($\overline{F}$, σ) and some appropriate multipliers (α_{xx}, s_{xx}) expressing relations between age and gender:

females - force averages: $\overline{F}_{fi} = \overline{F} \times \alpha_{fi}$

- standard deviation: $\sigma_{fi} = \sigma \times s_{fi}$

males - force averages: $\overline{F}_{mi} = \overline{F} \times \alpha_{mi}$

- standard deviation: $\sigma_{mi} = \sigma \times s_{mi}$

where

i = 1…3 are the age groups;

α_{xx}, s_{xx} are the subgroup multipliers;

$\overline{F}$, is the force average of reference group as specified in step B.2;

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3) Eur 12, Europa der 12 – Erhebung über Arbeitskräfte, Statistisches Bundesamt Wiesbaden, 1993

σ is the standard deviation of reference group as specified in step B.2.

Table B.2 — Example of user demography

Age groups	1	2	3
$\bar{F}_{fi}$	172,8	180,0	167,4
σ_{fi}	61,8	60,0	57,6
$\bar{F}_{mi}$	351,0	388,8	306,0
σ_{mi}	94,2	99,0	108

Table B.3 — Subgroup multipliers

Averages α_{xx}				Standard deviations s_{xx}			
Age groups	**1**	**2**	**3**	**Age groups**	**1**	**2**	**3**
Females α_{fi}	0,96	1,00	0,93	Females s_{fi}	1,03	1,00	0,96
Males α_{mi}	1,95	2,16	1,70	Males s_{mi}	1,57	1,65	1,81

B.3.2 Logarithmic distributions

At lower force levels (e.g.: $\bar{F}$ = 63,5 N, σ = 26,2 N) above approximation to normal yields increasingly poor results at lower percentiles (1 %), In this case logarithmic distributions are more realistic. An easy transformation is providing a new set of logarithmic distribution parameters:

females: $\bar{F}_{fi}^{L} = \ln(\bar{F}_{fi})$ $\sigma_{fi}^{L} = \ln \frac{\bar{F}_{fi} + \sigma_{fi}}{\bar{F}_{fi}}$

males: $\bar{F}_{mi}^{L} = \ln(\bar{F}_{mi})$ $\sigma_{mi}^{L} = \ln \frac{\bar{F}_{mi} + \sigma_{mi}}{\bar{F}_{mi}}$

The remaining calculations of the procedure apply to above logarithmic distribution parameters in the same way as they do to linear normal distributions.

In this case simply replace:

$\bar{F}_{fi}^{L} = \bar{F}_{fi}$ $\sigma_{fi}^{L} = \sigma_{fi}$ $x^{L} = x$

$\bar{F}_{mi}^{L} = F_{mi}$ $\sigma_{mi}^{L} = \sigma_{mi}$

where

x is the variable force in linear representation;

x^{L} is the variable force in logarithmic representation.

B.3.3 Generation of new distribution functions of male and female subgroups

- females: $$DF_{\text{fi}}(x) = \frac{1}{\sigma_{\text{fi}}\sqrt{2\pi}} \int_{-\infty}^{x} e^{-0,5 z_{\text{fi}}^2}\, dz_{\text{fi}}$$

with $$z_{\text{fi}} = \frac{x - \overline{F}_{\text{fi}}}{\sigma_{\text{fi}}}$$

- males: $$DF_{\text{mi}}(x) = \frac{1}{\sigma_{\text{mi}}\sqrt{2\pi}} \int_{-\infty}^{x} e^{-0,5 z_{\text{mi}}^2}\, dz_{\text{mi}}$$

with $$z_{\text{mi}} = \frac{x - \overline{F}_{\text{mi}}}{\sigma_{\text{mi}}}$$

When using logarithmic distributions then go back to $x = e^{x^L}$

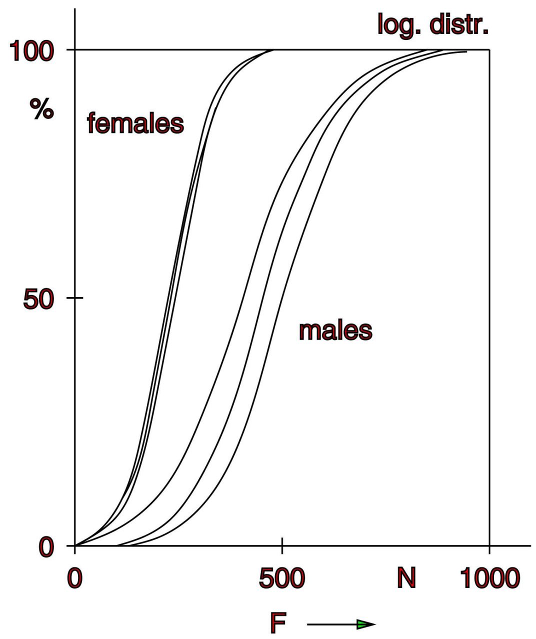

Figure B.3 — Example of force distribution functions of male and female subgroups

B.3.4 Weighting and combining of all subgroup distributions

$$DF(x) = \sum_{j} \frac{n_{fi} DF_{fi}(x) + n_{mi} DF_{fi}(x)}{100}$$

where

DF is the distribution function;

n_{fi} , n_{mi} are the percentages of all subgroups.

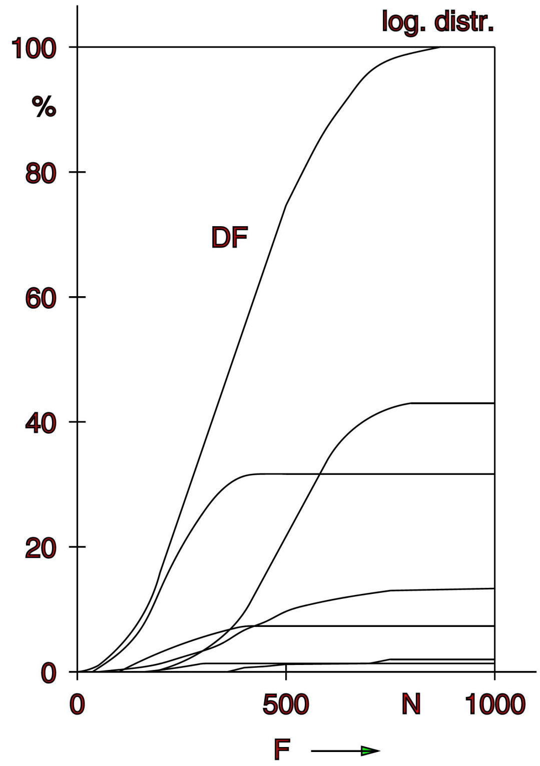

Figure B.4 — Example of weighting and combining of all subgroup distributions

B.3.5 Calculation of percentiles

DF(*x*) is the combined distribution function of all subgroups depending on force *x*,

So force limits may be found by calculating the 15th or the 1st percentile of *DF*(*x*):

$$DF(x) = \begin{cases} 0{,}15 & \text{for professional use} \\ 0{,}01 & \text{for domestic use} \end{cases}$$

→ force *x*

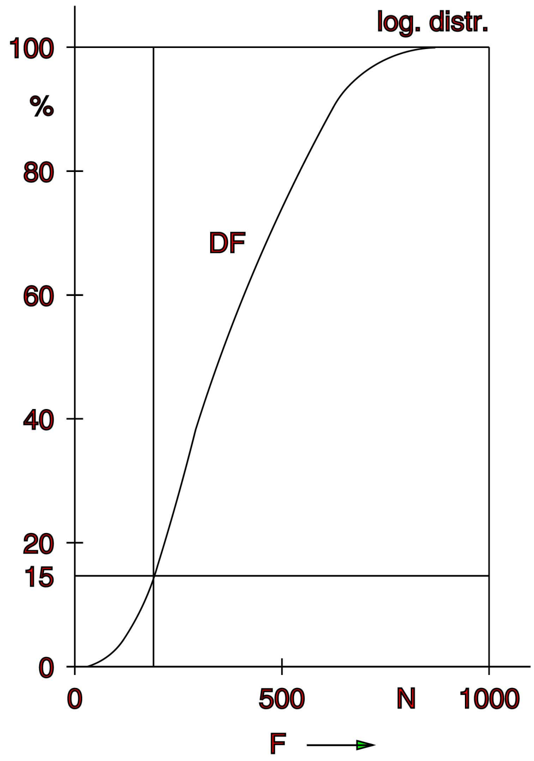

Figure B.5 — Example of calculation of percentiles

B.4 Result

Above procedure yields the required basic force limit as follows:

$$F_B = x \quad N$$

These limits allow work up to 85 % or 99 % of the user population as specified by the input distribution without exceeding their physical capacity.

Example:

$$F_B = 200{,}2 \quad \text{N}$$

Annex ZA
(informative)

Relationship of this document with EC Directives

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association and supports essential requirements of the following EC directive(s):

Machinery Directive 98/37/EC, amended by Directive 98/79/EC.

Compliance with this European Standard provides one means of conforming with the specific essential requirements of the Directive concerned and associated EFTA regulations.

WARNING — Other requirements and other EC Directives <u>may</u> be applicable to the product(s) falling within the scope of this standard.

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