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Safety of machinery — Relationship with ISO 12100 —

Part 3: Implementation of ergonomic principles in safety standards

Sécurité des machines — Relation avec l'ISO 12100 —

Partie 3: Mise en oeuvre des principes ergonomiques dans les normes de sécurité

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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The committee responsible for this document is ISO/TC 199, *Safety of machinery*.

ISO/TR 22100 consists of the following parts, under the general title *Safety of machinery — Relationship with ISO 12100*:

— *Part 1: How ISO 12100 relates to type-B and type-C standards*

— *Part 2: How ISO 12100 relates to ISO 13849-1*

— *Part 3: Implementation of ergonomic principles in safety standards*

Introduction

The primary purpose of this document is to provide designers with an overall framework and guidance for decisions about ergonomic aspects during the development of machinery, to help them design machines that are safe for their intended use. As mentioned in ISO 12100:2010, 6.2.8, failure to follow ergonomic principles in design can result in the inadequate adaptation of machines to the capacities and skills of the intended user population and hence place their health or safety at risk.

ISO 12100 describes an iterative process to reduce risks. This document describes the main ergonomic factors influencing the safety of machinery and gives a framework for incorporating them into this design process.

Mental (cognitive) aspects are also to be considered. For example, machines which are operated in an inappropriate manner or whose control devices are not clearly identifiable can lead to human error.

This document is intended to guide users to make effective use of ergonomics standards within the context of machinery design.

This document will help both ergonomics and machinery standards writers to incorporate the structure specified in ISO Guide 78.

Safety of machinery — Relationship with ISO 12100 —

Part 3: Implementation of ergonomic principles in safety standards

1 Scope

This document describes the main ergonomic risk factors influencing the safety of machinery and gives a framework for incorporating them into the design of machines by the integration of important ergonomic principles relating to:

— avoiding stressful postures and movements during use of the machine;

— designing machines, and more especially hand-held and mobile machines, which can be operated easily;

— avoiding as far as possible noise, vibration, thermal effects;

NOTE 1 The health effects of noise, vibration and adverse thermal conditions are well-known and are not addressed here. However environmental factors can interact with machine design and risks arising from such influences are addressed in this document.

— avoiding linking the operator's working rhythm to an automatic succession of cycles;

— providing local lighting on or in the machine;

NOTE 2 Lighting of the machine or of the surrounding workplace by the machine can have a significant impact on the safety of machine operation and this risk is addressed by this document.

— selecting, locating and identifying manual controls (actuators) so that they are clearly visible and identifiable and appropriately marked where necessary;

— selecting, designing and locating indicators, dials and visual display units.

The approach is based on ISO 12100 with its iterative process to identify significant hazards and reduce risks.

Relevant steps of this iterative process have been adapted to include ergonomic principles, and practical guidance is given to apply standards dealing with ergonomics which are relevant for machinery design.

This document is intended for use by standards writers and designers of machinery. It can be used when no relevant C-type standards are available.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12100 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
ergonomics
study of human factors
scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance

[SOURCE: ISO 6385:2004, 2.3]

3.2
ergonomic hazard
hazard arising from the failure to adequately consider ergonomic principles in machine design

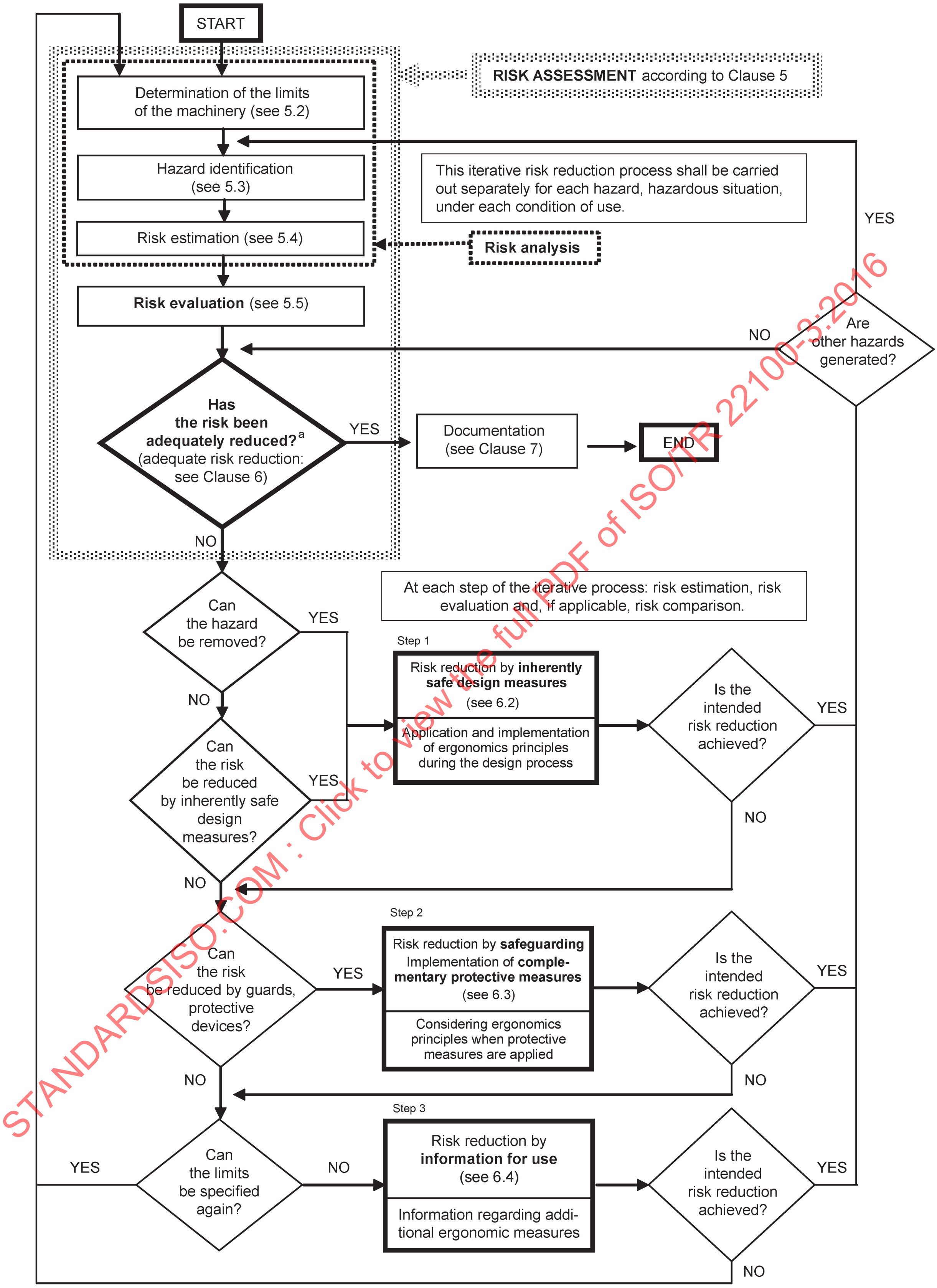
Note 1 to entry: For ergonomic hazards see also ISO 12100:2010, Table B.1, No. 8.

4 Strategy for risk assessment and risk reduction in relation to ergonomic hazards

4.1 General

The risk assessment process carried out by designers in accordance with ISO 12100:2010, Clause 5, provides information that is required for the risk evaluation through which decisions can be taken whether risk reduction is necessary. These decisions have to be supported by a qualitative or, where appropriate, a quantitative estimation of the risk identified. This is to be met by taking into account both the risks normally considered in machine design, and those arising from failing to consider the principles of ergonomics.

Figure 1 shows a schematic representation of the risk reduction process, derived from ISO 12100:2010, which illustrates how ergonomics can be integrated into the iterative three-step risk reduction process (including references to the relevant clauses in this document).



[a] The first time the question is asked, it is answered by the result of the initial risk assessment.

Figure 1 — Illustration of the integration of ergonomics into the iterative three-step design process for risk reduction (based on ISO 12100:2010, Figure 1)

4.2 Significant ergonomic hazards in relation to ISO 12100

Designs which do not take ergonomics into account can have potential consequences such as discomfort, fatigue, musculoskeletal disorders, stress and human error (see 4.3). When these are identified as being associated with the machine, they are relevant ergonomic hazards. Consequences such as discomfort and fatigue can also lead indirectly to human error. If the potential consequences require specific action, then these are significant hazards and are as important as those arising from mechanical, electrical and other hazards (see ISO 12100:2010, Table B.1).

NOTE 1 Discomfort and fatigue are relevant warning signals, as they can lead to occupational disease or to accidents and can influence performance and quality.

NOTE 2 The term ergonomic hazard is used in ISO 12100 to describe hazards resulting from the failure to adequately consider ergonomics during the design process. For consistency this term is therefore retained in this document.

Table 1 shows an example comparing mechanical hazards with ergonomic hazards.

Table 1 — Comparison of mechanical and ergonomic aspects of hazards

Work task: load/unload a machine		
Location of hazard: machine loading area		
Hazards arising from the failure to adequately consider	**Mechanical aspects**	**Ergonomic aspects**
Origin of hazard	Sharp edge	Sustained awkward posture
Factors influencing the risk	Surface characteristics	Space for movement restricted
Potential consequences	Cutting	Discomfort/Fatigue
Harm	Injury, pain, bleeding	Back pain, musculoskeletal disorders
Severity of harm	Light to serious damage to health	Light to serious damage to health (reversible or chronic)

4.3 Potential consequences

4.3.1 General

Taking ergonomic principles into account in designing machinery helps to reduce the mental or physical load on the operator. In turn this reduces strain and improves efficiency. It is important to consider these principles when allocating functions to operator and machine in the basic design.

As outlined in ISO 12100, failure to consider these principles can have potential consequences for the health, safety and performance of the operator. Table B.1 of ISO 12100:2010 lists some of these consequences, which are described below.

4.3.2 Discomfort

Discomfort refers to a lack of comfort, to a mental or physical uneasiness that is less intense and less localized than pain. On the contrary, comfort gives or brings aid, support, satisfaction. Comfort refers to a condition furnishing mental and/or physical ease. Sustained discomfort can lead to

— lack of attention or concentration (distraction),

— ill-health,

— absenteeism,

— decreased productivity — both qualitatively (with more discarded items) and quantitatively, and

— accidents.

Important aspects contributing to discomfort are

— awkward postures or sustained (static) postures,

— heavy physical work,

— repetitive movements,

— accessibility e.g. reaching distances,

— visual comfort, e.g. lines of sight, colour, visibility, light intensity and direction, viewing distances,

— surface contact e.g. shape, temperature, ease of contact,

— vibration (whole body and hand-arm),

— noise e.g. intensity, frequency, duration, pattern,

— climate/environment e.g. air temperature, wind speed (draught), relative humidity, clothing,

— odours e.g. fumes,

— inadequate cooperation or communication between operators during machine operation,

— balance between activity and inactivity; between vigilance and inattentiveness.

4.3.3 Fatigue

Fatigue is a state of impaired performance capability which can result from current or preceding physical and/or mental activities. Fatigue can be physical or mental, general or local. The extent of any fatigue depends on the intensity, duration and temporal pattern of these activities. Recovery from fatigue requires rest periods with sufficient time for recuperation.

Important aspects contributing to fatigue are:

— type of workload, e.g. mental or physical;

— intensity of the workload, e.g. weight to be moved, complexity of information to be processed;

— repetitiveness of task components (highly repetitive tasks can be more fatiguing);

— time for recovery e.g. rest breaks.

NOTE As well as variation in mental and physical capabilities between different operators, the capabilities of an individual operator and therefore their susceptibility to fatigue and other effects will vary over time.

4.3.4 Musculoskeletal disorders

Musculoskeletal disorders can be either acute or chronic. Acute disorders usually arise from some form of muscle overload, with work which is either too demanding, or with other characteristics such as sudden onset, which can tear or strain muscles or other soft tissue structures.

Chronic disorders usually arise from sustained or repeated demands which exceed the body's recovery and repair mechanisms. In some instances, unaccustomed activities create a hazard and an introductory or learning period can be beneficial.

Some disorders can be either acute or chronic in origin. For example, some tendon problems can arise from a short-term overload (acute) or a more sustained period of repeated activity.

Static loading (force application without movement) can also be problematic as muscle movement is an essential part of the recovery and repair process.

Important aspects contributing to musculoskeletal disorders:

— force requirements (are related to the size of the body part involved, with larger muscles being generally capable of higher forces);

— frequency of movements (smaller body parts such as fingers are naturally better suited to rapid movements than larger joints such as the shoulder);

— duration of force application (the greater the force, the less time it can be sustained for, especially without movement);

— position of body parts – posture - (body parts are more resilient when working close to their anatomical neutral position, such as with the arms by the side rather than raised above the shoulders);

— range of joint movement (as a rough guide, remaining within the middle 50 % of the range of movement is preferable and the more extreme a movement or posture the more strain will be experienced).

NOTE External environmental loads, such as vibration (hand-arm or whole-body) or extremes of temperature may need to be taken into account. This document does not cover noise and vibration requirements.

4.3.5 Stress

4.3.5.1 General

The terminology relating to "stress" is often both confused and confusing. In some instances, the term is used in the equivalent manner to the engineering use of the term, to reflect the loads placed on a person (with the outcome regarded as 'strain'). In others, these are referred to as stressors, with the impact regarded as stress. Still others term the loads as pressure – again with stress as the potential outcome.

When used in the engineering sense, the term is essentially neutral and stress can be beneficial or harmful depending upon its characteristics. In other instances however, stress as an outcome is, by definition an adverse consequence.

Both fatigue and discomfort, addressed above, can be caused by physical and psychological stressors. However, although the volume of work can be a contributor to psychological stress it is more usually psychological factors which combine to give rise to the negative outcome. For this reason in some countries, to avoid any confusion, the term "psychological stress" is used instead.

NOTE 1 Psychological stressors can also aggravate existing fatigue and discomfort.

NOTE 2 Psychological stress is sometimes referred to as mental stress.

4.3.5.2 Psychological stress

In a safety of machinery context, it is likely to be issues such as the complexity and variability of the tasks required of operators and others, together with cognitive factors such as requirements for sustained attention and the probability and consequences of errors which contribute to any risk.

Important aspects contributing to psychological stress, which can be influenced by the design of the machine, include

— complexity of task,

— variability of task,

— time constraints on performance,

— cognitive resources required,

— multitasking vs. serial task performance,

— probability of errors,

— consequences of errors,

— design of interfaces (e.g. displays, signals and controls),

— requirements for sustained attention,

— repetitiveness of task performance,

— intensity of workload, and

— temporal pattern of workload.

The general factors which contribute to the overall burden of psychological stress can be grouped into six broad categories:

1) demands (not being able to cope with the demands of the job);

2) control (not having sufficient influence over how work is done);

3) support (not having sufficient support from colleagues and superiors);

4) relationships (being subjected to unacceptable behaviours);

5) role (not understanding roles and responsibilities);

6) change (not being involved and informed in organisational changes).

However, central to the concept of psychological stress, and a major mediating influence over whether the demands placed on an individual become excessive, is the idea of the individual 'coping' with the demands placed upon them. Thus, psychological stress develops when work demands of various types and combinations exceed the person's capacity and capability to cope. The consequences can be considerable including poor mental wellbeing, anxiety or depression as well as contributing to physical ill-health.

4.3.6 Human error

Human error, which can be expressed as a discrepancy between the human action taken or omitted, and that intended or required is a very complex field, with many different approaches to defining and classifying errors. In a safety of machine design context, the focus turns to the potential for human error by the designer, in failing to adequately ensure that controls or displays can be clearly and unambiguously identified and operated correctly in accordance with operator expectations (stereotypes).

In essence, errors can occur when a person does something he or she should not (e.g. operating the wrong control device) or does not do something he/she should (e.g. spot a warning signal). However, the complexities increase when the possibilities are explored further. Thus, was the wrong control device activated, the right one operated wrongly, the right one operated at the wrong time, and so on. Do the consequences arise from the failure to operate the right control device — or the operation of the wrong one? The likelihood of error is also influenced by additional factors such as work demands or pressures, sustained vigilance, monotony, etc.

Some important machine design aspects contributing to human error are

— selection of inappropriate display designs (e.g. digital or analogue displays),

— inappropriate control design (e.g. small devices to be operated by gloved hands),

— inappropriate control-response relationships (e.g. direction of control movement in relation to the movement of the machine),

— poorly identified control devices or displays (e.g. inadequate labelling, wrong colour coding),

— poor layout of control devices (e.g. insufficient space between devices), and

— poor layout of displays (e.g. viewing angle from operating position).

This list presents aspects through which poorly considered design can increase the risk of human error and avoiding these through good design will improve machine safety.

5 Incorporating ergonomics into the risk assessment process

5.1 Information for risk assessment

5.1.1 General

5.2 to 5.5 describe the steps for incorporating ergonomics into the risk assessment process in accordance with ISO 12100:2010, Clause 5.

Because ergonomics deals with interactions between people and other elements of a system, special attention should be drawn to the overall work system (see ISO 6385), which is the basis for the determination of the limits of the machinery [see ISO 12100:2010, 5.2 d) and 5.3].

5.1.2 Information for establishing assessment criteria

Establishing assessment criteria requires knowledge of the technical design of the machine and the characteristics and capabilities of the intended operator population including their experience and training with similar machines.

In order to perform an adequate risk assessment, the following basic parameters of the machine should be defined:

a) functions and their limits;

b) human interfaces with different parts of the machine.

The determination of the characteristics of the operator population is based on

— physical limitations (stature, reach, strength, vision, etc.), and

— mental ability (education, training, experience, etc.).

Essential information for risk assessment is required relating to

— the functionality of the machine,

— the allocation of function between manual and automated processes,

— the job (task elements),

— the human/machine interface characteristics,

— where the machine will be installed,

— how the machine will be used (including maintenance) and removed,

— information for training of personnel, and

— production and maintenance procedures.

5.2 Determination of limits of machinery (user aspects)

Risk assessment starts with the determination of the limits of the machinery, which includes taking into account the characteristics and capabilities of the intended operator population.

NOTE The limits of machinery can be part of the contract between the supplier and user of a machine.

5.3 Hazard identification

5.3.1 General concept for identifying ergonomic hazards

Human error, musculoskeletal disorders, stress, discomfort and fatigue are potential consequences arising from ergonomic hazards which result from the failure to adequately consider ergonomics during the design process [see ISO 12100:2010, 5.4 a) and 5.4 c)].

Important ergonomic risk factors to be taken into account include

— human variability,

— posture and movement space,

— work rate and pattern,

— human error,

— operator/machine interface, and

— workplace environment.

Detailed information relating to the determination of hazards based on the essential characteristics and capabilities of the intended operator population is given in 5.3.2.1 to 5.3.2.7.

5.3.2 Determination of hazards based on essential characteristics and capabilities of intended operator population

5.3.2.1 General

Particular attention is drawn to the following seven ergonomic aspects of machinery design (see ISO 12100:2010, 6.2.8) that should be considered when identifying hazards:

a) forces, postures and movements during use of the machine;

b) operability or controllability of the machine, especially hand-held and mobile machines;

c) environmental effects of the machine and its surroundings (e.g. noise, vibration, thermal);

d) operator's working rhythm linked to an automatic succession of cycles;

e) integral task lighting (on or in the machine);

f) selection, design and location of control devices;

g) selection, design and location of indicators, dials and visual display units.

In order to help address these aspects, this document describes six important ergonomic risk factors that need to be considered. Each factor is relevant to one or more of the above ergonomic aspects. The main links between these factors (1 through 6) and the aspects a, b, c, d, e, f and g relating to them are described in the text below and summarized in Table 2.

Table 2 — Link between ergonomic risk factors and ergonomic aspects

Ergonomic risk factor	Ergonomic aspects of machinery design	
1) Human variability	a)	Forces, postures and movements during use of the machine
	b)	Operability or controllability of the machine, especially hand-held and mobile machines
2) Posture and movement space	a)	Forces, postures and movements during use of the machine
	b)	Operability or controllability of the machine, especially hand-held and mobile machines
	d)	Operator's working rhythm linked to an automatic succession of cycles
3) Work rate and pattern	d)	Operator's working rhythm linked to an automatic succession of cycles
4) Human error	c)	Environmental effects of the machine and its surroundings (e.g. noise, vibration, thermal)
	e)	Integral task lighting (on or in the machine)
	f)	Selection, design and location of control devices
	g)	Selection, design and location of indicators, dials and visual display units
5) Operator/machine interface	f)	Selection, design and location of control devices
	g)	Selection, design and location of indicators, dials and visual display units
6) Workplace environment	c)	Environmental effects of the machine and its surroundings (e.g. noise, vibration, thermal)
	e)	Integral task lighting (on or in the machine)

NOTE General ergonomic design standards are listed in Annex A, see Table A.1.

5.3.2.2 Human variability

Human beings differ widely in their attributes. When addressing this variability in the design process, the main factors to be taken into account are physical dimensions, strength (and stamina). These should be considered by taking into account gender, body dimensions and build, age, body weight and physical strength and disabilities. Psychological or cognitive factors may also need to be considered depending on the nature and function of the machine being designed (e.g. skills and experience).

Body dimensions can vary between different populations, more usually between countries from different parts of the world but, particularly in some larger or more diverse countries, from region to region.

Age-related adverse effects can be partly compensated by training and/or assistive technology. Other adverse effects of age can be compensated by operators adopting different strategies. Older people generally have more experience and higher decision-making capabilities than their younger peers.

Individual performance (e.g. vigilance) and capacity will vary not only with age, but also throughout a working day with generally poorer cognitive performance as fatigue develops.

NOTE 1 In particular instances it can be appropriate to consider health-related impairments, e.g. reduction in grip strength due to osteoarthritis, operators with pacemakers etc.

NOTE 2 The impact of some aspects of human variability can be modified or offset. For example: strength can be increased (by physical training); additional skills can be gained.

NOTE 3 Standards dealing with significant hazards associated with human variability are listed in Annex A, see Tables A.2 and Table A.3

5.3.2.3 Posture and movement space

The space necessary for the operator(s) postures and movements needed for machine operation should be taken into account in any design process.

Sustained working postures, such as sitting, standing, trunk bending, kneeling; together with tasks requiring the arms to be used above shoulder height can be critical if the posture is sustained or repeated for long periods. Twisting movements or extreme positions of the hand or arm, as well as repetitive body movements, especially where they involve the application of forces, should be avoided.

Sufficient space for movement is one of the basic principles in machinery design to prevent accidents and occupational diseases e.g. musculoskeletal disorders. Restricting movement can potentially be as harmful as requiring too great a range of movement. Appropriate body movements are indispensable to avoid physical stress and strain.

Anthropometric data for the intended operating population and knowledge of their work tasks are therefore important factors in identifying potential hazards arising from any mismatch between the dimensions of the human body and the size and dimensions allowed for in any machine design.

It should be remembered that worker's tasks are not limited to regular machine operating functions. Maintenance, troubleshooting, repairing and installing machinery are important tasks to consider and can give rise to risks. The need for access to danger zones for maintenance, lubrication and setting should be minimized. However, if needed, factors such as the access space and postures required to reach machine parts for these tasks should be taken into account during the design process.

NOTE Standards dealing with significant hazards associated with posture and movement space are listed in Annex A, see Table A.4.

5.3.2.4 Work rate and pattern

The work rate is a flow that describes the number of pieces per time unit measured at one operator's working station. There are benefits in providing the operator with some control over this rate although this is clearly not always possible (for example in complex production lines involving several operators working at different stages in the process). When non-adjustable by the operator(s), there is more potential for the work rate imposed by the machine to cause problems, either because of the rate itself, or due to the absence of personal control.

The most common types of harm when the physical work rate is too high and/or not controllable by the operator and if recovery periods are absent or too rare, are musculoskeletal disorders (see 4.3.4), and psychological stress (see 4.3.5).

In addition to potential physical work rate hazards, the designer should also consider the mental or cognitive demands placed on the operator such as information acquisition; cognitive processing and decision making requirements.

Information will be presented to the operator through a number of sensory channels including sight, hearing and touch as well as, less commonly, smell or taste. Visual information might be through designed displays (e.g. conventional dials or human machine interface) as well as observing the position and status of the machine or parts of the machine itself and its surroundings (sometimes referred to as "real" displays). Similarly auditory information might comprise warnings or indicators incorporated into the machine – or the sounds made by the machine itself.

This sensory information has to be mentally processed and evaluated, and the mental demands are related to the number and the complexity of these operations.

Each single component of these various work rates is easily determinable (and often measurable). However, the final work rate is sometimes more complex as it can result from the combination and interaction of multiple demands. When these demands are perceived as too high by the operator, they can lead to negative physical or psychological reactions.

NOTE Standards dealing with significant hazards associated with work rate and pattern are listed in Annex A, see Table A.5.

5.3.2.5 Human error

If the ergonomic factors influencing attention and concentration are not taken into account by machinery designers, the risk of unintended behaviour of the operator or reasonably foreseeable misuse of the machine occurs (see also ISO 12100:2010).

Machinery operations which result in very rapid or highly repetitive cyclic operations can increase the risk of human error. Similarly, operations requiring intense concentration or sustained attention (including those involving very long cycle times) can also increase such risks.

NOTE 1 Lighting, climate, noise and odours are other factors that can affect concentration and lead to human error.

The more effort (e.g. processing capacity) the operator expends on the task, the less capacity remains available for other tasks or circumstances that may demand attention leading to human error.

Vigilance requires attention and describes an individual's state of alertness, watchfulness and preparedness to attend to critical information that is not yet present. Vigilance decreases the longer the period of supervisory duty (the decline begins to be evident after the first 30 min).

Attention and vigilance are not constant and can be impacted by environmental factors such as noise and temperature.

NOTE 2 In this clause, it will be assumed that the term vigilance corresponds to a sustained concentration ability.

Task factors such as frequency of signals can affect performance on attention and vigilance tasks. A low number of critical signals significantly reduces performance (expressed in reaction time) during a vigilance task. More non-critical signals per minute results in greater distraction and greater difficulty in identifying critical signals.

NOTE 3 Standards dealing with significant hazards associated with human error are listed in Annex A, see Table A.6.

5.3.2.6 Operator/machine interface

The operator/machine interface is mainly made up of control devices and displays which provide ways of controlling what the machine does and provide the means for the operator to get information on the status of the machine. Failure to adequately consider the design of the interface can mean a machine is difficult to operate correctly and this can result in errors. The physical characteristics — shape, size, placement, etc. — are important, as is the way in which the control devices and displays have to be used. Control devices and displays that are easy to use and understand are more likely to be used properly and less likely to give rise to significant hazards. For example control devices that require excessive force can cause muscle fatigue, and/or be misused; displays that are difficult to interpret or are not very visible can give rise to visual fatigue and/or be misread.

NOTE Standards dealing with significant hazards associated with operator/machine interface are listed in Annex A, see Table A.7.

5.3.2.7 Workplace environment

The environment in which the machine is to be operated is an important consideration, not just for the integrity of the machine itself but also because of the potential impact on the operator. Failure to adequately consider the foreseeable operating environment can create hazards.

EXAMPLE 1 A machine designed for use outside should have displays which take into account the fact that they might need to be read in full sunlight or at night.

EXAMPLE 2 Auditory warnings should accommodate the frequency and level of likely background noise to ensure audibility and attention-gaining (without contributing to noise dose).

The effect of the machine and its operation on the surrounding environment will often be within the control of the designer and consideration should be given to the potential impact of possible emissions (noise, vibration, dust, heat, fumes, etc.) on the operator.

EXAMPLE 3 Control devices requiring a high degree of fine motor coordination will be difficult to operate precisely with high levels of vibration.

NOTE Standards dealing with significant hazards associated with workplace environment are listed in Annex A, see Table A.8.

5.4 Risk estimation

5.4.1 General

The risk estimation which is generally described in ISO 12100:2010, 5.5, is based on the risk elements "severity of harm" and "probability of occurrence of that harm" and has to be carried out for each ergonomic factor mentioned in 5.3.1 which influences the risks. ISO/TR 14121-2:2012, Clause 5, gives general guidance on the risk estimation process. Since discomfort, fatigue and musculoskeletal disorders are significant consequences arising from ergonomic hazards, the factors influencing the risk explained in 5.3.2 are the basis to estimate ergonomic risks.

NOTE 1 One of the aspects to be considered during risk estimation is human factors (see ISO 12100:2010, 5.5.3.4.).

NOTE 2 ISO/TR 14121-2:2012, 5.4.3, gives guidance on the probability of occurrence of cumulative harm.

5.4.2 Risk estimation tools

In order to support a risk estimation process, the risk estimation tools stated in ISO/TR 14121-2:2012, Clause 6, may be used, or others e.g. human error analysis techniques, fault tree analyses.

5.5 Risk evaluation

5.5.1 General

For risk evaluation, see ISO 12100:2010, 5.6. As shown in Figure 1, the extent of the risk reduction achieved should be evaluated after applying each of the three steps of risk reduction described in Clause 6.

5.5.2 Evaluating the risk reduction achieved by the application of ergonomic principles

Following the application of the iterative three steps, adequate risk reduction can be regarded as being achieved when

— all operating conditions and all intervention procedures have been considered,

— the variability within the characteristics of the intended users of the machines has been considered,

— the ergonomic aspects of hazards (see for example Table 1) have been eliminated or ergonomic risk factors (see Table 2) reduced to the lowest practicable level,

— any new ergonomic hazards introduced by the protective measures have been properly addressed,

— operators are sufficiently informed and warned about the residual risks, and

— the protective measures do not adversely affect the operator's working conditions or the usability of the machine.

5.5.3 Comparison of ergonomic risks

As part of the process of risk evaluation, as described in ISO 12100:2010, 5.6.3, the risks associated with the machinery or parts of machinery can be compared with those of similar machinery or parts of machinery, provided the criteria specified in ISO 12100 apply. In addition to these criteria the following criteria relating to ergonomic aspects are also applicable:

— both machines are intended to be used by operators with comparable characteristics and capabilities;

— both machines are used in similar working environments.

6 Risk reduction — Design guidance

6.1 General

Risk reduction in an ergonomic sense can best be achieved by inherently safe design. This can be developed through the incorporation of ergonomic design principles into the design (or modification) of the machine. Annex A lists standards which provide guidance on how to incorporate relevant principles into machine design to reduce these risks.

Subclauses 6.2 to 6.7 identify important technical issues for risk reduction. Each highlights the ergonomic factors influencing the risk, gives an indication of the main aspects relating to these factors that need to be considered and provides some design guidance to reduce risk.

NOTE The division of information into these separate clauses is not necessarily distinct and can overlap, e.g. aspects of human variability, posture and movement space, human error and operator/machine interface are all relevant to control design.

Annex A presents a reference list of ergonomics standards which provide additional information. See Table A.1 for a list of general ergonomic design standards.

It is important to consider the work system as this can influence the design of the machine. Annex B presents some factors from the work system which might need to be taken into account in the design.

Annex C presents a list of some ergonomics standards for specific applications: control centres, human system interaction and mobile machinery.

Annex D presents an example of part of the implementation of the ergonomic factors listed in 6.2 to 6.7 in the design of an interactive control element for a CNC milling machine.

6.2 Risk reduction — Human variability

To what extent will the risks be affected by variability within the characteristics of the intended users of the machines?

Important practical issues to be considered, many of which are influenced by both gender and age, include the following.

— **Body size and weight** (relevant for, e.g. reach distances, clearances, work surface height, support surfaces)

Design guidance: If these factors are likely to affect the safe and effective use of the machine, can the workplace dimensions be adjusted in such a way that they are suitable for different body sizes and dimensions?

— **Strength and stamina** (relevant for e.g. control operation forces, component weights, frequency and duration of operation)

Design guidance: Where forces have to be applied these forces should be within recommended force limits.

— **Mobility and dexterity** (relevant for e.g. accessibility of work space, manipulative tasks)

Design guidance: Requiring an unusually high degree of mobility or flexibility will restrict the range of users for whom the design is suitable, especially amongst older workers.

— **Sensory capabilities**, especially hearing, visual acuity, colour perception (relevant for e.g. warning signal detection, use of colour for safety status)

Design guidance: Warning signal design should take the characteristics of human hearing (and the range of variation in that hearing amongst the intended users) into account. Correct colour identification should not be relied on as the only means of recognizing or identifying controls or displays.

— **Knowledge, experience and skills** (relevant for e.g. education, instruction manuals, fault finding)

Design guidance: If a particular level of cognitive ability is necessary for safe operation, this should be made clear. If safe operation depends on operators having particular skills, arrangements need to be included for means for them to acquire such skills (training, etc.).

If operators are required to wear personal protective equipment (PPE), the impact (including health issues) of wearing PPE or other work clothing should be taken into account, e.g. wearing a breathing apparatus will affect body size and weight, restrictive clothing can impair mobility, and wearing gloves will affect dexterity.

Tables A.2 and A.3 provides a list of ergonomic design standards relevant to human variability (physical dimensions and strength).

Data for particular groups such as children, elderly people and people with restricted capabilities may be needed where they are part of the intended user population.

6.3 Risk reduction — Posture and movement space

Do space constraints (e.g. around the operating position) require operators to adopt adverse postures or present a risk of inadvertent control operation? Is the workplace dimensioned in such a way that a lack of motion and body postures beyond the usual upright or seated body postures are prevented?

The characteristics of the intended users of the machine and the variability of these characteristics have a significant impact on the design of work space (and hence the working postures adopted) and the movement space required. In addition to those issues listed in 6.2 other important practical issues to be considered include the following.

— **Range of movement of limbs** (relevant for, e.g. layout of control devices, reach envelope)

Design guidance: The layout of control devices should generally reflect the frequency of use of those devices (with the exception of emergency stop devices which should always be readily accessible). Those used most often should be closer to hand and less used control devices further out in the reach envelope. However, this should not exclude grouping sets of devices relating to a particular function, even where some are used less frequently.

— **Space to manipulate tools and component parts** (relevant for e.g. maintenance and setting up operations)

Design guidance: As well as being able to move body parts, the ability to move tools and machine components is essential, especially for maintenance activities. Ensure adequate access to fastenings to reduce the risk of them being incorrectly tightened with adverse safety consequences.

— **Provision of access to machinery and equipment** (relevant for e.g. ladders and stairways, access hatches)

Design guidance: Ensure adequate provision of a safe means of access and egress to reduce the risk of injury to the operator or damage to machinery, for example, through the operator using machine components as steps or handholds.

— **Viewing angles, lines of sight, viewing distances** (relevant for e.g. mobile plant, placement of displays)

Design guidance: Poor attention to visual aspects of machine design can result in hazards or degraded performance. Ensure adequate fields of view for operators of mobile machinery to reduce the risk of hitting workers or objects. Other effects can include the operator needing to adopt adverse postures in order to see sufficiently well, or taking shortcuts to compensate, leading to poorer quality output.

— **Workplace layout** (relevant for, e.g. arrangement of controls, parts of workstations).

Design guidance: Ensure that consideration is given to reducing the need to move between work elements, controls etc. Their spatial organization should not require rapid or excessive movement within the workplace, for example to perform successive tasks.

Table A.4 provides a list of ergonomic design standards relevant to posture and movement space.

6.4 Risk reduction — Work rate and pattern

Has the workflow at and with the machine been chosen in such a way that it can be managed by the operators physically and in terms of time?

Designers need to take account of the potential impact of the work rate and pattern on the operators. These issues are of particular importance where individual operators cannot control their own work rate.

Important practical issues to be considered, which can be influenced by both gender and age, include the following.

— **Interactions between frequency, force and body part** (relevant for, e.g. design of machine-paced tasks, selection of type of control device).

Design guidance: Ensure that activities requiring repetitive movements at high frequency are performed by smaller body parts which are better able to tolerate them. However it is also necessary to ensure that any force required in performing these movements is low because smaller body parts are less able to exert higher forces without risk of injury.

— The scope for individual adjustment of work rate with machine-paced activities (relevant for, e.g. highly repetitive tasks)

Design guidance: Ensure that individual operators are able to adjust their work rate, for example by including buffer space within the production flow.

— Information acquisition and processing (relevant for, e.g. tasks requiring decision making, visual inspection, process control)

Design guidance: Ensure that the rate of presentation of information takes into account the time required to access and process that information and to decide how to proceed.

Table A.5 provides a list of ergonomic design standards relevant to work rate and pattern.

6.5 Risk reduction — Human error

Is there potential for human error when operating the designed machine? Has this been taken into account in the design?

Important practical issues within risk reduction to be considered on human error include:

— **Discriminability of control devices** (relevant for, e.g.: panel design, mobile plant)

Design guidance: Ensure that the design avoids using rows of seemingly identical control devices which are not easy to differentiate. Wherever possible ensure that more than one modality is used to differentiate between control devices, for example do not rely on labelling but use differing shapes or colours as appropriate.

— Control-response stereotypes and other control characteristics (Relevant for, e.g.: all control devices)

Design guidance: Ensure that control movements take into account the natural expectation of the movement or other response evoked for a particular movement of that control device (control-response stereotype). Note that this expectation can vary between different populations. Where there is a clear stereotype this should be used in designing a control device. Ensure that use of a movement which is the opposite of a strong stereotype is avoided as this will increase the probability of error.

— **Selection of appropriate display characteristics** (relevant for e.g.: all displays)

Design guidance: Ensure that where precise values are presented numeric displays are used if possible. In contrast, where dynamic information is presented analogue forms of display are preferred. Ensure that information is displayed in a manner which is unambiguous and readily understood.

— **Layout of control devices and displays** (relevant for e.g. complex panels)

Design guidance: Ensure that related control devices and displays are arranged in a logical manner, e.g. by grouping them together. Where a number of devices are required, ensure that those which are most frequently used are positioned where they can most easily be reached and that the spacing between them is sufficient to avoid the risk of accidental operation.

Ensure that different examples of the same type of machine adopt a consistent layout for similar control devices. For example, in fork-lift trucks, confusion can arise when the arrangement and function of accelerator pedals varies between different vehicles.

— **Detection of fault conditions** (e.g. warning signals and the identification of defects)

Design guidance: Ensure that where possible the design of the machine makes it easy to detect defects in operation. For example this might be achieved by the combination of visual alarms with easily detectable and discriminable auditory warning signals. As a second example, the use of special lighting (colour, direction, intensity) can make it easier to detect product defects.

Table A.6 provides a list of ergonomic design standards relevant to human error.

6.6 Risk reduction — Operator/machine interface

Does safe and effective machine operation rely on rapid and effective transfer of information between the machine and the operator?

When designing the operator/machine interface, the characteristics of the operators should be taken into account, including how they acquire and process information.

Important practical issues which should be considered are the following.

— **Information on displays readable from operating positions**

Design guidance: Ensure that the design of the display (e.g. size, contrast, clarity) takes into account factors such as the reading distance to the operating position and the environmental conditions in which it is likely to be viewed (e.g. strong light, dust).

— **Control devices provide feedback to the operator**

Design guidance: Ensure that control devices provide feedback when activated and that where appropriate they provide an indication of the status of the controlled function.

— **Avoiding need for operator to remember or process many pieces of information in parallel**

Design guidance: Ensure that information is presented at a rate consistent with normal human capabilities.

— **Providing means for operators to correct or recover from their errors**

Design guidance: Ensure wherever possible that errors are readily identifiable and that how to correct them is apparent.

— **Trialling designs so that operators will find them straightforward and easy to use**

Design guidance: Ensure wherever possible that mock-ups or other devices are used to test and validate designs before finalisation.

NOTE The definition of the production process and its limits is based on EN 614-1:2006+A1:2009, 5.2.2 b and 5.5.3 a and b. The description of the determination of the essential characteristics and capabilities of the intended operator population is described in EN 614-1:2006+A1:2009, 5.2.2 c.

Table A.7 provides a list of ergonomic design standards relevant to the operator/machine interface.

6.7 Risk reduction — Workplace environment

6.7.1 General

This section examines effects of the workplace environment which can have an influence on the design of the machine.

NOTE The issue of any direct health effects of the emissions of the machine on the environment is addressed in other specific guidance and standards, e.g. ISO 14123-1.

EXAMPLE It does not consider design aspects of visual displays but, if the machine is expected to be operated in poor visual environments these factors are addressed.

Any environmental factor which makes operation of the machine unpleasant or uncomfortable can distract the operator from their task or encourage them to rush the task to remove themselves from the adverse effects. In addition to the specific issues outlined below the possibility of this should be considered in the design.

Table A.8 provides a list of ergonomic design standards relevant to the workplace environment.

6.7.2 Visual factors

Does the machine rely on correct and accurate rendition of visual information for its safe and reliable operation? Careful attention should be paid to factors such as the colour, intensity and directionality of ambient lighting and its impact on machine operation where this is the case.

Ensure that, if the machine is to be operated in un-illuminated environments, any need for supplementary lighting is considered.

The visual field (field of view) is particularly important for mobile machinery. Any obstructions to this view should be minimised.

Ensure that the operator can see all that they need to see for safe and effective machine operation. If not, consider providing additional devices such as cameras or sensors.

6.7.3 Auditory factors

Does the machine rely on correct and accurate rendition of auditory information for its safe and reliable operation?

Ensure that any warning signals are designed to be suitably audible and attention-gaining against expected levels and frequencies of background noise.

If other machine sounds carry important operational cues consider providing additional (non-auditory) cues if high levels of ambient noise might interfere with this function.

6.7.4 Vibration factors

Is machine operation likely to result in significant exposure to vibration? Do machine controls require a high degree of fine motor coordination?

Consider control designs less likely to be affected by the influence of vibration to offset any adverse effects.

6.7.5 Thermal factors

Is machine operation likely to result in significant exposure to high or low temperatures?

Ensure that, if the machine is likely to be operated in ambient temperatures above normal 'comfortable' conditions, or it is expected to generate adverse temperatures itself, additional control measures are considered to offset such effects, as elevated work temperatures can impair vigilance or cognitive ability.

Ensure that, if the machine is likely to be operated in temperatures lower than normal comfortable levels such that operators may need to wear gloves or mittens for protection, machine control devices are selected which are compatible with this to enable safe and accurate machine operation.

7 Verification of safety requirements

When concluding the iterative process, it should be ensured that the measures of Clause 6 have been carried out/implemented in the machine and demonstrated to be effective. The criteria given in 5.5.2 in combination with ISO 12100:2010, 5.6.2 can be used for verification. In practice, the evaluation is divided into two branches:

— **practical tests** — Is the machine actually built in consideration of all ergonomic requirements? — for the execution of practical tests, checklists can be helpful;

— **testing of documents** — Are the instruction handbook and all instructions complete in terms of ergonomic basic requirements?

Annex A
(informative)

Standards dealing with ergonomics relevant to machinery design

Tables A.1 to A.8 provide lists of some international, regional and other standards for each of the ergonomic risk factors. Where a regional or other standard uses a different number to the International Standard published by ISO, even though it is identical in content, this is also listed.

Those standards of most relevance are listed in full. At the end of each table, other standards which provide limited further information are listed by number.

Not all of the standards listed are directly addressed to machine design, however, they contain information which may be of value to designers.

Table A.1 — General ergonomic design standards (see 6.1)

International Standards	Regional or other standards
ISO 6385:2004, *Ergonomic principles in the design of work systems*	
ISO 26800:2011, *Ergonomics — General approach, principles and concepts*	
	EN 614–1, *Safety of machinery — Ergonomic design principles — Part 1: Terminology and general principles*
	EN 614–2, *Safety of machinery — Ergonomic design principles — Part 2: Interactions between the design of machinery and work tasks*
	CEN/TR 614–3, *Safety of machinery — Ergonomic principles for the design of mobile machinery*
	ANSI B 11 TR 1, *Ergonomic guidelines for the design, installation and use of machines*
See also ISO/TS 18152.	

Table A.2 — Human variability — Physical dimensions (see 6.2)

International Standards	Regional or other standards
ISO 14738:2002, *Safety of machinery — Anthropometric requirements for the design of workstations at machinery*	
ISO/TR 7250-2:2010, *Basic human body measurements for technological design — Part 2: Statistical summaries of body measurements from national populations*	
ISO 7250-3:2015, *Basic human body measurements for technological design — Part 3: Worldwide and regional design values for use in ISO equipment standards*	
ISO 15537:2004, *Principles for selecting and using test persons for testing anthropometric aspects of industrial products and designs*	
See also ISO 7250-1; ISO 9355-3,-4; ISO 11064-4; ISO 15534-1, -2,-3; ISO 11226; EN 614–1; EN 1005–1,-4.	

Table A.3 — Human variability — Strength (see 6.2)

International Standards	Regional or other standards
ISO 11228-1:2003, *Ergonomics — Manual handling — Part 1: Lifting and carrying*	EN 1005–2, *Safety of machinery — Human physical performance — Part 2: Manual handling of machinery and component parts of machinery* (Not identical to International Standard)
ISO 11228-2:2007, *Ergonomics —Manual handling — Part 2: Pushing and pulling*	EN 1005–3, *Safety of machinery — Human physical performance — Part 3: Recommended force limits for machinery operation* (Not identical to International Standard)
ISO 11228-3:2007, *Ergonomics — Manual handling — Part 3: Handling of low loads at high frequency*	EN 1005–5, *Safety of machinery — Human physical performance — Part 5: Risk assessment for repetitive handling at high frequency* (Not identical to International Standard)
See also ISO 15536-1; EN 614–1; EN 1005–1.	

Table A.4 — Posture and movement space (see 6.3)

International Standards	Regional or other standards
ISO 11226:2000, *Ergonomics — Evaluation of static working postures*	EN 1005–4, *Safety of machinery — Human physical performance — Part 4: Evaluation of working postures and movements in relation to machinery* (Not identical to International Standard)
ISO 15534-1:2000, *Ergonomic design for the safety of machinery — Part 1: Principles for determining the dimensions required for openings for whole-body access into machinery*	EN 547–1, *Safety of machinery — Human body measurements — Part 1: Principles for determining the dimensions required for openings for whole body access into machinery* (Content identical to International Standard)
ISO 15534-2:2000, *Ergonomic design for the safety of machinery — Part 2: Principles for determining the dimensions required for access openings*	EN 547–2, *Safety of machinery — Human body measurements — Part 2: Principles for determining the dimensions required for access openings* (Content identical to International Standard)
ISO 15534-3:2000, *Ergonomic design for the safety of machinery — Part 3: Anthropometric data*	EN 547–3, *Safety of machinery — Human body measurements — Part 3: Anthropometric data* (Content identical to International Standard)
ISO 13857:2008, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs*	
See also ISO 14738; ISO 11064-3; ISO 9355-2, 3,-4; ISO 14122-1, -2,-3,-4.	

Table A.5 — Work rate and pattern (see 6.4)

International Standards	Regional or other standards
ISO 11228-3:2007, *Ergonomics — Manual handling — Part 3: Handling of low loads at high frequency*	
ISO 9355-1:1999, *Ergonomic requirements for the design of displays and control actuators — Part 1: Human interactions with displays and control actuators*	
See also ISO 11228-1, -2; ISO 9355-2, -3, -4; ISO 14738; EN 1005–1, -2,-3.	

Table A.6 — Human error (see 6.5)

International Standards	Regional or other standards
ISO 9355-1:1999, *Ergonomic requirements for the design of displays and control actuators — Part 1: Human interactions with displays and control actuators*	
ISO 1503:2008, *Spatial orientation and direction of movement — Ergonomic requirements*	
ISO 10075:1991, *Ergonomic principles related to mental work-load — General terms and definitions* (+ *Part 2: Design principles; Part 3: Principles and requirements concerning methods for measuring and assessing mental workload*)	
ISO 7731:2003, *Ergonomics — Danger signals for public and work areas — Auditory danger signals*	
ISO 11429:1996, *Ergonomics — System of auditory and visual danger and information signals*	EN 981, *Safety of machinery — System of auditory and visual danger and information signals* (Content identical to International Standard)
	EN 842, *Safety of machinery — Visual danger signals — General requirements, design and testing*
See also ISO 1503; ISO 9355-2, -3,-4; ISO 6385; IEC 61310; EN 614–1; EN 614–2.	

Table A.7 — Operator/machine interface (see 6.6)

International Standards	Regional or other standards
ISO 9355-1:1999, *Ergonomic requirements for the design of displays and control actuators — Part 1: Human interactions with displays and control actuators*	EN 894–1, *Safety of machinery — Ergonomics requirements for the design of displays and control actuators — Part 1: General principles for human interactions with displays and control actuators* (Content identical to International Standard)
ISO 9355-2:1999, *Ergonomic requirements for the design of displays and control actuators — Part 2: Displays*	EN 894–2, *Safety of machinery — Ergonomics requirements for the design of displays and control actuators — Part 2: Displays* (Content identical to International Standard)
ISO 9355-3:2006, *Ergonomic requirements for the design of displays and control actuators — Part 3: Control actuators*	EN 894–3, *Safety of machinery — Ergonomics requirements for the design of displays and control actuators — Part 3: Control actuators* (Content identical to International Standard)
ISO 9355-4:2004, *Ergonomic requirements for the design of displays and control actuators — Part 4: Location and arrangement of displays and control actuators*	EN 894–4, *Safety of machinery — Ergonomics requirements for the design of displays and control actuators — Part 4: Location and arrangement of displays and control actuators* (Content identical to International Standard)
IEC 60447:2004, *Basic and safety principles for man-machine interface, marking and identification — Actuating principles*	EN 60447, *Basic and safety principles for man-machine interface, marking and identification — Actuating principles*
IEC 60073:2002, *Basic and safety principles for man-machine interface, marking and identification — Coding principles for indicators and actuators*	
See also ISO 7731; ISO 11429 (EN 981); EN 842; IEC 60204–1; EN 614–1; EN 1005–4; EN 1005–5.	

Table A.7 *(continued)*

International Standards	Regional or other standards
IEC 61310–1:2007, *Safety of machinery — Indication, marking and actuation — Part 1: Requirements for visual, auditory and tactile signals*	EN 61310–1, *Safety of machinery — Indication, marking and actuation — Part 1: Requirements for visual, auditory and tactile signals*
IEC 61310–2:2007, *Safety of machinery — Indication, marking and actuation — Part 2: Requirements for marking*	EN 61310–2, *Safety of machinery — Indication, marking and actuation — Part 2: Requirements for marking*
IEC 61310–3:2007, *Safety of machinery — Indication, marking and actuation — Part 3: Requirements for the location and operation of actuators*	EN 61310–3, *Safety of machinery — Indication, marking and actuation — Part 3: Requirements for the location and operation of actuators*
See also ISO 7731; ISO 11429 (EN 981); EN 842; IEC 60204–1; EN 614–1; EN 1005–4; EN 1005–5.	

Table A.8 — Workplace environment (see 6.7)

International standards	Regional or other standards
ISO 28803:2012, *Ergonomics of the physical environment — Application of International Standards to people with special requirements*	
ISO 9921:2003, *Ergonomics — Assessment of speech communication*	
	EN 1837, *Safety of machinery — Integral lighting of machines*
ISO 11399:1995, *Ergonomics of the thermal environment — Principles and application of relevant International Standards*	
ISO 13732-1:2006, *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 1: Hot surfaces*	
ISO/TS 13732-2:2001, *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 2: Human contact with surfaces at moderate temperature*	
ISO 13732-3:2005, *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 3: Cold surfaces*	
See also ISO 11429; ISO 7731; ISO 11429 (EN 981); ISO 9355-2; ISO 6385; ISO 14738; EN 614–1; CEN/TR 614–3.	

Annex B
(informative)

Work system and machinery design

Annex B presents some aspects from the work system which might need to be taken into account in the design. The information given complements one or more of the ergonomics risk factors described in the main body of the text (see also ISO 12100:2010, 5.4). In order to support work performance, designers need to take the aspects set out in Table B.1 into account (there is no order of priority in the list).

Table B.1 — Aspects to be considered when designing machines

Aspect	Objectives	Some design guidance	Points requiring special care
WORKSPACE ORGANIZATION	– To make the overall organization of the workshop in which the machine is to be used consistent with the constraints and requirements of the work that is to be done (use, maintenance, supply or feed, discharge, etc.).	– Plan connection of the machine to the energy sources (distance, supply path, accessibility). – Incorporate the related activities (storage of raw materials, of semi-finished products, and of finished products, management of consumables, quality control, etc.) in order to guarantee continuity for the workspaces. – Check that the location of the machine takes on board the design choices in terms of: accessibility, communications, continuity of production flow, and compatibility with environmental constraints (heat, cold, humidity, dust, bad weather, etc.).	– Do not be confined to the machine, but rather take account of its environment and of its links with the rest of the workshop. – Do not neglect arduous postures and large efforts, even for short or infrequent actions (e.g. for maintenance or feed needs). – Do not omit secondary or degraded operating modes.
OPERATING MODES	– To choose the operating modes that are appropriate to the tasks (production, maintenance) and to the operators (level of knowledge and experience, fatigue, etc.).	– Identify the interventions to be performed, including in foreseeable abnormal situations (production problems, cleaning, monitoring, adjustment, greasing, clearing jams, etc.). – Make sure that the interventions are really necessary (e.g. appropriate equipment can prevent or eliminate the risk of jamming). – Choose operator control and protection modes in such a manner that the operator: • retains control over the pace or the speed of operation of the machine during the interventions, e.g. by implementing "down times for maintenance";	– Avoid burdensome or wearisome operations because they generate shortcut strategies that are often hazardous. For example, all of the parts to be cleaned should be properly accessible and readily cleanable. – If tasks remain for which the operator absolutely has to intervene during operation, refer to the recommendations of the INRS document referenced ED 6129.
NOTE Information based on INRS ED 6154.			

Table B.1 *(continued)*

Aspect	Objectives	Some design guidance	Points requiring special care
		• is not required to concentrate for prolonged periods by incorporating sensors or appropriate devices for detecting malfunctioning; • can perform the task with greater ease, e.g. for high-frequency cycle triggering, do not use "two-handed" control.	
COMMUNICATIONS BETWEEN OPERATORS	– To make it possible for collective work and co-activity (task coordination) to take place. – To enable operators to have audio and visual exchanges side-by-side or remotely.	– List the communications to be provided. – Provide the means to enable those communications to take place: • by taking proper account of the "language" of the trade (codes and gestural signs of a group of operators); • by choosing interfaces that are appropriate (console or screen for written information, warning or indicator lights, sound signals, etc.) and accessible (nature, scope of the message, mental representation); • by placing the work stations so as to facilitate verbal and visual communications; • by removing or significantly reducing all sources of noise for verbal communications.	– Do not isolate operators by neglecting the necessity for exchange. – Do not underestimate the importance of the language of the trade. – Do not be limited to a single mode of communication, but rather make provision for several modes: written, verbal, and gestural for ensuring that information circulates better.
HUMAN-MACHINE INTERACTIONS	– To enable the operator to understand how the machine operates (its state, its interfaces, etc.) and to interact accordingly (concept of usability).	– Identify the information necessary and sufficient for controlling the machine (start-up, operation/driving, maintenance, diagnostics, and production management). – Choose the appropriate interfaces (control devices, signalling and dialogue devices, etc.) depending on the constraints, be they: • cognitive and physical, e.g. by providing assistance for diagnostics and for operating/driving, and by choosing intuitive controls (accessibility and cognitive availability), or	– Take into account the risks of malfunctioning (breakdown, erroneous indication) for information that is critical from the point of view of safety: e.g. giving an instruction to a valve does not mean that the instruction has been executed (the indicator light should not go from red to green, but rather from red to amber, and then from amber to green).
NOTE Information based on INRS ED 6154.			

Table B.1 *(continued)*

Aspect	Objectives	Some design guidance	Points requiring special care
		• environmental (cold, heat, vibration, humidity, etc.).	– Take account of foreseeable abnormal situations when choosing the interfaces. – Be limited to the most representative functions that are induced by the interface. – Do not make it possible for one function to be mistaken for another. – Do not propose simultaneous actions that are inconsistent.
DIMENSIONING OF THE WORK STATIONS	– To enable work positions to be appropriate and non-hazardous to health.	– Gather data on: • the tasks to be done (size and mass of objects to be handled, requirements relating to force, accuracy/precision, duration of the work, rate/throughput, position and nature of the controls, etc.); • the substances used and emitted (raw materials, finished products, waste, chippings, dust, etc.). – On the basis of this data, choose the main working position (sitting, raised-sitting, half-standing/half-sitting, standing), while also making it possible to alternate between positions in order to avoid prolonged static postures. – Design and fit out the work station in such a manner as to (cf. ISO 14738): • take into account the morphological variability of the operators (for example, make heights of work surfaces and of seats adjustable); • prefer keeping the most frequent gestures and positions within the comfort zones, and keep the other gestures and positions in the zones within reach; • enable the task to be performed while taking account of the relative movements of the operators (turning, stooping, backing off, etc.).	– Do not design work zones that are too confined, preventing the operator from moving easily, from having all of the tools and accessories available, and from benefiting from being assisted by a trainer.
NOTE Information based on INRS ED 6154.			

Table B.1 *(continued)*

Aspect	Objectives	Some design guidance	Points requiring special care
HANDLING AND EFFORTS	– To limit the handling and the efforts to be made by the operator during the various operations on the machine (transport, assembly/installation, production, maintenance, disassembly/removal, etc.).	– Identify the actions requiring efforts, and gather data on: • the masses to be manipulated (volume and weight, type of packaging, etc.); • the operating modes and the rate/throughput in order to determine the frequency of handling the objects and of the efforts to be exerted; • the control devices (efforts, position, etc.). – Evaluate the efforts and compare them with the allowable reference values (EN 1005 — 2 and 3) depending on the constraints present (wearing PPE, movement, ease of grasping, etc.). If those values are exceeded, design so as to: • limit the masses (choice of materials, choice of shapes, modular design, order of assembly, etc.). • facilitate the handling, e.g. by avoiding changes of level, by using assisted handling (trolleys, conveyor belts, ball tables, load balancers, etc.).	– Avoid manually handling unit loads that are bulky or difficult to take hold of. – Avoid carrying loads over long distances.
ACCESS	– To offer easy access to all locations where intervention is necessary.	– Identify all of the zones that require access and characterize them (frequency, nature of the intervention, number of people, wearing PPE, tools, energy needs, etc.). – Ask whether access is really necessary or whether it is necessary so frequently (e.g.: replace access for point-by-point greasing with centralised greasing, and more appropriate stocks of consumables). – Prefer same-level access; otherwise install permanent access means that are practical (ramps, stairs, lifts/elevators, etc.) and safe (appropriate dimensioning of the steps and platforms, guard rails, skirting boards, non-slip floor, etc.). – For large facilities, lay out paths/walkways, footbridges, or overhead walkways (for crossing over conveyors, for example). – Dimension the passage openings (manholes, inspection trapdoors, etc.) so as to enable the operations to be conducted easily.	– When identifying accesses, do not forget the intervention needs such as: adjustments, changes in manufacturing process, defect detection, cleaning, training, etc. – Do not forget access for exceptional interventions, such as for replacing an overhead motor or engine. In which case, the use of appropriate means such as articulating boom lifts or elevator platforms should be defined in the instruction manual. The location and the shape of the machine should enable it to be used safely.
NOTE Information based on INRS ED 6154.			

Table B.1 *(continued)*

Aspect	Objectives	Some design guidance	Points requiring special care
		Commercial documents – Check that they are not in contradiction with the instruction manual. – Indicate the emission information on the documents (concerning emission of noise, vibration, hazardous radiation, toxic substances, etc.).	
INFORMATION FOR USERS	– To inform any person who might intervene about the conditions and procedures for use, in clear and unequivocal manner	– List all of the instructions necessary for the machine to be used correctly and safely at all stages of its life cycle (transport, assembly/installation, production, maintenance, disassembly/removal, etc.). – Present them to operators in understandable manner: standardised symbols, pictograms, texts in an appropriate language for the users and easy to read. – Choose their location: commercial documents, instruction manual, packaging, machine, etc.	– Do not draft information about use at the last minute. It should be established and validated throughout the design of the machine. – Do not forget to list all of the instructions necessary for the machine to be used correctly and safely at all stages of its life cycle (transport, assembly/installation, production, maintenance, disassembly/ removal, etc.). – Do not neglect to present them to operators in understandable manner: standardized symbols, pictograms, texts in an appropriate language for the users and easy to read. – Do not omit to choose their location: commercial documents, instruction manual, packaging, machine, etc.
		On the machine or on the packaging: – The written information should be readily accessible, legible, and indelible. *Visual or audio signals, viewing screens and other communications means are addressed under the aspect "communications between operators".*	
		In the instruction manual – Explain uncommon technical terms clearly. – Include all items helping understanding (illustrations, figures, diagrams, photos, animations, etc.). – Adapt the medium (CD-ROM, Internet, paper, etc.) to suit the conditions of use by the operators. In all cases, supply a hard copy (paper) version.	
NOTE Information based on INRS ED 6154.			

Table B.1 *(continued)*

Aspect	Objectives	Some design guidance	Points requiring special care
LIGHTING	– To provide lighting appropriate to the requirements of the work: need for accuracy/precision, appearance inspection, maintenance, etc.	– Design the machine so that it takes fullest advantage of the ambient lighting (natural and artificial) of the place of location (outdoors, workshop, tunnel, etc.). – Opt for matt or satin-finish surfaces so as to avoid sources of dazzle. – For each zone of activity, define the required level of lighting (intensity, and colour temperature). – Incorporate lighting where the ambient lighting of the workplace is not adapted to suit the activity. – Choose lighting whose position and/or intensity can be adjusted. – Integrate emergency lighting if necessary (e.g. for machines of large size).	– Lighting of moving elements can constitute sources of stroboscopic effects. – Make the lighting devices accessible for being serviced (cleaning and replacement).
POLLUTION AND DISCOMFORT GENERATED BY THE MACHINE	– To reduce all of the pollution and discomfort generated by the machine in order to make such pollution and discomfort compatible with the safety and health of the operators.	– Identify all of the pollution and discomfort generated by the machine (noise, vibration, radiation, toxic substances, etc.) in its various operating modes: production, maintenance, adjustment, cleaning, etc. – Use products, equipment and processes making it possible to eliminate the pollution and discomfort, or, failing that, to minimize the effects thereof.	– The exposure limit values are regulatory markers. Designers should seek to keep significantly below those values when they cannot remove the risk.
NOTE Information based on INRS ED 6154.			

Annex C
(informative)

Ergonomics standards for specific applications

Table C.1 — Ergonomics standards for specific applications

Ergonomics standards for specific applications — Control centres
ISO 11064-1:2000, *Ergonomic design of control centres — Part 1: Principles for the design of control centres*
ISO 11064-2:2000, *Ergonomic design of control centres — Part 2: Principles for the arrangement of control suites*
ISO 11064-3:1999, *Ergonomic design of control centres — Part 3: Control room layout*
ISO 11064-4:2013, *Ergonomic design of control centres — Part 4: Layout and dimensions of workstations*
ISO 11064-5:2008, *Ergonomic design of control centres — Part 5: Displays and controls*
ISO 11064-6:2005, *Ergonomic design of control centres — Part 6: Environmental requirements for control centres*
ISO 11064-7:2006, *Ergonomic design of control centres — Part 7: Principles for the evaluation of control centres*
Ergonomics standards for specific applications — Human system interaction
ISO/TR 9241-100:2010, *Ergonomics of human-system interaction — Part 100: Introduction to standards related to software ergonomics*
ISO 9241-210:2010, *Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems*
ISO 9241-300:2008, *Ergonomics of human-system interaction — Part 300: Introduction to electronic visual display requirements*
ISO 9241-400:2007, *Ergonomics of human–system interaction — Part 400: Principles and requirements for physical input devices*
Ergonomics standards for mobile machinery
ISO 2860:1992, *Earth-moving machinery — Minimum access dimensions*
ISO 2867:2011, *Earth-moving machinery — Access systems*
ISO 3411:2007, *Earth-moving machinery — Physical dimensions of operators and minimum operator space envelope*
ISO 6682:1986, *Earth moving machinery — Zones of comfort and reach for controls*
ISO 11112:1995, *Earth-moving machinery — Operator's seat — Dimensions and requirements*
ISO 21281:2005, *Construction and layout of pedals of self-propelled sit-down rider-controlled industrial trucks — Rules for the construction and layout of pedals*
See also CEN/TR 614–3.

