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Machine tools — Environmental evaluation of machine tools —

Part 2: Methods for measuring energy supplied to machine tools and machine tool components

Machines-outils — Évaluation environnementale des machines-outils —

Partie 2: Méthode pour mesurer l'énergie apportée aux machines-outils et aux composants de machines-outils

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Foreword

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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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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 39, *Machine tools*.

A list of all parts in the ISO 14955 series can be found on the ISO website.

Introduction

As environmental impact is a common challenge for all products and as natural resources become scarce, environmental performance criteria for machine tools need to be defined and the use of these criteria needs to be specified.

Machine tools are complex systems used by industry to manufacture “ready for use” products or semi-finished workpieces. Their environmental impact includes wasted raw material, use of auxiliary substances such as lubricants and other material flows, as well as conversion of electrical energy into heat, dissipation of heat to the ambient or heat exchange by fluids and possibly the use of other resources such as compressed air. Based on relevance considerations, the ISO 14955 series is focussed on environmental impacts related to the energy supplied to the machine tool during the use stage.

The performance of a machine tool as key data for investment is multi-dimensional regarding its economic value, its technical specification and its operating requirements which are influenced by the specific application. The energy supplied to the same machine tool can vary depending on the part which is being manufactured and the conditions under which the machine tool is operated. Therefore, the environmental evaluation of a machine tool cannot be done regardless of these aspects.

ISO 14955-1 describes a methodology for the environmental evaluation of machine tools and gives reasons for measuring energy supplied to the machine tool.

ISO 14955-3 to ISO 14955-5 describe the application of ISO 14955-1 and ISO 14955-2 to specific groups of machine tools.

Machine tools — Environmental evaluation of machine tools —

Part 2: **Methods for measuring energy supplied to machine tools and machine tool components**

1 Scope

This document describes how measurements are made by providing measuring methods in order to produce reproducible data about the energy supplied to a machine tool under specified conditions. Furthermore, it provides methods to quantify the energy supplied to components in order to assign their share to generalized machine tool functions as described in ISO 14955-1.

It supports the energy-saving design methodology according to ISO 14955-1 by providing measuring methods for the energy supplied to machine tools. The assignment of the energy supplied to machine tool functions requires measurements at machine tool component level. These measurements need to be reproducible and independent of conditions other than those being recorded and documented.

The results of the measurements are intended to document improvements to the design, specifically under energy aspects, and/or to allow evaluating the energy involved in the manufacturing of a given part by a given machine tool. Any comparison requires identical conditions and ensures by specification and measurement that similar results are achieved.

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 1217, *Displacement compressors — Acceptance tests*

ISO 8778, *Pneumatic fluid power — Standard reference atmosphere*

ISO 14955-1:2017, *Environmental evaluation of machine tools — Part 1: Design methodology for energy-efficient machine tools*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14955-1 and the following apply.

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

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

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

3.1
average electrical power
average value of active electrical power for a given period in time

Note 1 to entry: Definitions for the measurement of electric power quantities under sinusoidal, non-sinusoidal, balanced, or unbalanced conditions are available in IEEE 1459-2010[13].

3.2
electrical energy
active electrical power integrated over a given period of time

3.3
electrical energy equivalent
electrical energy (3.2) necessary to provide any other form of energy supplied to the *machine tool* (3.4)

3.4
machine tool
mechanical device which is fixed (i.e. not mobile) and powered (typically by electricity and compressed air), typically used to process workpieces by selective removal/addition of material or mechanical deformation

Note 1 to entry: Machine tools operation can be mechanical, controlled by humans or by computers. Machine tools may have also a number of peripherals used for machine tool cooling/heating, process conditioning, workpiece and tool handling (workpiece feeding excluded), recyclables and waste handling and other tasks connected to their main activities.

[SOURCE: ISO 14955-1:2017, 3.16]

3.5
machine tool component
mechanical, electrical, hydraulic, or pneumatic device of a *machine tool* (3.4), or a combination thereof

[SOURCE: ISO 14955-1:2017, 3.13]

3.6
machine tool function
machine tool (3.4) operation (machining process, motion and control), process conditioning, workpiece handling, tool handling or die change, recyclables and waste handling, machine tool cooling/heating

Note 1 to entry: Any machine tool function may be realized by one *machine tool component* (3.5) or by a combination of machine tool components. Some machine tool components may realize more than one machine tool function.

Note 2 to entry: Machine tool functions may be used for identifying machine tool components relevant for energy supplied to the machine tool.

[SOURCE: ISO 14955-1:2017, 3.12, modified — The Note 2 to entry has been deleted and the Note 3 to entry has become Note 2 to entry.]

3.7
evaluation period
continuous time interval in which the energy supplied and the result obtained are quantified

3.8
operating state
combination of ON, HOLD and OFF etc., settings of mains, peripheral units, *machine tool* (3.4) control, machine tool processing unit and machine tool motion units including relevant machine tool activities

Note 1 to entry: Peripheral units are, for example, units for machine tool cooling/heating, process conditioning, workpiece and tool handling, recyclables, and waste handling.

Note 2 to entry: Machine tool processing units are, for example, main spindle of a turning machine, tool spindle of a machining centre, generator for electro-discharge machine, slide of a press, draw cushions of a press.

Note 3 to entry: Machine tool motion units are, for example, linear axes of a turning machine, linear and rotary axes of a machining centre, linear axes of a wire electro-discharge machine.

Note 4 to entry: Reference to operating states (e.g. OFF, STANDBY, EXTENDED STANDBY, WARM UP, READY FOR PROCESSING, PROCESSING and CYCLING) requires definition of these states. An example for such a definition for a metal-cutting machine tool is given in ISO 14955-1:2017, Annex C.

Note 5 to entry: Examples of machine tool activities are tool loading, workpiece loading, axes movements, waiting, machining or cycling, or complete test cycles.

Note 6 to entry: Depending on the operating state and the machine tool activities, a mode of operation is selected as defined by relevant safety standards of machine tools.

[SOURCE: ISO 14955-1:2017, 3.7, modified — The reference in Note 4 to entry has been updated.]

3.9
pneumatic energy
energy supplied by a flux of compressed air

3.10
shift regime
set of operating states and their time shares within an evaluation period

3.11
machine tool activity
set of operations of a *machine tool* (3.4) in operating states other than OFF

Note 1 to entry: Machine tool activities are caused by a defined control input to the machine tool by the user such as setting of a parameter or starting a program.

Note 2 to entry: Examples for machine tool activities are tool loading, workpiece loading, axes movement at specified speed and acceleration, machining or cycling, or complete test cycles (with relevant parameters specified).

4 System and machine tool state description

4.1 General

To perform the energy assessment, the system and the state of the machine tool shall be described. The description of the system is suggested in Clause 6. The machine tool state is the result of three distinct but not necessarily independent types of influences:

— ambient conditions;

— operating states;

— machine tool activity.

A complete statement shall comprise the system description and the state of the machine tool, characterized by ambient conditions, operating state and machine tool activity. Measurements shall be documented accordingly.

4.2 Ambient conditions

Measurements should be made at a stable ambient temperature, preferably at 20 °C. Ambient temperature and its fluctuations shall be monitored and reported in terms of average value and its variation (e.g. standard deviation or minimum/maximum values). Other ambient conditions, if relevant, shall be reported (e.g. humidity, direct sunlight, heat transfer).

4.3 Operating states and machine tool activity

Operating states result from the selection of a mode of operation and, eventually, from the introduction of further parameters by the operator, putting the machine tool in a desired state. The machine tool may include provisions to switch automatically to a particular operating state when default conditions, such as changing to STANDBY some time after finishing a part cycle and being unattended, are reached.

The transition from one operating state to another shall be considered as a separate operating state if the assumed amount of energy supplied has a relevant share, e.g. the transition from OFF to READY FOR PROCESSING, if the machine tool passes through a compulsory warm-up cycle.

Examples of operating states are OFF, transition from STANDBY to READY FOR PROCESSING, STANDBY, READY FOR PROCESSING or CYCLING, PROCESSING or CYCLING, and transition from STANDBY to OFF.

DOWN BY FAILURE due to process failure or due to an emergency stop may be a relevant machine tool operating state to be included in the evaluation. Definitions of operating states depend on the specific machine tool and shall be documented (see ISO 14955-1:2017, Annex C).

4.4 Machine tool activity

Within an operating state and under stable ambient conditions, the energy supplied to the system can depend on the machine tool activity. For certain operating states such as OFF or STANDBY, the machine tool activity can depend on default settings. For others, such as READY FOR PROCESSING or PROCESSING, the machine tool activity, comprising the set up with tools and parts, and programming by the operator strongly influence the energy supplied to the system.

NOTE 1 Different machine tool activities can require certain modes of operation as laid down in safety standards for machine tools.

NOTE 2 For sample or reference machine tool activities for testing, refer to subsequent parts of ISO 14955.

5 Test scenarios

5.1 General

Energy supplied to machine tools depends on the actual use. The test scenario depicts the prescribed sequence of machine tool operating states, further on called “shift regime”, and, if necessary, the corresponding machine tool activities (typically for the PROCESSING state). The scenario may include non-productive times, such as organizational downtime, maintenance time and others. The shift regime shall be determined according to the actual use of the machine tool in the field (e.g. based on information acquired by data logging systems).

Test scenarios can be defined in two ways. Either they consider a generic production mission for that machine kind, i.e. a machine-based test scenario, optionally referring to a specific application sector (e.g. for a milling machine, automotive or mould and dies sectors). Or they refer to a specific manufacturing task (e.g. a customer production), further on called “task-based test scenario”.

NOTE Machine-based test scenarios are proposed in subsequent parts of ISO 14955.

5.2 Machine-based test scenario

5.2.1 General

Machine-based test scenarios require the definition of shift regimes and corresponding machine tool activities.

5.2.2 Sample shift regime

The sample shift regime illustrates how to describe and manage the reference sequence of machine tool operating states. It reflects a simplified and clustered industrial use scenario with an average of 2,5 shifts, a selection of three characteristic operating states with one machine tool activity each and an assumed time share for PROCESSING of 80 %. The default evaluation period is 24 h (see Figure 1, Table 1).

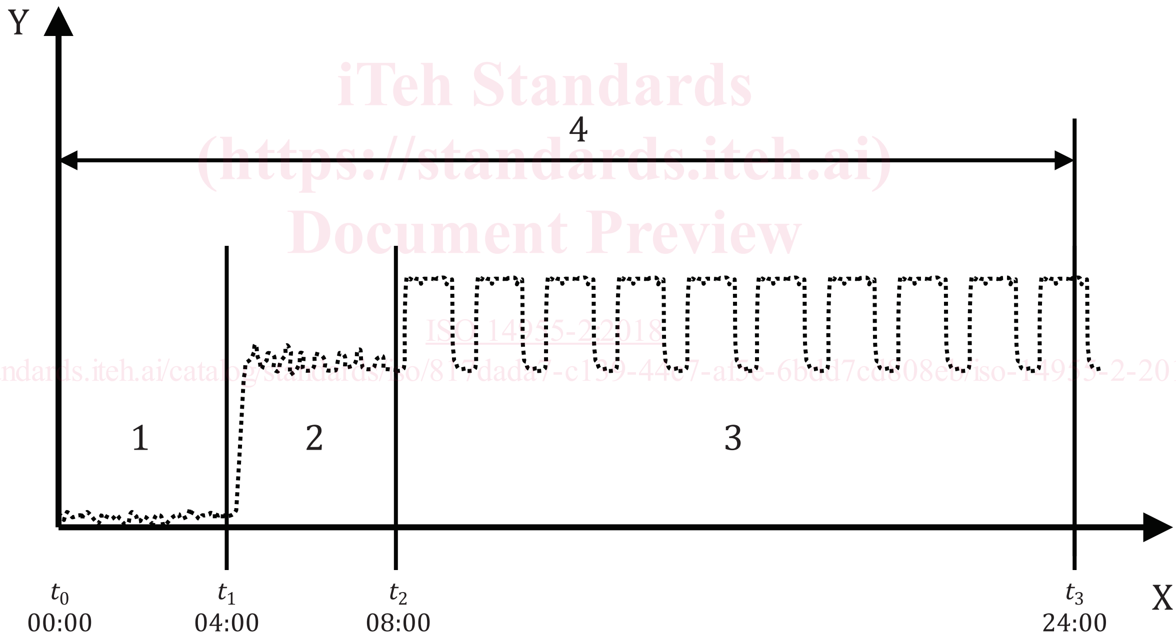
NOTE 1 The measuring period can be significantly shorter than the evaluation period, see 7.7.

NOTE 2 The energy supplied in the operating state OFF can be significant, in particular for resources other than electricity.

Table 1 — Sequence of operating states for the sample shift regime

	Duration	Operating state	Machine tool activity
1	4 h (0,5 shifts)	OFF The operating state OFF or the operating state commonly used when the machine tool is unattended and not producing for more than one hour.	None.
2	4 h (0,5 shifts)	READY FOR PROCESSING	The machine tool is ready to start machining immediately, as an indicative value within 10 s.
3	16 h (2,0 shifts)	PROCESSING	Typical machining cycle with or without a part being machined.

If a part is being machined, process parameters (e.g. depth of cut, cutting speed, feed speed, type of tool, tool condition), raw part (e.g. type of material, pre-processing of part including tolerances of pre-machined surfaces), machining time and tolerances for machined surfaces (e.g. tolerances for diameters, for position and orientation, for form, for roughness) shall be specified.



Key

1 OFF
2 READY FOR PROCESSING
3 PROCESSING
4 evaluation period
X time, in h
Y power, in W

Figure 1 — Illustration of power measurement during a sample shift regime

5.2.3 Specific shift regime

5.2.3.1 Motivation

Specific shift regimes shall be applied in cases where use scenarios and/or typical operating states differ significantly from the sample shift regime. They may be suggested by the manufacturer/supplier or result from an agreement between the manufacturer/supplier and the user. Specific shift regimes shall be determined according to the actual or intended use of the machine tool, i.e. based on operating data or on operating schedules. Operating states other than stated in 5.2.2 may be considered (e.g. warm-up periods). The evaluation period shall be determined such as to minimize the influence of power fluctuations caused by temperature gradients, switching and control of peripherals and any other transients.

Time share and sequence of each operating state and/or each machine tool activity shall be defined.

5.2.3.2 Clustering of time shares for specific shift regimes

In some cases, the actual use of the machine consists of a sequence with numerous changes of operating states and machine tool activities, as depicted in the example of Table 2. If, by expert judgement, transients can be assumed to be negligible, or when they are considered as a separate operating state, scattered time shares of each sequence of operating states and machine tool activity can be clustered to a single share of the evaluation period for the chosen shift regime, as depicted for the same example in Table 3. Operating states and machine tool activities are classified and numbered (e.g. 0, 1-0, 1-1, 2-0, 2-1) for easier clustering. The purpose of clustering is the simplification of the shift regime in order to facilitate measuring and assessment.

Table 2 — Example for time shares of operating states and machine tool activities within a specific shift regime

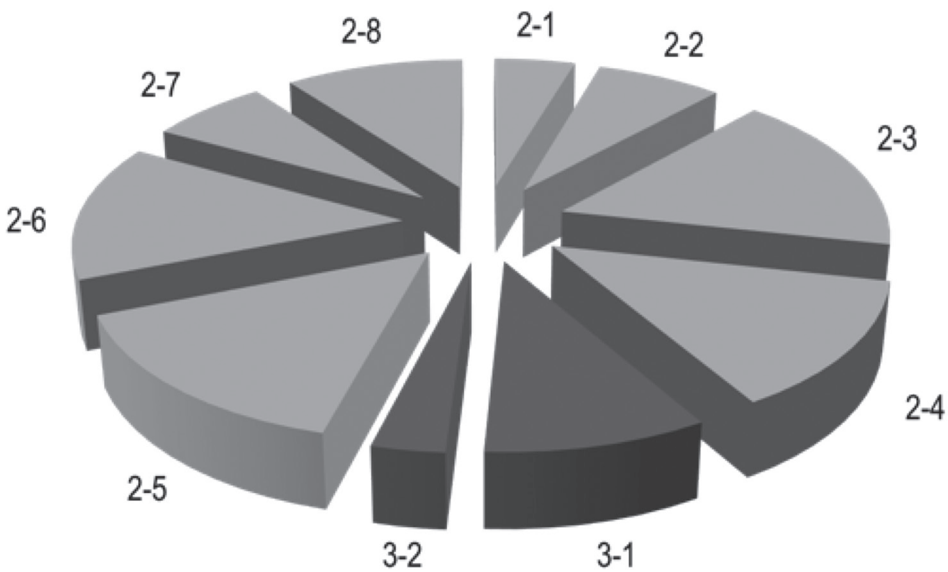
<table>
<tr><th>Operating state</th><th colspan="2">READY FOR PROCESSING</th><th colspan="7">PROCESSING</th><th>OFF</th><th>READY FOR PROCESSING</th><th colspan="2">PROCESSING</th><th colspan="2">READY FOR PROCESSING</th></tr>
<tr><td>Operating state number</td><td colspan="2">2</td><td colspan="7">3</td><td>1</td><td>2</td><td colspan="2">3</td><td colspan="2">2</td></tr>
<tr><td>Machine activity number</td><td>1</td><td>2</td><td colspan="2">1</td><td colspan="2">2</td><td>1</td><td>2</td><td>1</td><td>1</td><td>2</td><td colspan="2">1</td><td>2</td><td>1</td></tr>
<tr><td>Evaluation period</td><td colspan="15">10 h</td></tr>
<tr><td>Time of day</td><td>06:00 to 07:00</td><td colspan="2">07:00 to 08:00</td><td colspan="3">08:00 to 09:00</td><td>09:00 to 10:00</td><td colspan="2">10:00 to 11:00</td><td>11:00 to 12:00</td><td>12:00 to 13:00</td><td>13:00 to 14:00</td><td>14:00 to 15:00</td><td colspan="2">15:00 to 16:00</td></tr>
<tr><td>Duration (h)</td><td>1</td><td>0,5</td><td>0,5</td><td colspan="2">0,5</td><td>0,5</td><td>1</td><td>0,5</td><td>0,5</td><td>1</td><td>1</td><td colspan="2">2</td><td>0,5</td><td>0,5</td></tr>
</table>

Table 3 — Example for clustering of operating states and machine tool activities within a specific shift regime

Evaluation period	10 h				
Clustered shift regime	OFF number 1–1 1,0 h	READY FOR PROCESSING number 2–1 1,5 h	READY FOR PROCESSING number 2–2 2,0 h	PROCESSING number 3–1 4,5 h	PROCESSING number 3–2 1,0 h

5.2.3.3 Determination of specific shift regimes

As an example, Figure 2 presents the different operating states and machining activities for air-bending processes on a press brake. In this case, the actual bending operation (operating state 3-1) takes less than 10 % of the total production time[11].



Key

2–1 tool setup: get tool, change and carry away
2–2 preparation on PC: load new order from central server and programming or adapting bending program
2–3 supporting task: move pallets, rearrange sheets, counting, administrative tasks
2–4 loading new sheet: take a new sheet and position it against back gauge
3–1 punch moving downwards and bending: actual bending process
3–2 punch moving upwards
2–5 intermediate action: consult instruction screen and part handling between two bends
2–6 workpiece transport: put workpieces away and rearrange them
2–7 workpiece measure: measure the workpiece
2–8 human needs and distraction: being absent, non-productive human reasons

Figure 2 — Operating states and machine tool activities for air-bending processes[11]

In this case, the use scenario differs significantly from the sample shift regime.

— A variety of machine tool activities take place in the operating state READY FOR PROCESSING, with a time share of 77,2 %:2-1, 2-2, 2-3, 2-4, 2-5, 2-6, 2-7.

— The time share of PROCESSING is 12,5 %: 3-1, 3-2.

— Manual operation causes idle time for human needs and distraction in the operating state READY FOR PROCESSING with a time share of 10,2 %:2-8.

These states comprise occupied time only, i.e. no operating state OFF. Due to necessary human presence, the use scenario is based on two shifts only. A specific shift regime may therefore be composed as depicted in Table 4, comprising one shift of 8 h in the operating state OFF.

Table 4 — Example for specific shift regime for an air bending machine tool according to Figure 2

Evaluation period: 24 h		
OFF: 8 h	READY FOR PROCESSING: 14 h number 2–1, 2–2, 2–3, 2–4, 2–5, 2–6, 2–7, 2–8	PROCESSING: 2 h number 3–1, 3–2

5.2.3.4 Reduced shift regimes

In addition to the clustering of time shares, shift regimes may be further simplified to reduced shift regimes in two ways.

Machine tool activities and/or operating states with a similar energy supplied during a given time interval may be summarized, as shown in the example in 5.2.3.3.

Operating states with little impact on the total of energy supplied to the machine tool may be omitted. As an example, if a machine tool has a dedicated operating state for tool change, which is, for the case given, rarely used, and average power in this operating state is not significantly higher than in any other operating state, this operating state may be omitted. An indicative value for rareness is 1 % of the evaluation period, or 15 min per 24 h.

5.3 Task-based test scenario

Task-based test scenarios shall be derived from a given application (e.g. a machine tool specifically configured for the production of one part or a part family). Task-based test scenarios shall be agreed upon between manufacturer/supplier and user.

The definition of the task shall comprise a specification of the part geometry and of the features, of the part quality and of the permissible machining time. Tolerances and times shall be measured, treatment of parts out of tolerance shall be defined (e.g. addition of energy in parts, including material, as parts out of tolerance are waste) and treatment of machining times beyond the specified maximum shall be defined, i.e. comparison of excessive machining times with times within specification. The design of the production process shall include necessary non-productive times, as depicted in Figure 3.