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Machine tools — Environmental evaluation of machine tools —

Part 3:
Principles for testing metal-cutting machine tools with respect to energy efficiency

Machines-outils — Évaluation environnementale des machines-outils —

Partie 3: Principes des essais des machines travaillant par enlèvement de métal à l'égard de l'efficacité énergétique

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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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For an explanation of 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 www.iso.org/iso/foreword.html.

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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

Introduction

Machine tools are complex products for industrial use to manufacture parts ready for use or semi-finished products. 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. Therefore, the same machine tool can show quite different energy supplied to the machine depending on the part which is manufactured and the conditions under which the machine is operated. Therefore, the environmental evaluation of a machine tool cannot be considered in isolation from these considerations.

ISO 14955-1 defines an analysis and evaluation procedure for machine tools based on functional units with the intention of a unified approach. ISO 14955-1 enables simplified and general evaluation methods in order to define and assess the energetic behaviour and the individual energetic and/or efficiency weaknesses of a machine tool.

ISO 14955-2 defines the required parameters and procedures for machine tool and machine tool component measurement, including required parameters which are relevant for the assessment of the energetic machine tool behaviour.

The reference scenario introduced in this part reflects the actual machine process in the field under best knowledge. The definition of the reference scenario and its measurement helps to indicate application-dependent improvement potential and the application of the methodology as defined in ISO 14955-1 and related improvement measures for given industrially driven applications.

The ISO 14955 series takes care of relevant environmental impacts during the use stage. Aside from the design and engineering of machine tools, the intended utilization of machine tools is addressed by this document.

Machine tools — Environmental evaluation of machine tools —

Part 3: Principles for testing metal-cutting machine tools with respect to energy efficiency

1 Scope

This document supports the energy-saving design methodology according to ISO 14955-1 and the methods for measuring energy supplied to machine tools and machine tool components defined in ISO 14955-2. This document addresses the environmental evaluation of machine tools during the use stage based on reference scenarios. It contains an example for metal cutting machine tools.

This document defines a methodological approach to assess relevant machine tool operating states based on an individual reference scenario for the energy assessment of machine tools and the integration of energy-efficiency aspects into machine tool design.

This document explains what needs to be measured in line with ISO 14955-1 and ISO 14955-2. Furthermore, it shows how a reference scenario for the measurement of the machine function "processing", according to ISO 14955-1, is evaluated.

An example of how to use this document is given in Annex A.

The results from applying this document are influenced by the effect of user behaviour and manufacturing strategies during the use phase. This document does not support the comparison of machine tools.

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

ISO 14955-2:2018, *Machine tools — Environmental evaluation of machine tools — Part 2: Methods for measuring energy supplied to machine tools and machine tool components*

DIN 8580:2003, *Manufacturing processes — Terms and definitions, division*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14955-1, ISO 14955-2 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 http://www.electropedia.org/

3.1
reference part
workpiece with defined specification of geometry, material, size, geometric tolerances, surface quality and defined related manufacturing procedure

Note 1 to entry: The reference part is a determined number of geometric elements in given composition and dimension which are manufactured under defined operating states (see [8]).

3.2
reference scenario
individually defined manufacturing process, containing the definition of part handling and the environmental conditions to achieve an individual *reference part* (3.1)

Note 1 to entry: The reference scenario covers machine based and task-based scenarios according to ISO 14955-2:2018.

3.3
discrete part manufacturing
production process in which its output is individually countable, or identifiable by serial numbers, and is measurable in distinct units rather than by weight or volume

Note 1 to entry: Term used in distinction to process manufacturing, e.g. of substances such as plastics, food, beverages or pharmaceuticals.

3.4
mass production
large-scale production
manufacturing of large quantities of standardized products, frequently utilizing assembly line technology

Note 1 to entry: Mass production refers to the process of creating large numbers of similar products efficiently. Mass production is typically characterized by some type of automation, as with an assembly line, to achieve high volume, the detailed organization of materials flow, careful control of quality standards and division of labour.

3.5
tool
device for imparting a desired shape, form, or finish to a material

Note 1 to entry: The desired shape can be achieved by different means, e.g. by material removal, forming, shaping.

3.6
shop floor production
job shop
fabrication-outfit specializing in small quantities of custom-made parts, produced according to customer specifications

Note 1 to entry: Usually, in shop floor production, there is no workpiece defined between machine tool builder/supplier and machine tool user at the time of machine tool acquisition.

Note 2 to entry: In shop floor production, time shares are strongly related to the specific production being executed. A typical utilization of a machine tool in a shop floor production is 8 h/day for 5 days/week.

3.7
energy performance indicator
EnPI
measure or unit of energy performance, as defined by the organization

Note 1 to entry: EnPI(s) can be expressed by using a simple metric, ratio or a model, depending on the nature of the activities being measured.

Note 2 to entry: See ISO 50006 for additional information on EnPI(s)[4].

Note 3 to entry: Examples for organizations are manufacturer, supplier and user.

[SOURCE: ISO 50001:2018, 3.4.4]

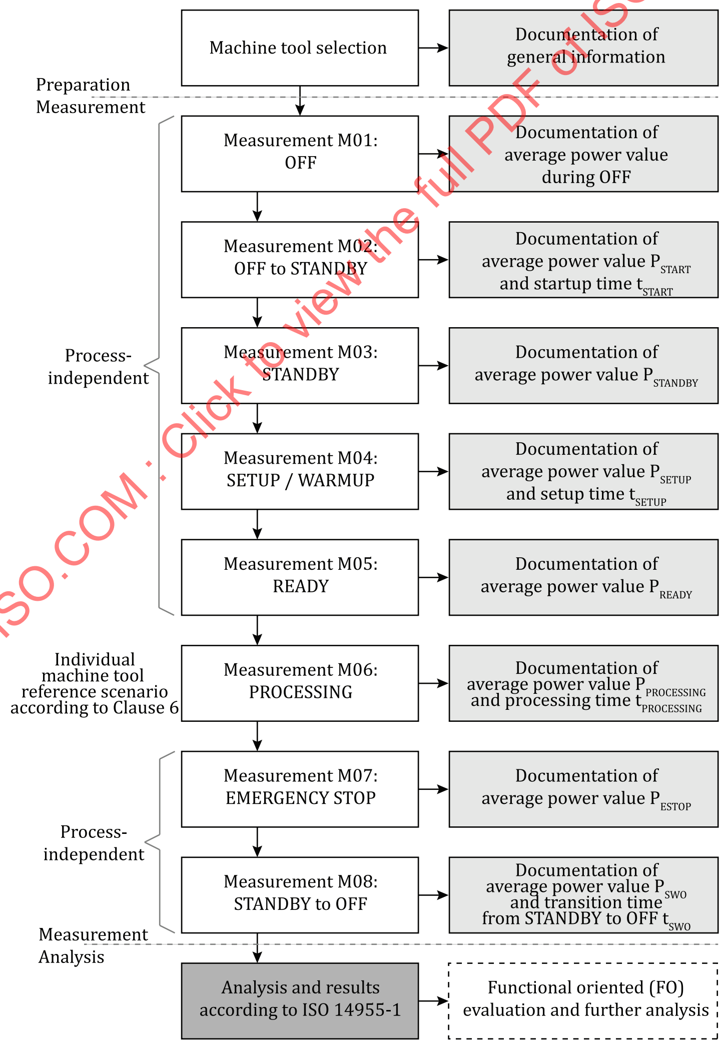
4 General approach for the environmental evaluation of machine tools

4.1 General

This clause describes the procedure for the environmental evaluation of machine tools according to ISO 14955-1. This approach requires the measurement of all possible operating states of the machine tool, including the reference scenario, as defined in Clause 6. Based on this assessment, relevant machine tool operating states can be indicated and assessed and the functional oriented analysis according to ISO 14955-1 can be performed.

Stable conditions are assumed if the difference of the average of the measured value over two measurement periods is not larger than 100 W or ±5 % of the connected load (nominal power).

Figure 1 shows the general approach for the environmental evaluation of machine tools. Detailed information is given in 4.2 to 4.10. Clause 5 shows the results and further assessments based on the performed machine tool measurement.



NOTE STANDBY is a stable state after machine tool is turned ON. This state can include heating on some machine tools.

Figure 1 — General approach for the environmental evaluation of machine tools

In 4.2 to 4.10, each step is explained in detail.

4.2 Step 1 — Documentation of general information

The following table shows the information that shall be given for the intended machine tool assessment.

Table 1 — General information

Information	Description
Company	Company and location where the machine tool is measured
Responsible person	Person in charge of machine tool assessment and measurement service provider (if different from company)
Machine tool manufacturer/ model/serial number	Name and serial number indicating the type and configuration setup of the machine tool
System boundary	According to ISO 14955-2:2018, Clause 6.
Nominal power [kW]	Nominal power [kW] as declared by the machine tool manufacturer
Temperature/humidity during measurement	Indication of conditions during measurement. In order to proof stable conditions the values should be documented at least every 30 min during the measurement
Date and time	Date of performed measurement and duration of the measurement

4.3 Step 2 – Measurement of machine tool state OFF — M01

4.3.1 Description

The power, P_{OFF} [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool are measured during OFF. The main switch is off. The measurement shall be performed when steady-state conditions are reached and should last for at least 300 s (default value). If this condition is not fulfilled, measurements shall last longer.

NOTE This measurement aims to indicate compressed air leakage and/or active components during OFF, e.g. monitoring modules. This machine tool state is independent of the process.

4.3.2 Measurements

Measurement of power during machine tool state OFF, as exemplified in Figure 2.

Key

P power [kW]

t time [s]

P_{OFF} average power [kW] during machine tool state OFF

t_{OFF} measurement time [s] during machine tool state OFF

Figure 2 — Example of measurement of power during machine tool state OFF

4.3.3 Documentation

Table 2 shows the required values for machine tool state OFF.

Table 2 — Required values for machine tool state OFF

Required value	Unit	Description
P_{OFF}	kW	Average power during machine tool state OFF
t_{OFF}	s	Default value is 300 s. It is required to document the duration of the measurement, even if it is equal to the default duration.

4.4 Step 3 — Measurement of transition from machine tool state OFF to STANDBY (START) — M02

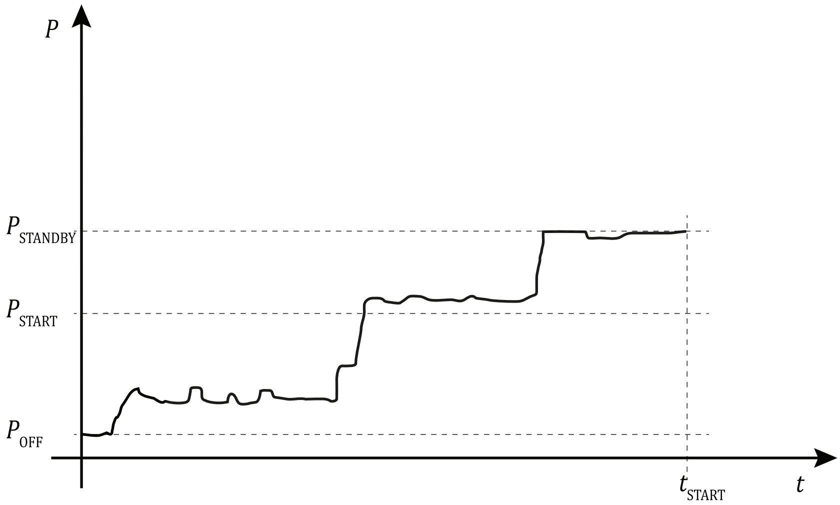
4.4.1 Description

The power, P_{START} [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool is measured during the transition from OFF to STANDBY. The main switch is turned from OFF to ON. The machine starts up until it reaches a steady state (STANDBY). P_{START} represents the average power value during machine tool start up. This measurement does not contain axis reference or any movement of axis.

NOTE This measurement aims to indicate the required time for machine tool start-up and related component activity. The duration of the start-up depends on the machine tool.

4.4.2 Measurements

Measurement of power during transition from machine tool state OFF to STANDBY, as exemplified in Figure 3.



Key

P	power [kW]
t	time [s]
P_{OFF}	average power [kW] during machine tool state OFF
P_{START}	average power [kW] during transition from machine tool state OFF to machine tool state STANDBY
$P_{STANDBY}$	average power [kW] during machine tool state STANDBY
t_{START}	duration of transition from machine tool state OFF to machine tool state STANDBY

Figure 3 — Example of measurement of power during transition from machine tool state OFF to STANDBY

4.4.3 Documentation

Table 3 shows the required values for transition from machine tool state OFF to STANDBY.

Table 3 — Required values for transition from machine tool state OFF to STANDBY

Required value	Unit	Description
P_{START}	kW	Average power during transition from machine tool state OFF to STANDBY
t_{START}	s	Duration of transition from machine tool state OFF to STANDBY. This duration depends on the machine tool.

4.5 Step 4 — Measurement of machine tool state STANDBY — M03

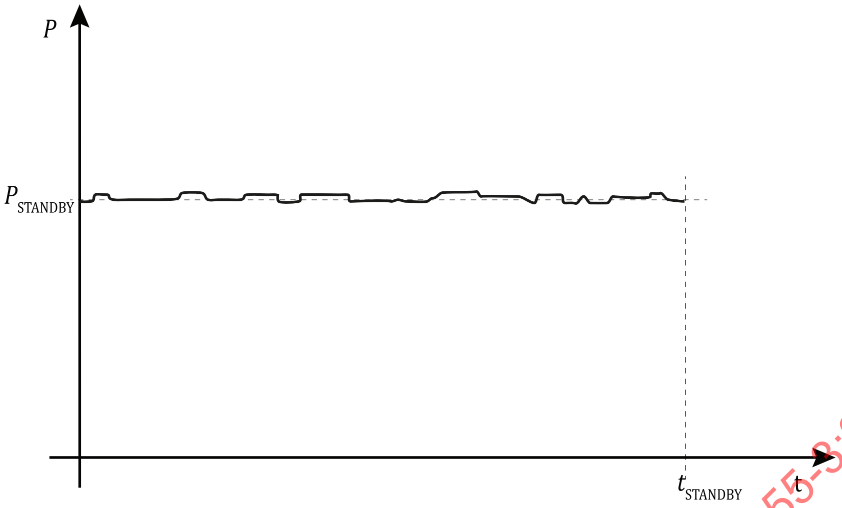
4.5.1 Description

The power, $P_{STANDBY}$ [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool are measured during STANDBY. The machine tool is in a steady state. The measurement should be performed in stable conditions for a time, $t_{STANDBY}$, of 300 s (default value). Measurement should be performed when stable conditions are reached, for a time, $t_{STANDBY}$, of at least 300 s (default value). If none of these conditions are fulfilled, measurement shall last longer.

NOTE This measurement aims to indicate the required average power during machine tool standby including related component activity. This state is independent of the process.

4.5.2 Measurements

Measurement of power during machine tool state STANDBY, as exemplified in Figure 4.



Key

P power [kW]

t time [s]

$P_{STANDBY}$ average power [kW] during machine tool state STANDBY

$t_{STANDBY}$ measurement time [s] during machine tool state STANDBY

Figure 4 — Example of measurement of power during machine tool state STANDBY

4.5.3 Documentation

Table 4 shows the required values for machine tool state STANDBY.

Table 4 — Required values for machine tool state STANDBY

Required value	Unit	Description
$P_{STANDBY}$	kW	Average power during machine tool state STANDBY
$t_{STANDBY}$	s	Default value is 300 s. It is required to document the duration of the measurement even if it is equal to the default duration.

4.6 Step 5 — Measurement of machine tool state SETUP/WARMUP — M04

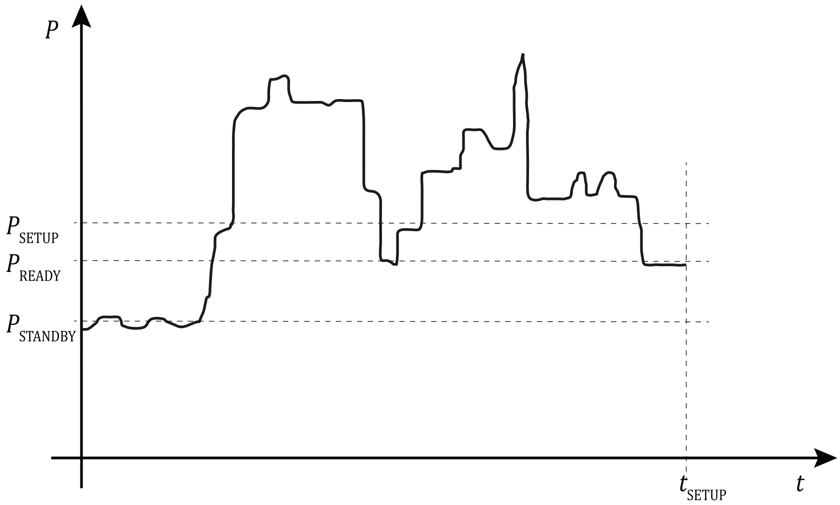
4.6.1 Description

The power, P_{SETUP} [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool is measured during the machine tool process preparation and/or warm up. This measurement includes all required activities for machine tool process preparation. This state can include machine tool-specific warm up times.

NOTE This measurement aims to indicate required activities, e.g. moving of axes, fixing workpiece, cleaning process area and/or warm up time. It shows the required average power during machine tool setup including related component activity. This state depends on the machine tool, in some cases it depends also on the process. Some machine tools do not require the machine tool state SETUP.

4.6.2 Measurements

Measurement of power during machine tool state SETUP, as exemplified in Figure 5.



Key

P	power [kW]
t	time [s]
$P_{STANDBY}$	average power [kW] during machine tool state STANDBY
P_{READY}	average power [kW] during machine tool state READY
P_{SETUP}	average power [kW] during machine tool state SETUP
t_{SETUP}	measurement time [s] during machine tool state SETUP

Figure 5 — Example of measurement of power during machine tool state SETUP

4.6.3 Documentation

Table 5 shows the required values for machine tool state SETUP.

Table 5 — Required values for machine tool state SETUP

Required value	Unit	Description
P_{SETUP}	kW	Average power during machine tool state SETUP
t_{SETUP}	s	Duration during machine tool state SETUP. This duration depends on the machine tool and in some cases on the process as well.

4.7 Step 6 — Measurement of machine tool state READY — M05

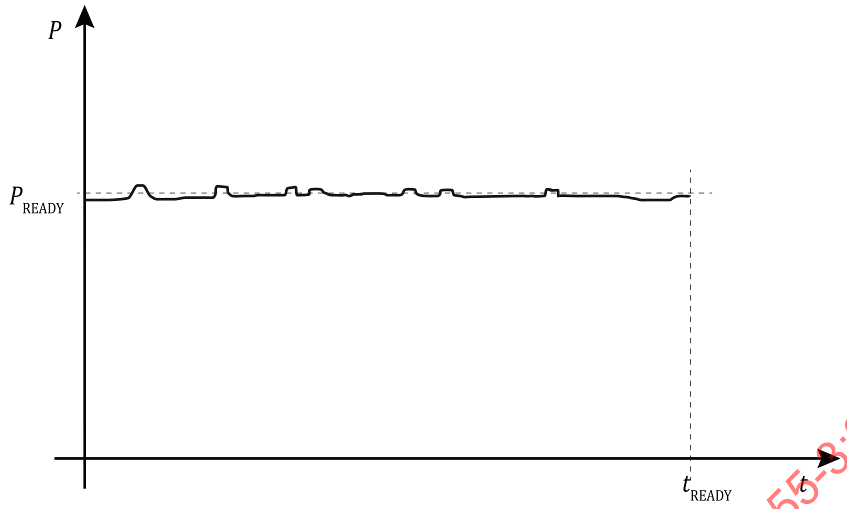
4.7.1 Description

The power, P_{READY} [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool is measured during the machine tool state READY. This state represents the machine tool state just before processing. The process preparation, including warm up, axis reference and setup activities are already done. The machine tool is ready for processing and waiting for start signal. Measurement should be performed when stable conditions are reached, for a time, t_{OFF}, of at least 300 s (default value). If this condition is not fulfilled, measurements shall last longer.

NOTE This measurement aims to indicate the required average power during the machine tool state READY including related component activity.

4.7.2 Measurements

Measurement of power during machine tool state READY.



Key

P	power [kW]
t	time [s]
P_{READY}	average power [kW] during machine tool state READY
t_{READY}	measurement time [s] during machine tool state READY

Figure 6 — Example of measurement of power during machine tool state READY

4.7.3 Documentation

Table 6 shows the required values for machine tool state STANDBY.

Table 6 — Required values for machine tool state READY

Required value	Unit	Description
P_{READY}	kW	Average power during machine tool state READY
t_{READY}	s	Default value is 300 s. It is required to document the duration of the measurement even if it is equal to the default duration.

4.8 Step 7 — Measurement of machine tool state PROCESSING — M06

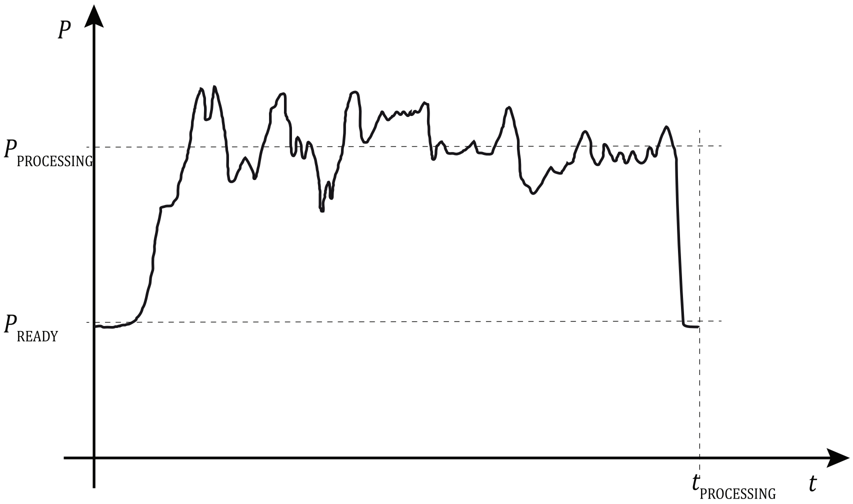
4.8.1 Description

The power, $P_{PROCESSING}$ [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool is measured during the reference scenario according to the definition in Clause 6. This machine tool state represents the typical and individual machine tool processing.

NOTE This measurement aims to indicate the required average power during machine tool processing including related component activity. This machine tool state depends on the process.

4.8.2 Measurements

Measurement of power during machine tool state PROCESSING, as exemplified in Figure 7.



Key

P	power [kW]
t	time [s]
P_{READY}	average power [kW] during machine tool state READY
$P_{PROCESSING}$	average power [kW] during machine tool state PROCESSING
$t_{PROCESSING}$	measurement time [s] during machine tool state PROCESSING

Figure 7 — Example of measurement of power during machine tool state PROCESSING

4.8.3 Documentation

Table 7 shows the required values for machine tool state PROCESSING.

Table 7 — Required values for machine tool state PROCESSING

Required value	Unit	Description
$P_{PROCESSING}$	kW	Average power during machine tool state PROCESSING
$t_{PROCESSING}$	s	Individual duration of reference scenario

4.9 Step 8 — Measurement of machine tool state EMERGENCY STOP — M07

4.9.1 Description

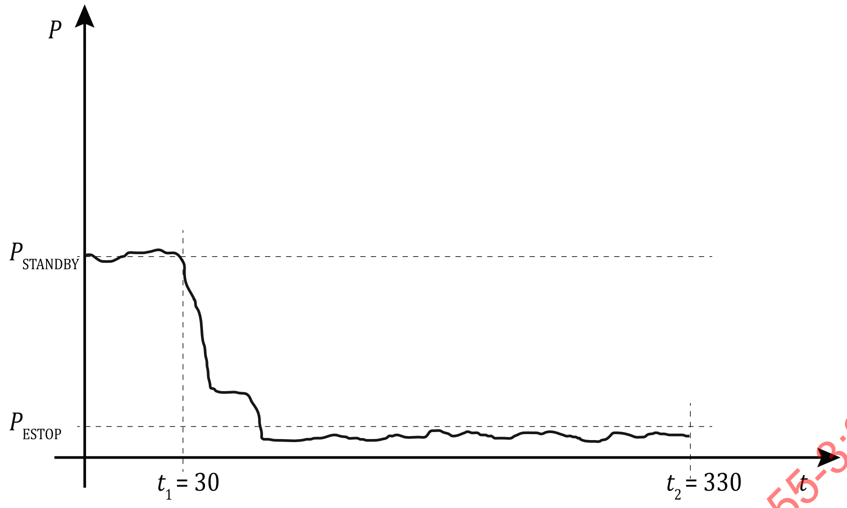
The power, P_{ESTOP} [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool is measured during machine tool state EMERGENCY STOP. After t_1 = 30 s in machine tool state STANDBY, EMERGENCY STOP is initiated. Measurement should be performed during stable conditions in machine tool state EMERGENCY STOP for a time, t_{ESTOP}, of at least 300 s (default value).

Some machine tool users use the machine tool state EMERGENCY STOP when a machine tool is not operating. In such cases the machine tool state EMERGENCY STOP is relevant and shall be measured.

NOTE This measurement aims to indicate the required average power during machine tool state EMERGENCY STOP (ESTOP) and related component activity. This machine tool state does not depend on the process.

4.9.2 Measurements

Measurement of power during machine tool state EMERGENCY STOP, as exemplified in Figure 8.



Key

P power [kW]

t time [s]

P_{ESTOP} average power [kW] during machine tool state ESTOP

$P_{STANDBY}$ average power [kW] during machine tool state STANDBY

Figure 8 — Example of measurement of power during machine tool state EMERGENCY STOP (ESTOP)

4.9.3 Documentation

Table 8 shows the required values for machine tool state EMERGENCY STOP (ESTOP).

Table 8 — Required values for machine tool state EMERGENCY STOP (ESTOP)

Required value	Unit	Description
P_{ESTOP}	kW	Average power during machine tool state EMERGENCY STOP
t_{ESTOP}	s	Default value is 300 s. It is required to document the duration of the measurement even if it is equal to the default duration.

4.10 Step 9 — Measurement of transition from machine tool state STANDBY to OFF — M08

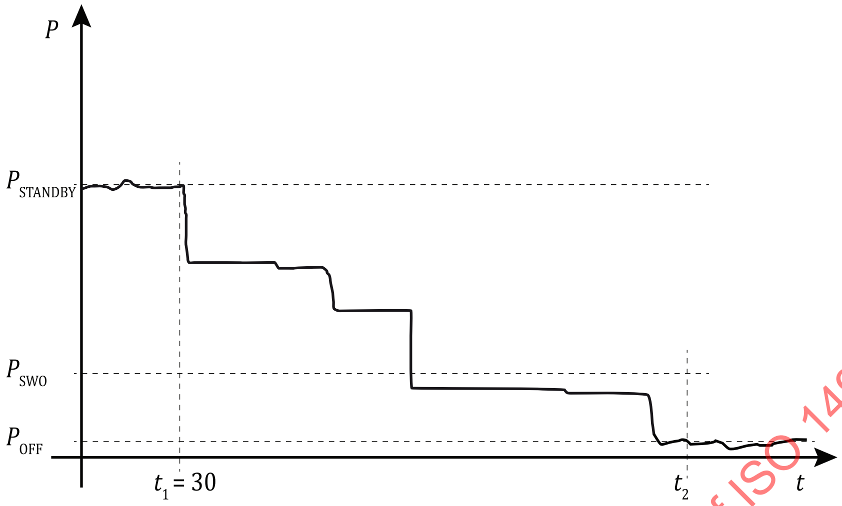
4.10.1 Description

The average power, P_{SWO} [kW], including all required external media, e.g. compressed air, according to the system boundary definition of the machine tool, is measured during the transition from machine tool state STANDBY to OFF. After t_1 = 30 s the machine tool is switched off according to the typical switch off procedure as indicated by the machine tool manufacturer. The machine tool SWITCH OFF ends when stable conditions are reached at t_2. The transition from STANDBY to OFF lasts the time t_{SWO} that is defined as $t_2 - t_1$. P_{SWO} represents the average power value including all external media during the machine tool switch off. This measurement is independent of the process.

NOTE This measurement aims to indicate the required time for machine tool switch off and related component activity. The duration of the switch off depends on the machine tool. This machine tool activity depends on the machine tool.

4.10.2 Measurements

Measurement of power during transition from machine tool state STANDBY to OFF, as exemplified in Figure 9.



Key

P	power [kW]
t	time [s]
P_{OFF}	average power [kW] during machine tool state OFF
P_{SWO}	average power [kW] during transition from machine tool state STANDBY to machine tool state OFF
$P_{STANDBY}$	average power [kW] during machine tool state STANDBY
t_2	end of transition from machine tool state STANDBY to machine tool state OFF

Figure 9 — Example of measurement of power during transition from machine tool state STANDBY to OFF (SWO)

4.10.3 Documentation

Table 9 shows the required values for transition from machine tool state STANDBY to OFF (SWO).

Table 9 — Required values for transition from machine tool state STANDBY to OFF (SWO)

Required value	Unit	Description
P_{SWO}	kW	Average power during transition from machine tool state STANDBY to OFF
t_{SWO}	s	Individual duration of transition from machine tool state STANDBY to OFF. $t_{SWO} = t_2 - t_1$.

5 Machine tool analysis for environmental evaluation

5.1 General

Based on the given information and performed measurements on all required machine tool operating states, and resulting EnPI values, the assessments in 5.2 shall be carried out.

5.2 Average machine tool performance

5.2.1 General

The average machine tool performance indicates the estimated energy supplied according to the time shares of the given machine tool operating states. The shares are defined based on one production year.

The evaluation of the operating state shares shall be based on an individual share of operating states that represent the actual usage of the machine tool including OFF, STANDBY, etc. If the individual share of operating states is not known, neither by the machine tool user nor the manufacturer, the operating state share given in Table 10 shall be used. The related procedure is shown in Figure 10.

Table 10 shows default time shares of operating states which result from numerous measurements in the workshop and production field. These shares shall be used if an individual time share cannot be defined or is unknown.

Table 10 — Default time share of operating states

	OFF	STANDBY	SETUP	READY	PROCESS-ING	EMERGEN-CY STOP	OTHERS (transient operating states)
Share per year	5 %	15 %	10 %	5 %	60 %	5 %	0 %
Share value per year	s_{OFF} = 0,05	$s_{STANDBY}$ = 0,15	s_{SETUP} = 0,1	s_{READY} = 0,05	$s_{PROCESSING}$ = 0,6	s_{ESTOP} = 0,05	s_{O} = 0

s_{OFF}: Share value of machine tool state OFF per year

$s_{STANDBY}$: Share value of machine tool state STANDBY per year

s_{SETUP}: Share value of machine tool state SETUP per year

s_{READY}: Share value of machine tool state READY per year

$s_{PROCESSING}$: Share value of machine tool state PROCESSING per year

s_{ESTOP}: Share value of machine tool state ESTOP per year

s_{O}: Share value of machine tool state OTHERS per year

Based on different knowledge, different pre-knowledge, an educated guess or on different machine tool applications different individual time shares may be defined.

5.2.2 Approach

Figure 10 shows the procedure for the selection of the machine tool operating state share option.

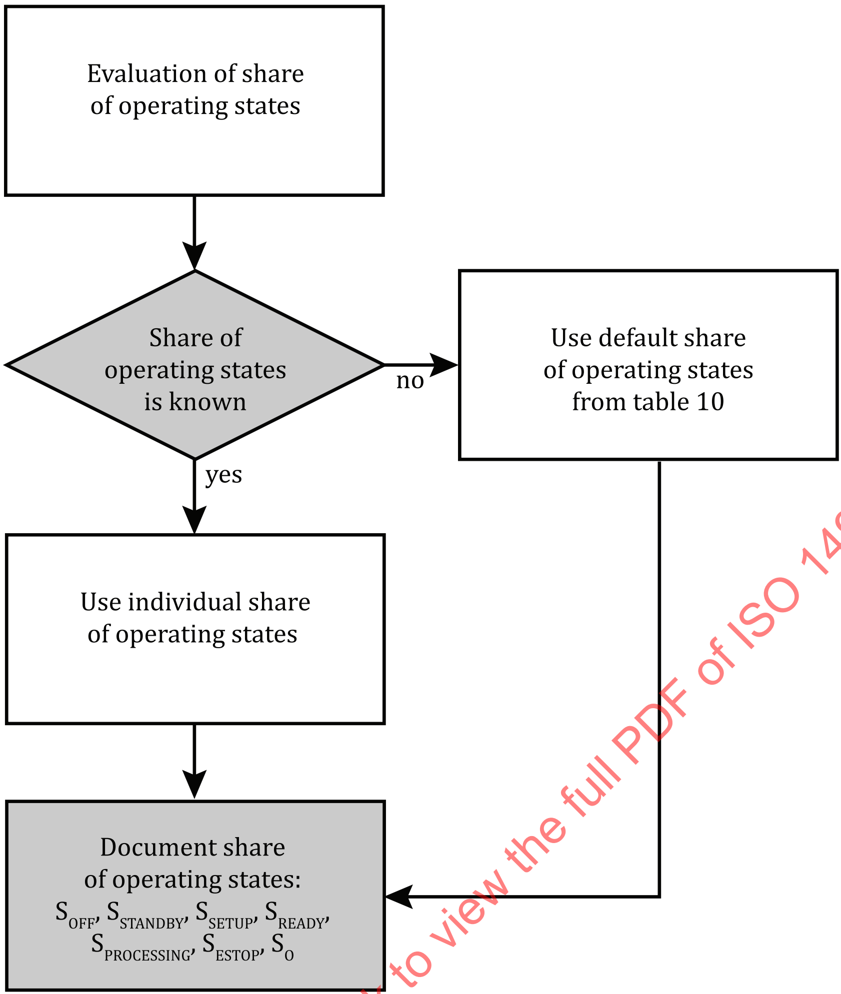


Figure 10 — Approach for the evaluation of operating states

5.2.3 Estimated energy supplied

Based on the defined share of the operating states, Formula (1) can be calculated. It indicates the estimated energy supplied for one production year. This value and related calculation of the operating state share shall be documented.

NOTE In shop floor production, power supplied related to non-productive machine tool states can have a strong impact on total energy demand. If available, automatic machine tool switch-off shall be applied and reported.

$$E = \left(\begin{array}{l} s_{\mathrm{OFF}} * P_{\mathrm{OFF}} + s_{\mathrm{STANDBY}} * P_{\mathrm{STANDBY}} + s_{\mathrm{SETUP}} * P_{\mathrm{SETUP}} + s_{\mathrm{READY}} * P_{\mathrm{READY}} \\ + s_{\mathrm{PROCESSING}} * P_{\mathrm{PROCESSING}} + s_{\mathrm{ESTOP}} * P_{\mathrm{ESTOP}} + s_{\mathrm{O}} * P_{\mathrm{O}} \end{array} \right) * (365*24) \quad (1)$$

where

E	is the estimated energy supplied for one production year under the given circumstances in kWh;
P_{OFF}	is the average power during machine tool state OFF in kW;
P_{STANDBY}	is the average power during machine tool state STANDBY in kW;
P_{SETUP}	is the average power during machine tool state SETUP in kW;

P_{READY}	is the average power during machine tool state READY in kW;
$P_{PROCESSING}$	is the average power during machine tool state PROCESSING in kW;
P_{ESTOP}	is the average power during transition from machine tool state STANDBY to machine tool state ESTOP in kW;
P_{O}	is the average power during machine tool state OTHERS in kW;
s_{OFF}	is the share value of machine tool state OFF per year;
$s_{STANDBY}$	is the share value of machine tool state STANDBY per year;
s_{SETUP}	is the share value of machine tool state SETUP per year;
s_{READY}	is the share value of machine tool state READY per year;
$s_{PROCESSING}$	is the share value of machine tool state PROCESSING per year;
s_{ESTOP}	is the share value of machine tool state ESTOP per year;
s_{O}	is the share value of machine tool state OTHERS per year.

The time share per year value is the average time share calculated on a full year of average production, so it can be directly derived from measures of an average production day only for a production of 365 days, 24 h/day. Otherwise, the measures shall be scaled taking into account non-operative times. Because Formula (1) computes energy supplied estimated for one full production year, the state of the machine tool when the production plant is not operative, even if the power supplied to the machine tool is 0 kW, shall be taken into account.

EXAMPLE 1

— Mass production with 365 days/year production

— 2 shifts/day (= 16 h/day) operational times

— 8 h/day non-operative times with machine tool in OFF

During the operative times (16 h/day), the measured time share per year are the ones of Table 10: OFF 5 %, STANDBY 15 %, SETUP 10 %, READY 5 %, PROCESSING 60 %, EMERGENCY STOP 5 %.

Therefore, the real share per year of non-operative times to be used for Formula (1) is: OFF = 1/3+2/3*0,05 = 36,6 %. As an example, the resulting time share according to Table 10 for PROCESSING = 2/3*0,6 = 0,4 = 40 %.

EXAMPLE 2

— Shop floor production with 220 days/year production

— 1 shift/day (= 8 h/day) operational times

— 16 h/day non-operative times with machine tool in OFF

During the operative times (8 h/day), the measured time share per year are the ones of Table 10: OFF 5 %, STANDBY 15 %, SETUP 10 %, READY 5 %, PROCESSING 60 %, EMERGENCY STOP 5 %. The machine tool is in OFF for 16 h/day and for 145 days/year (365 – 220).

The resulting time shares according to Table 10 for this example are: OFF 81 %, STANDBY 3 %, SETUP 2 %, READY 1 %, PROCESSING 12 %, EMERGENCY STOP 1 %.

5.2.4 Calculation of relevant operation states

Based on the measurement values, the relevant operating states can be defined. Relevant operating states show a high time share or energetic relevance. Furthermore, relevant operating states shall be analysed with the functional oriented analysis (FO) according to ISO 14955-1.

For the default share of operating states, the relevant operating state(s) during machine tool use phase can be defined according to Table 11.

Table 11 — Relevant parameters for the calculation of supplied energy for the default share of operating states

	OFF	STANDBY	SETUP	READY	PROCESSING	EMERGENCY STOP	OTHERS (transient operating states)
Share per year	5 %	15 %	10 %	5 %	60 %	5 %	0 %
Share value per year	s_{OFF} = 0,05	$s_{STANDBY}$ = 0,15	s_{SETUP} = 0,1	s_{READY} = 0,05	$s_{PROCESSING}$ = 0,6	s_{ESTOP} = 0,05	s_0 = 0
Measured average power, P, per operating state	P_{OFF}	$P_{STANDBY}$	P_{SETUP}	P_{READY}	$P_{PROCESSING}$	P_{ESTOP}	P_0
Calculated supplied energy, E, per operating state per year	$E_{OFF} = P_{OFF} * s_{OFF} * 365 * 24$	$E_{STANDBY} = P_{STANDBY} * s_{STANDBY} * 365 * 24$	$E_{SETUP} = P_{SETUP} * s_{SETUP} * 365 * 24$	$E_{READY} = P_{READY} * s_{READY} * 365 * 24$	$E_{PROCESSING} = P_{PROCESSING} * s_{PROCESSING} * 365 * 24$	$E_{ESTOP} = P_{ESTOP} * s_{ESTOP} * 365 * 24$	$E_0 = P_0 * s_0 * 365 * 24$

The calculated energy, E, per operating state per year shows which operating state is relevant. Based on this relevance, the functional oriented analysis according ISO 14955-1 shall be performed.

5.2.5 Relevant values

The EnPI values in Table 12 shall be collected and documented where applicable. Non-existent or specific operating states should be mentioned, respectively documented.

Table 12 — Relevant performance indicators to be documented

Required value	Unit	Description
P_{OFF}	kW	Average power during machine tool state OFF
t_{OFF}	s	Default value is 300 s. It is required to document the duration of the measurement even if it is equal to the default duration
P_{START}	kW	Average power during transition from machine tool state OFF to STANDBY
t_{START}	s	Duration of transition from machine tool state OFF to STANDBY. This duration is machine tool dependent
$P_{STANDBY}$	kW	Average power during machine tool state STANDBY
$t_{STANDBY}$	s	Default value is 300 s. It is required to document the duration of the measurement even if it equal to the default duration
P_{SETUP}	kW	Average power during machine tool state SETUP
t_{SETUP}	s	Duration during machine tool state SETUP. This duration depends on the process
P_{READY}	kW	Average power during machine tool state READY
t_{READY}	s	Default value is 300 s. It is required to document the duration of the measurement even if it is equal to the default duration
$P_{PROCESSING}$	kW	Average power during machine tool state PROCESSING
$t_{PROCESSING}$	s	Individual duration of reference scenario
P_{ESTOP}	kW	Average power during machine tool state EMERGENCY STOP
t_{ESTOP}	s	Default value is 300 s. It is required to document the duration of the measurement even if it is equal to the default duration
P_{SWO}	kW	Average power during transition from machine tool state STANDBY to OFF

Table 12 *(continued)*

Required value	Unit	Description
t_{SWO}	s	Individual duration of transition from machine tool state STANDBY to OFF
E_{OFF}	kWh	Calculated energy for one year required during machine tool state OFF
$E_{STANDBY}$	kWh	Calculated energy for one year required during machine tool state STANDBY
E_{SETUP}	kWh	Calculated energy for one year required during machine tool state SETUP
E_{READY}	kWh	Calculated energy for one year required during machine tool state READY
$E_{PROCESSING}$	kWh	Calculated energy for one year required during machine tool state PROCESSING
E_{ESTOP}	kWh	Calculated energy for one year required during machine tool state EMERGENCY STOP
E_O	kWh	Calculated energy for one year required during machine tool state OTHER, e.g. manufacturer or user specific machine tool states
E	kWh	Calculated estimated energy for one year based on stated time shares of the operating states

5.2.6 Functional oriented analysis

Figure 11 shows the approach for the functional oriented evaluation according to ISO 14955-1 based on relevant operating states.

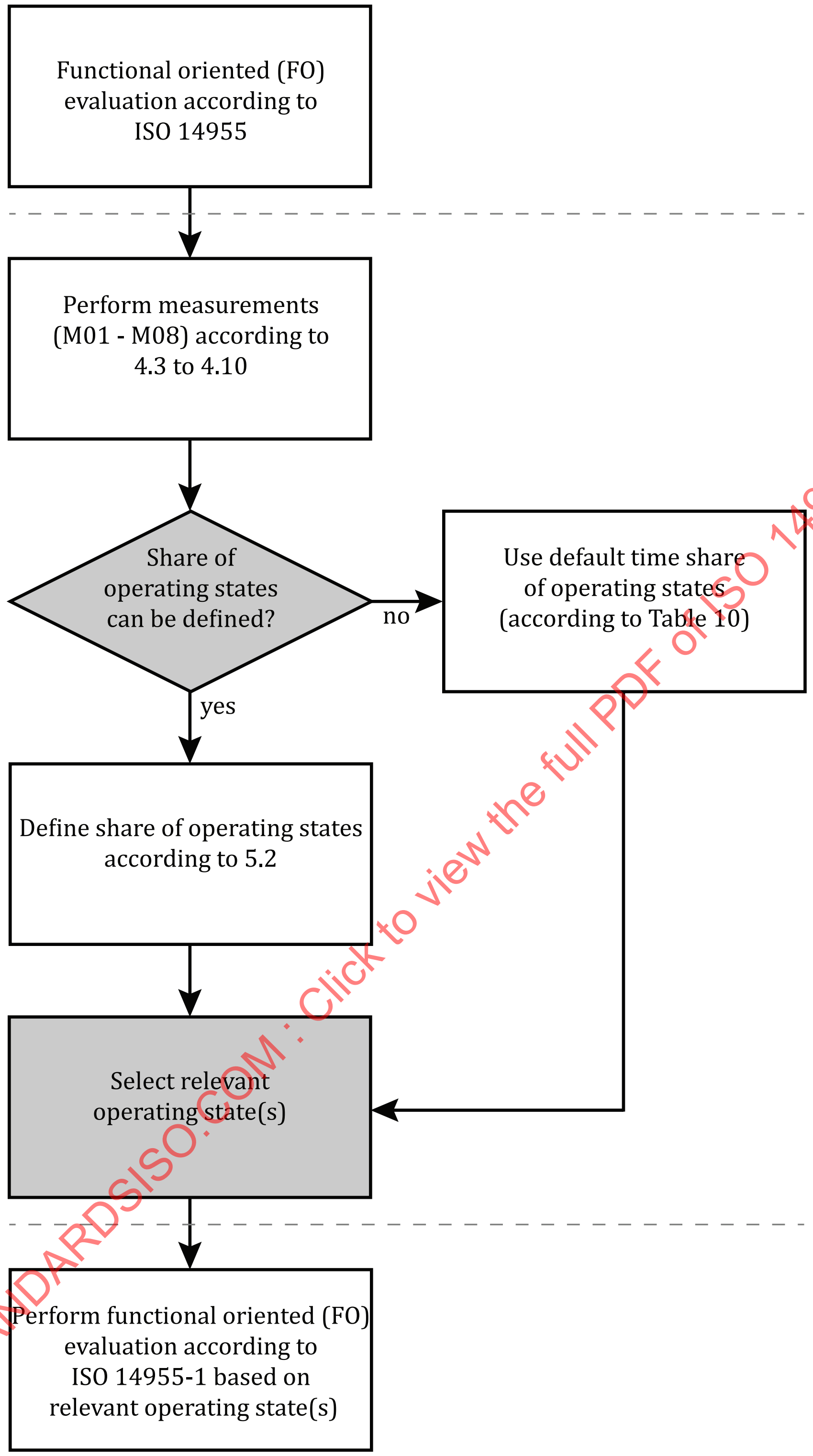


Figure 11 — Approach for the functional oriented (FO) evaluation according to ISO 14955-1 based on relevant operating states

Based on relevant machine tool functions, relevant machine tool components can be definded that shall be measured individually as per ISO 14955-1:2017, 6.4.

6 Machine tool reference scenario

6.1 General

Machine tools represent an assemblage of different machine tool components (e.g. spindles, guideways, drives, fans, motors) with individual configurations and specific applications. The individual energetic machine tool behaviour and related specific energy efficiency optimization measures are primary dependent on the machine tool configuration, machining process and application, active components and their control, machine tool operating states sequence, manufacturing environment, and individual handling.

Metal-cutting machine tools, their configuration and their application are highly individual and heterogeneous. It is therefore obvious that a definition for a standardized reference part or process with a defined geometry and material properties is cumbersome. A given reference part is always directly or indirectly related to a specific machine tool and can therefore be manufactured under optimized conditions on one machine tool, whereas it is not intended to be manufactured on a different machine tool and related machine tool configuration. Certain machine tool – workpiece combinations are not realistic, common or useful in industrial applications. Energy assessments and related indications for energy efficiency optimization measures based on an unrealistic or uncommon machining application can be wrong, leading to an indication of an energetic efficiency/inefficiency and/or energetic disadvantage/advantage for certain applications. For this reason, a standardized reference part is not intended in this document as it can not reflect a realistic metal-cutting machine tool application in industrial environments.

Sample shift regime as mentioned in ISO 14955-2:2018, 5.2.2 and 5.2.3, can indicate an unrealistic machine tool use. It can be concluded that reference parts, as well as reference scenarios are strongly dependent on the target and individual machine tool and related configuration and shall be defined individually as well. This document focuses on the definition of an individual and machine tool and application-dependent reference scenario for metal-cutting. The definition of individual reference scenarios should ensure that a typical machining process as represented in industry is assessed. The reference scenario of the machine tool represents the intended value adding process for the given machine tool. This document is not meant to be used for machine tool comparison.

In large scale production with discrete part manufacturing, the process variance is limited. Large scale production machine tools are commonly designed to manufacture a certain workpiece or set of workpieces of similar geometric complexity. The workpiece complexity, workpiece material property, required machining operations and related process parameters on each machine tool are similar. Studies/research/measurements on metal-cutting machine tools show that, especially in automotive and aerospace processes (mass production), the variety of a target machining processes is limited to one or a few similar processes. This means that a defined customer-specific machining process is representative of this application and can be selected. A higher flexibility/process variability can be observed on machine tool in mid and shop floor production.

It is seen that sometimes machine tool manufacturers/suppliers have limited access to the actual customer application (e.g. part size, materials, cutting forces, process programming). On the user side, the expected parts and related applications are known, but there is limited knowledge of the given and possible machine tool configuration.

NOTE 1 Examples for the machine tool configuration are: moving or fixed portal, internal and external cooling, internal and external exhauster, handling features.

NOTE 2 Example for manufacturing environment definition can contain information on the temperature and moisture of the environment.

NOTE 3 Example for the large-scale production is the automotive industry.

6.2 General structure

6.2.1 General

The definition of a reference scenario can be described in two parts:

— a common definition that is valid independent from the machine tool, process and application;

— a specific and individual definition which requires specific parameterization.

Individual and process information shall be documented, it can be documented not publically. The elements are explained in detail in Figure 12.

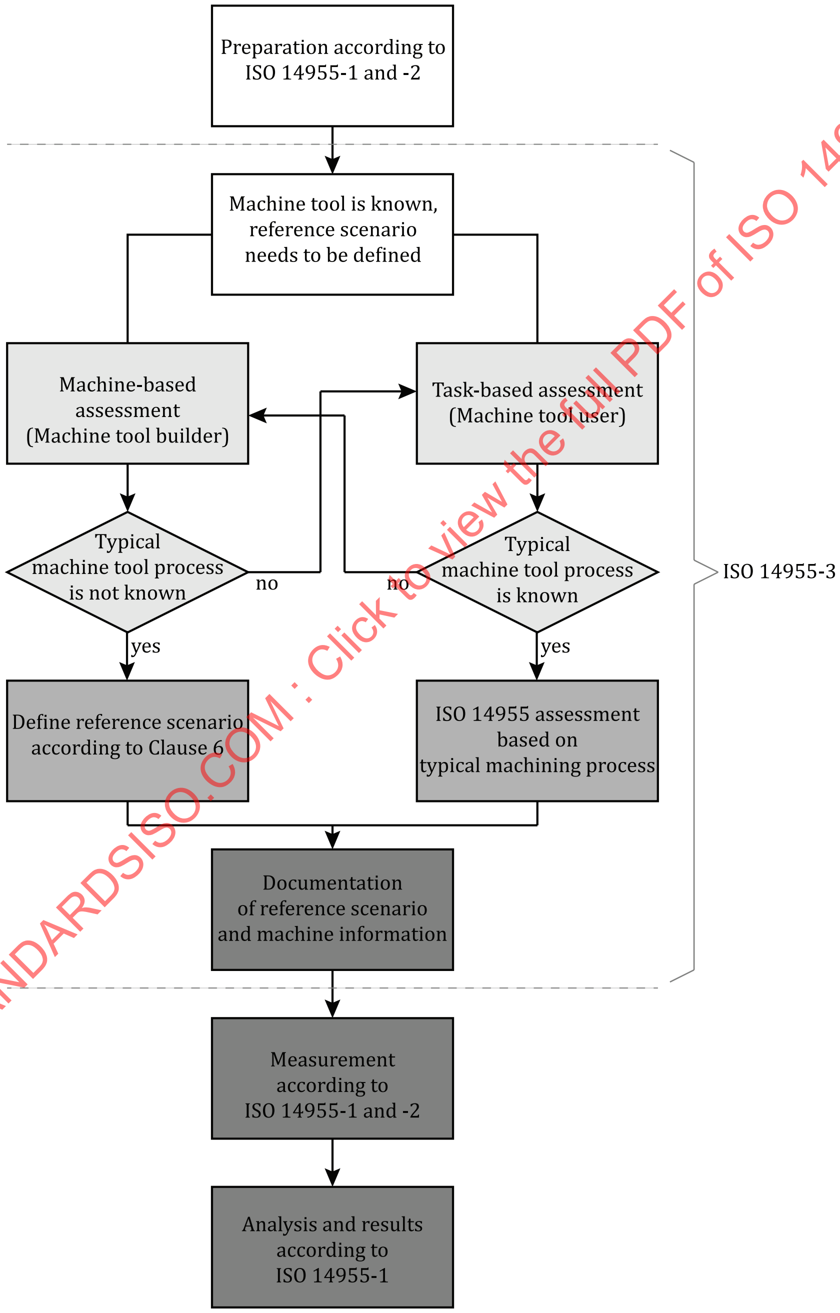


Figure 12 — General description of the application and definition of the reference scenario

The reference scenario should include the definition of time shares of operating states (see 5.2.2).

6.2.2 Preparation

The preparation should follow the information as indicated in ISO 14955-1:2017, Clauses 6 and 8, and ISO 14955-2:2018, Clauses 4 to 9, with the definition of possible analysis features, required system boundaries and required energy forms as well as measurement procedure and remarks.

6.3 Guide for the definition of the reference scenario

The reference scenario represents a typical machine tool activity in use. The used materials, tools, parameters and related NC program and processing duration reflect the typical and intended application of the given machine tool. The following indications shall be used to identify a reference scenario.

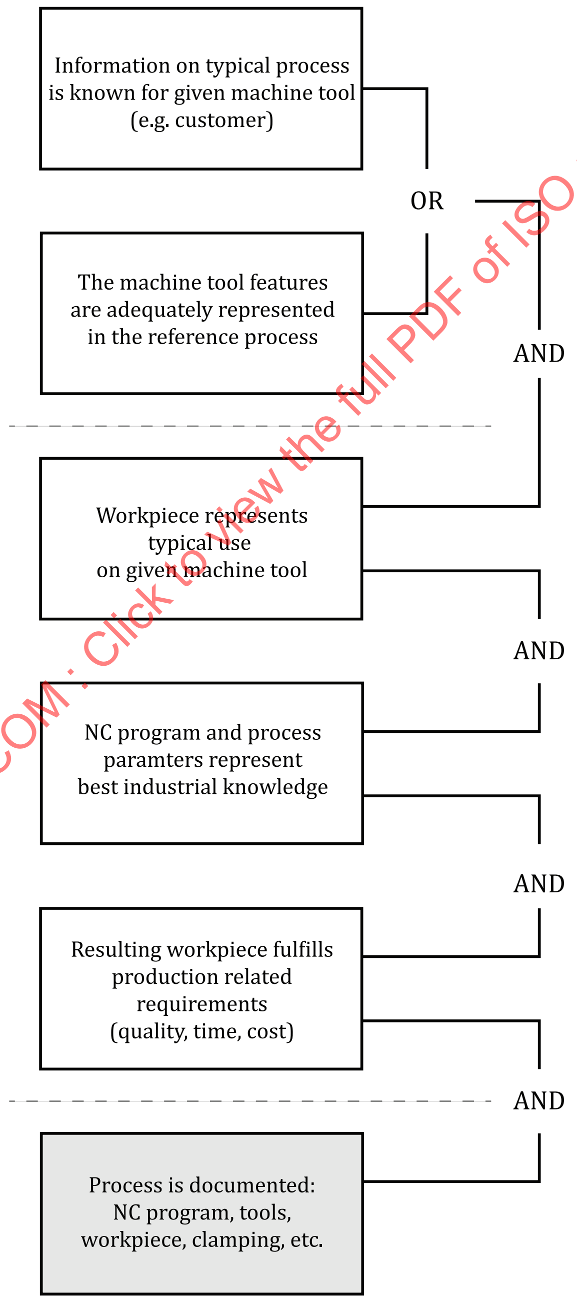


Figure 13 — Guideline for the definition of a reference scenario

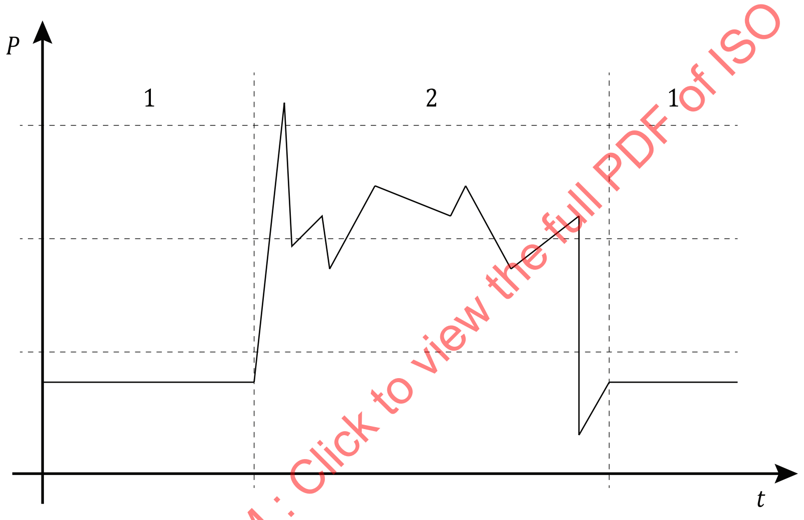
6.4 Definition of a reference scenario

6.4.1 General

The reference scenario represents an individually defined manufacturing process containing the definition of a specific procedure, part handling, material used, tools used, conditions and environment to achieve an individual and specific workpiece. It represents the typical value adding application on the given metal-cutting machine tool. The reference scenario describes the machine tool activity in a reproducible way.

The definition of a reference scenario should be performed in line with the functional mapping according to ISO 14955-1 and in cooperation between the machine tool manufacturer/supplier and the machine tool user. The assignment of a reference scenario benefits the user by a precise assessment of the target machining process and the manufacturer/supplier, by detailed information on the actual use in order to identify an appropriate and optimized machine tool configuration. System boundary and relevant energy forms are already defined in ISO 14955-1 and ISO 14955-2.

Figure 14 shows an example for a reference scenario.



Key

P power [kW]

t time [s]

1 STANDBY or other operating states than PROCESSING (may be included in the reference scenario)

2 PROCESSING (included in the reference scenario)

Figure 14 — Indication of the reference scenario within the machine tool processing

The definition of the reference scenario defines the machine tool activity during the operating state processing. The reference scenario is defined by the machine tool manufacturer, the machine tools user, or by agreement between the manufacturer/supplier and the user, and represents a typical machine tool application for the given machine tools and related configuration. If the machine tool manufacturer cannot specify a representative reference scenario on the given machine tool and machine tool configuration, a machine tool user specific reference scenario in coordination with the machine tool user shall be defined.

Based on the selected reference scenario, general and process specific information according to 6.7 shall be given. The measurement of the machine tool according to ISO 14955-1 and ISO 14955-2 can be performed.

For the definition of a reference scenario, the requirements and aspects in 6.4.2 to 6.4.5 shall be satisfied.

6.4.2 Machining process

In discrete part manufacturing, and especially in large scale production, specific machining processes are assigned to selected machine tools. The knowledge of the machine tool user for the intended machining process, in procurement and retrofit, is generally given. Therefore, not only the type of the manufacturing process is known, but also the range of process parameters (e.g. feed speed, torque, rotational speed, generator power of EDM, properties and complexity of workpiece, cooling requirements), machine tool activity and used NC programs. Settings of the programmable logic controller (PLC) influence the manufacturing process as well. For this reason, the machine tool manufacturer/supplier needs to consult machine tool users and define a machine tool and configuration specific machining process based on the given range of process parameters and related information. It is in the interest of machine tool user and manufacturer/supplier to define the reference scenarios for the target application.

6.4.3 Tools

In relation to the machining process, the quantity, type and quality of the tools used is generally known by the machine tool user. This is valid for the purchasing and the machine tool configuration phase. In relation to the tools used, the required preconditions (e.g. cooling requirements, tool handling and storage) are known as well and shall be used for the definition of the reference scenario.

6.4.4 Workpiece material and process parameters

In relation to the known machining processes, their share, the tools used and the related process parameters and workpiece used and/or set of materials used and workpiece geometries are known by the machine tool user.

6.4.5 Variation of process parameters

The manufacturer can set low, medium and high application. Those levels should represent the parameter sets in low, middle and high and be further used for unknown but assumed customer applications.

Any exceptions shall be handled by the machine tool manufacturer in cooperation with the machine tool user. The reference scenario shall be defined in accordance to the specific quantity of processed parts. The most common material and tools for the typical machining process shall be used. If the application is unknown or not present, the reference scenario shall be defined based on low, medium and high process parameter sets. These parameter sets represent low, medium and high duty operations.

6.5 Major machine tool operating states

The machine tool operating states with a significant share of energy according to 5.2.4 shall be taken into account to setup a useful reference scenario, at least PROCESSING and STANDBY are necessary operating states.

— PROCESSING

  Represents the actual machine tool use and target value adding application (no air cut). The machine tool operating state processing starts with the start of the NC program and ends with the end of this NC program.

— STANDBY

  The operating state STANDBY of a machine tool shall only be included within the reference scenario if this state is related to the value adding of the intended application. For instance, the operating state STANDBY can be given in automated or manual workpiece handling or for cooling and/or workpiece conditioning.

— other operating states

Other machine tool operating states shall be included in the reference scenario if they are required for the target machine tool application.

6.6 Relevant test scenarios

The evaluation of test scenarios, machine-based or task based, as defined in ISO 14955-2:2018, Clause 5, is covered by the definition of a reference scenario (see Figure 13). All possible scenarios include different machine tool operating states, such as OFF, STANDBY, READY, SETUP and PROCESSING. The definition of the reference scenario as performed in the operating state processing is represented in all possible machine tool test scenarios.

6.7 Documentation of reference scenario

The reference scenario shall be adequately defined and reproducible under the same conditions. It shall be documented. The required information can be further divided into general information and process- and application-dependent information. All necessary information to perform the reference scenario is required.

NOTE If the reference scenario is not public, it is handled confidentially between the machine tool user and manufacturer.

The following general information shall be documented. It does not depend on the process and on the application:

— machine tool type, brand, model and serial number;

— machine tool configuration;

— related machining process according to DIN 8580;

— measurement conditions according to ISO 14955-1 and ISO 14955-2.

Annex A
(informative)

Example for grinding machine tool

A.1 General information

NOTE The following example is based on a real measurement. The informations are anonymized and do not provide any real case values or applications.

Table A.1 gives an overview of the machine tool under investigation.

Table A.1 — General information overview

Information	Description
Company	Examplecompany, Examplestreet 1, 8005 Zürich, Switzerland
Responsible person(s)	Mr. M. Tool (machine tool responsible) Mr. A. Measurement (measurement provider)
Machine tool manufacturer Model Serial No. Year of installation	Example manufacturer, Cylindrical grinding machine ggg, 20162000002, 2016
System boundary	According to ISO 14955-2:2018, Clause 6, including electrical energy and compressed air supply
Nominal power [kW]	120
Temperature / humidity during measurement	Temperature and humidity were monitored as follows: 08:00 am: 25,1 °C at 26,1 % 08:30 am: 25,1 °C at 24,7 % 09:00 am: 25,2 °C at 23,9 % 09:30 am: 25,5 °C at 23,7 % 10:00 am: 25,7 °C at 23,7 % 10:30 am: 25,8 °C at 23,9 % 11:00 am: 25,5 °C at 24,3 % Delta: <±1 K; <5 %-influences of temperature can be neglected
Date and time	2017-11-30/8:00 am—11:00 am

A.2 Measured machine tool states

Table A.2 shows the measured machine tool states of the machine tool under investigation.

Table A.2 — Measurement machine tool states

Name	Description
OFF	Machine tool "OFF", Main switch OFF, compressed air supply valve open
OFF → STANDBY	System startup by main switch OFF to ON until stable conditions
STANDBY	Machine tool in STANDBY
SETUP/WARMUP	Warmup of machine tool according to machine tool manufacturer instructions
READY	Machine tool ready for processing
PROCESSING	Processing according 6.2, reference scenario xyz-123

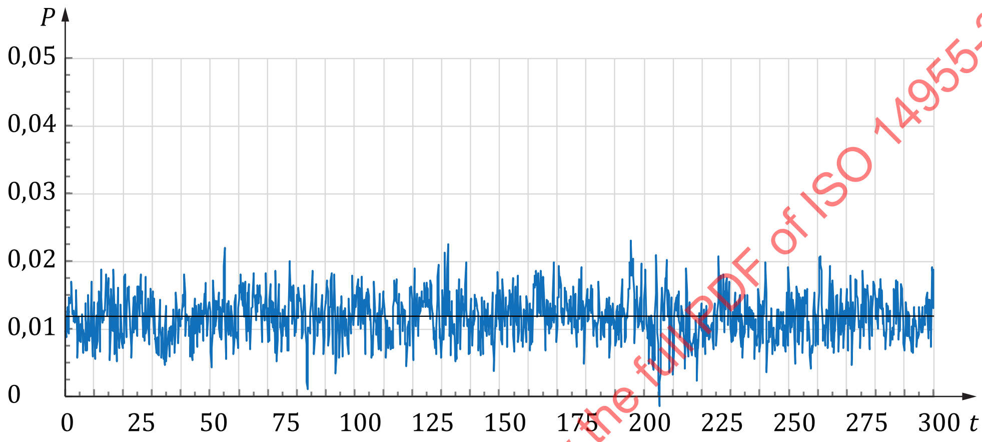
Table A.2 *(continued)*

Name	Description
EMERGENCY STOP	EMERGENCY STOP
STANDBY → OFF	Shut down of machine tool according to machine tool manufacturer instructions

A.3 Measurements

A.3.1 Measurement of machine tool state OFF — M01

Figure A.1 shows the measurement of power during machine tool state OFF.



Key

P power [kW]

t time [s]

Figure A.1 — Measurement of power during machine tool state OFF

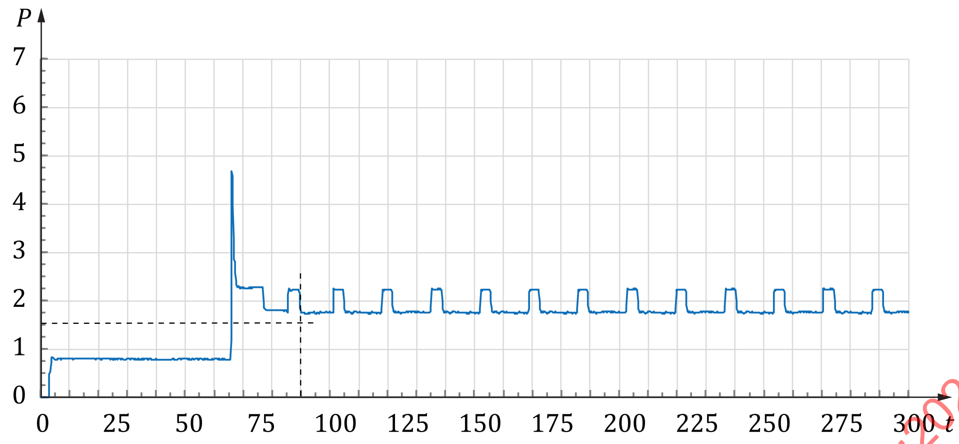
Table A.3 shows the measurement values for machine tool state OFF.

Table A.3 — Measurement values for machine tool state OFF

Required value	Unit	Description
P_{OFF}	kW	0,012 5 kW (average)
t_{OFF}	s	300 s

A.3.2 Measurement of machine tool state OFF to STANDBY (START) — M02

Figure A.2 shows the measurement of power during machine tool state OFF to STANDBY.



Key

P power [kW]

t time [s]

Figure A.2 — Measurement of power during machine tool state OFF to STANDBY

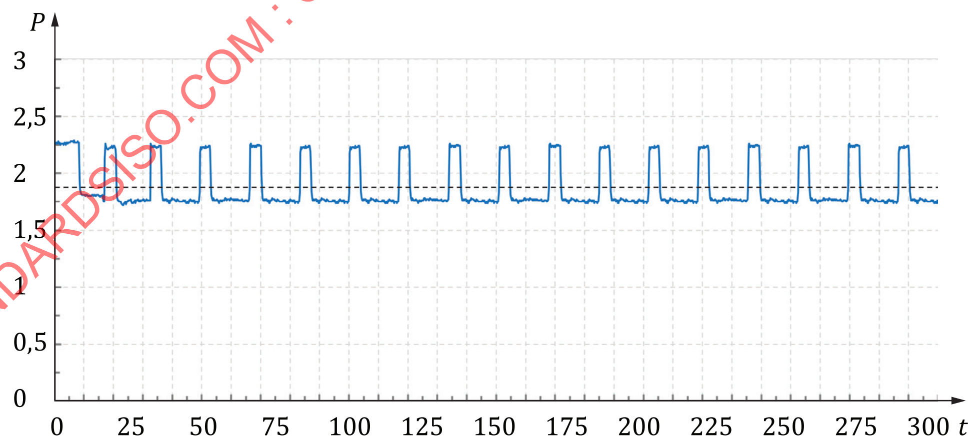
Table A.4 shows the measurement values for machine tool state OFF to STANDBY.

Table A.4 — Measurement values for machine tool state OFF to STANDBY

Required value	Unit	Description
P_{START}	kW	1,52 kW (average)
t_{START}	s	90 s

A.3.3 Measurement of machine tool state STANDBY — M03

Figure A.3 shows the measurement of power during machine tool state STANDBY.



Key

P power [kW]

t time [s]

Figure A.3 — Measurement of power during machine tool state STANDBY

Table A.5 shows the measurement values for machine tool state STANDBY.