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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).

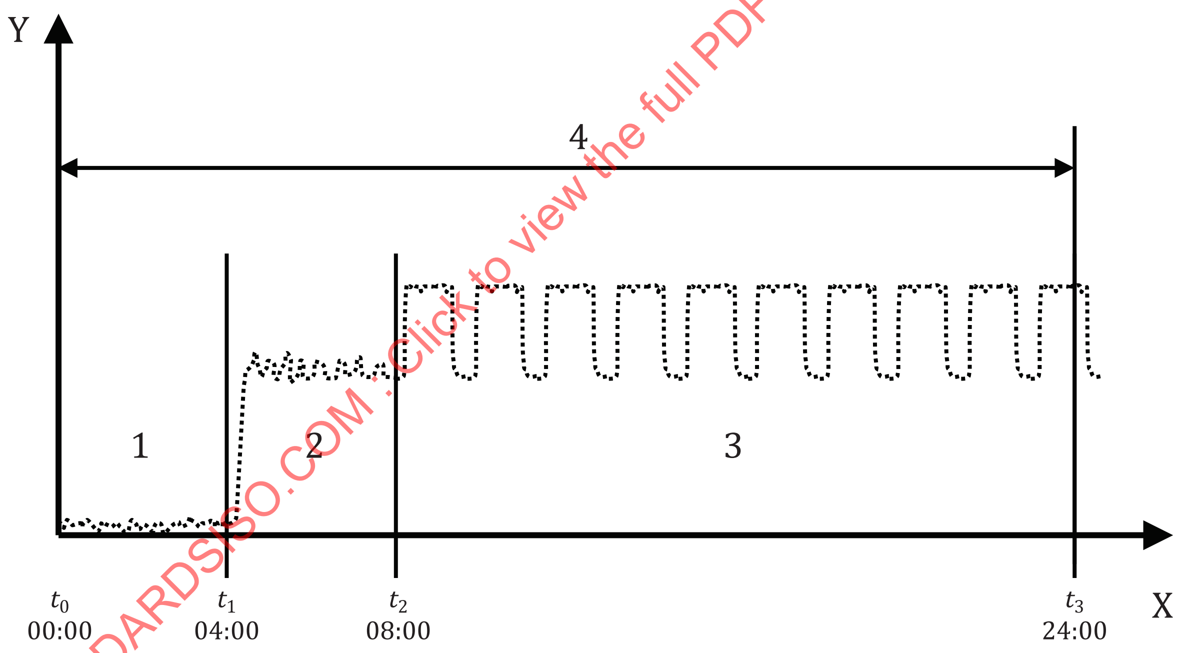
NOTE 1 The measuring period can be significantly shorter than the evaluation period, see 7.7.

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

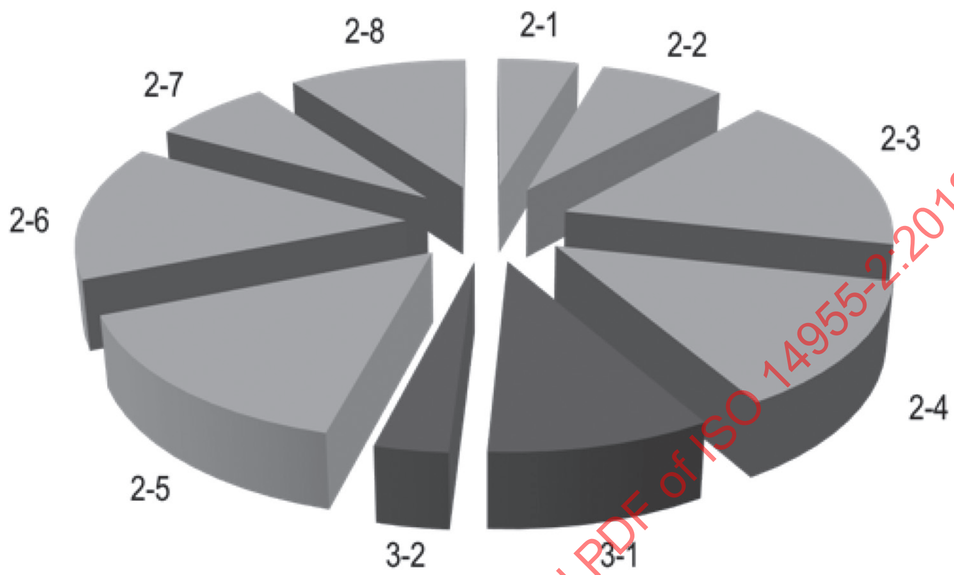
<table>
<tr><th>Operating state</th><th colspan="2">READY FOR PROCESSING</th><th colspan="7">PROCESSING</th><th>OFF</th><th>READY FOR PROCESSING</th><th colspan="2">PROCESSING</th><th colspan="2">READY FOR PROCESSING</th></tr>
<tr><td>Operating state number</td><td colspan="2">2</td><td colspan="7">3</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

<table>
<tr><th>Evaluation period</th><th colspan="5">10 h</th></tr>
<tr><td>Clustered shift regime</td><td>OFF
number
1–1
1,0 h</td><td>READY FOR PROCESSING
number
2–1
1,5 h</td><td>READY FOR PROCESSING
number
2–2
2,0 h</td><td>PROCESSING
number
3–1
4,5 h</td><td>PROCESSING
number
3–2
1,0 h</td></tr>
</table>

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.

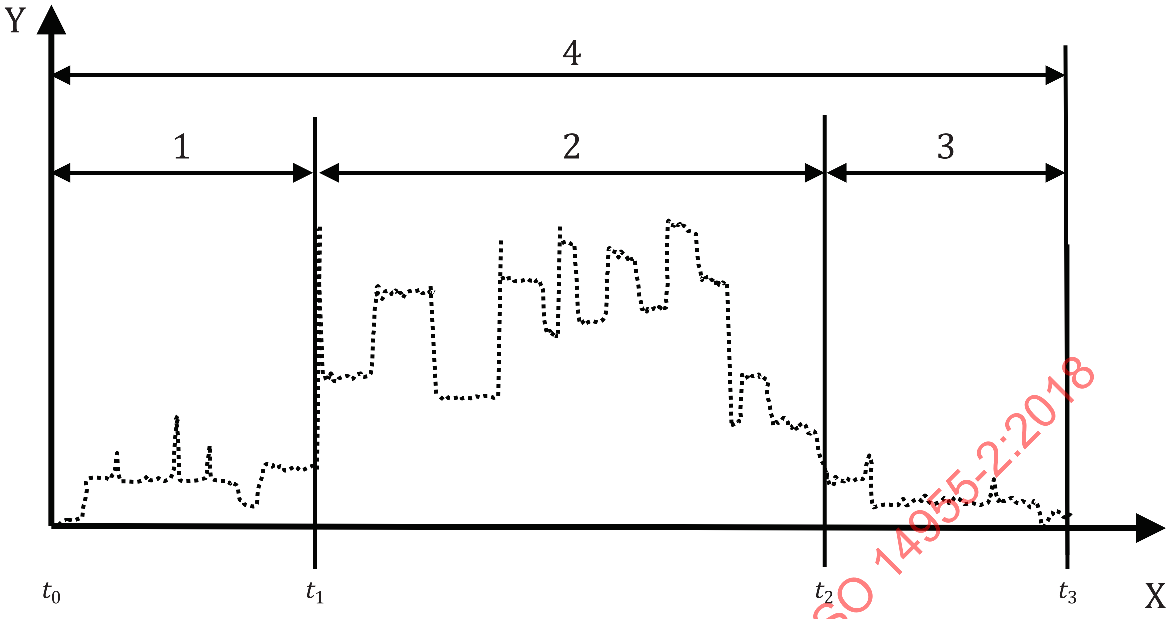
Machine tool activities and/or operating states with a similar energy supplied during a given time interval may be summarized, as shown in the example in 5.2.3.3.

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.



Key

1 PRE-PROCESSING
2 PROCESSING
3 POST-PROCESSING
4 evaluation period
X time, in h
Y power, in W

Figure 3 — Example of power measurement during task-based test scenario

6 System definition for measurement

All measurements shall be performed with the purpose of measuring all relevant energy supplies crossing the system boundaries according to ISO 14955-1 under reproducible conditions. The system boundary shall be defined in such a way as to include all necessary components of the machine tool and to facilitate measurements at the system boundary.

The point of reference is the total electrical energy supplied. Other supplies shall be included in the assessment if they are relevant. Relevancy for any other than electrical energy supplied is assumed if the electrical energy equivalent exceeds 10 % of the total electrical energy supplied during the evaluation period.

Energy supplies considered as not being relevant shall be listed and the basis for the assumption for not being relevant shall be reported.

The evaluation may be developed stepwise in the following order and the energy may be calculated as follows:

$$W_{Sys} = W_a + W_b + W_c + W_d \quad (1)$$

where

W_{Sys} is the total energy supplied;

W_a is the electrical energy supplied;

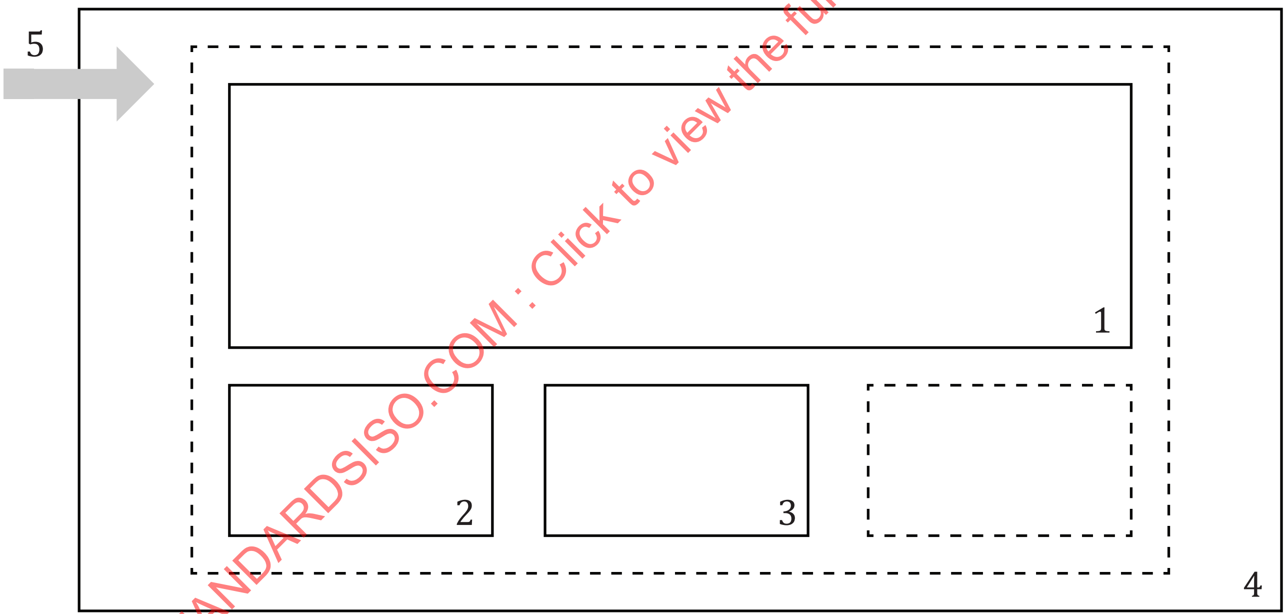
W_b is the energy supplied by tube-bound supplies with inlet measuring only;

W_c is the energy supplied by tube-bound supplies with inlet and outlet measuring;

W_d is the energy supplied by other functions.

NOTE The energy supplied is not necessarily the physical energy flow across the system boundary. For example, if a machine tool needs heat exchange by a cooling water circuit, the energy supplied is the electrical energy equivalent of the cooling water, i.e. the energy needed for pumping and cooling the cooling water by a factory installation.

a) Electrical energy (see Figure 4)



Key

1 machine tool

2 peripheral A

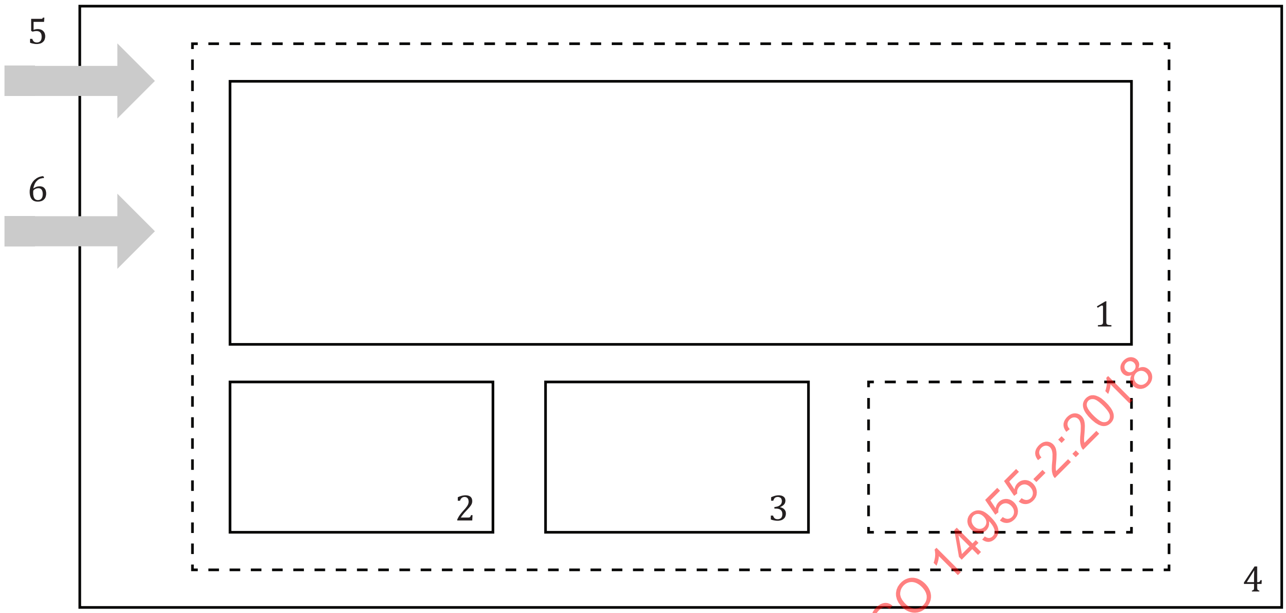
3 peripheral B

4 system boundary

5 electrical energy

Figure 4 — Point of reference for assessment is electrical energy supplied

b) Tube-bound supplies with inlet measuring only (e.g. compressed air) (see Figure 5)

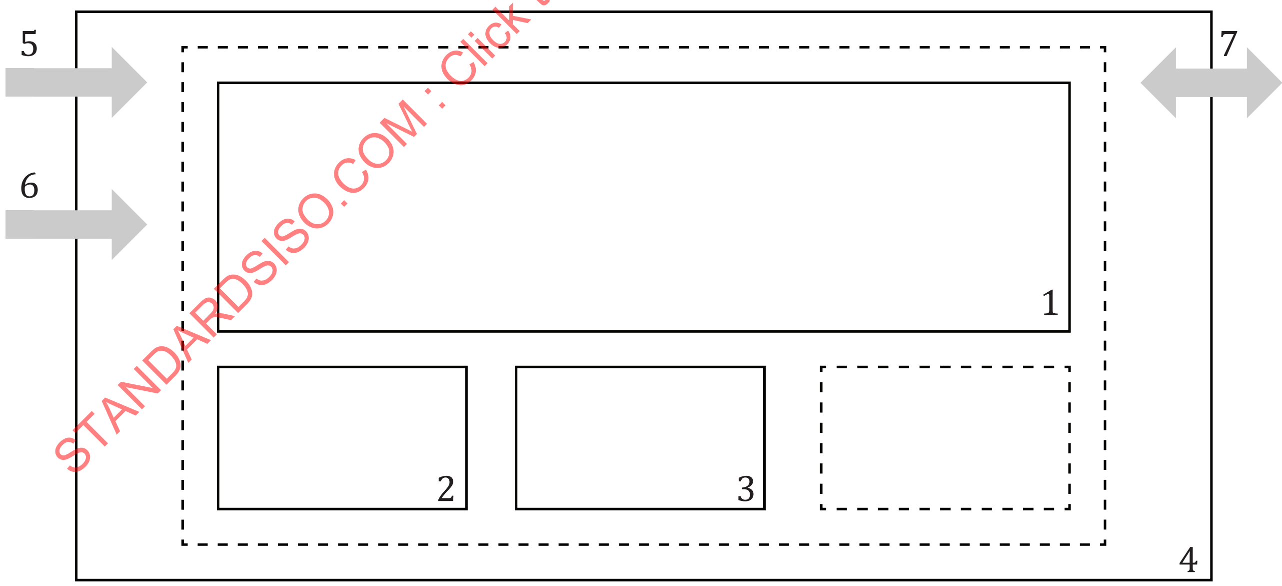


Key

1 machine tool
2 peripheral A
3 peripheral B
4 system boundary
5 electrical energy
6 compressed air

Figure 5 — Inclusion of compressed air

c) Tube-bound supplies with inlet and outlet measuring (e.g. cooling water circuit for heat exchange) (see Figure 6)

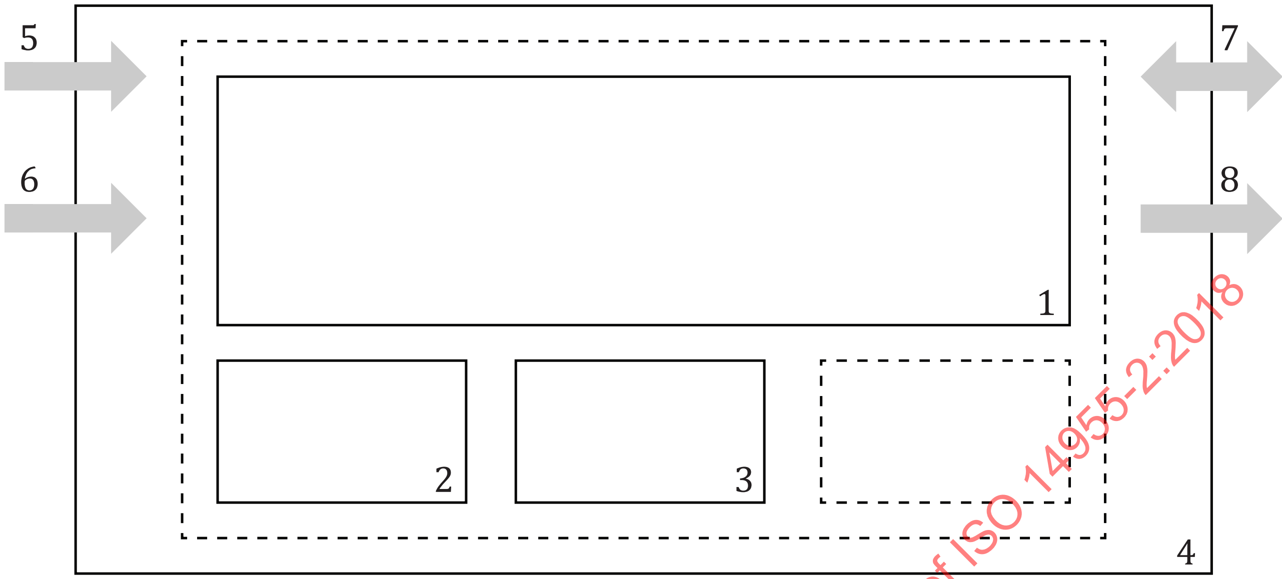


Key

1 machine tool
2 peripheral A
3 peripheral B
4 system boundary
5 electrical energy
6 compressed air
7 cooling fluid

Figure 6 — Inclusion of cooling water circuit

d) Other functions which are supplied primarily under the use of electrical energy (e.g. extraction of contaminated air) (see Figure 7) or resources (e.g. process gas produced in a factory installation)



Key

1 machine tool
2 peripheral A
3 peripheral B
4 system boundary
5 electrical energy
6 compressed air
7 cooling fluid
8 contaminated air

Figure 7 — Inclusion of extraction of contaminated air

7 Measuring set up and methodology

7.1 Measuring points selection

As a minimum, each supply shall be measured at the system boundary. Furthermore, for relevant machine tool components with a common supply at the system boundary, a measuring point within the system boundary shall be considered. Relevancy of a machine tool component is assumed if the supply of a machine tool component – all energies supplied to the machine tool component included — exceeds 10 % of the total electrical energy. The assumption may be based on experience with comparable machine tools, estimations or calculations.

Over all, the measuring points shall enable a functional assignment of machine tool components to machine tool functions according to ISO 14955-1 for 80 % or more of the energy supplied to the machine tool within the evaluation period.

NOTE For compressed air system optimization and measuring, see ISO 11011.

7.2 Power measurement and calculation of energy supplied

Measuring of power is the base to evaluate the energy supplied by integration of power over time. To determine the energy supplied to machine components, as required in ISO 14955-1:2017, 6.4.2, the power applied to the machine tool components can be determined by measurement of auxiliary values (e.g. voltage and current, pressure and flow) followed by calculation of power and energy.

The power measurement in systems described in this document cannot cover all possible technical solutions but defines the principle of how to do power measurement also for other similar systems. For examples of machine tool–specific power measurement setups, see machine tool-specific annexes in the machine tool–specific parts of the ISO 14955 series.

Formulae for calculation of energy supplied and energy efficiency are given in Annex D. Examples of power measurement setup are given in Annex E.

NOTE An example is measuring the pressure and stroke of a die cushion and calculating the energy by multiplying the die cushion stroke by die cushion force (area multiplied by pressure) or calculating the power by multiplying the die cushion velocity by die cushion force.

The energy supplied at the system boundary during a shift regime is calculated by multiplying the average power of the operating states and machine tool activities with their time shares in the shift regime.

For the sample shift regime according to 5.2.2, the total energy supplied is calculated as follows:

$$W_{\text{total}} = 4 \times P_{\text{OFF}} + 4 \times P_{\text{READY FOR PROCESSING}} + 16 \times P_{\text{PROCESSING}} \quad (2)$$

where

W_{total}	is the total energy supplied during the evaluation period in [kWh];
P_{OFF}	is the average power measured in the operating state OFF in [kW];
$P_{\text{READY FOR PROCESSING}}$	is the average power measured in the operating state READY FOR PROCESSING in [kW];
$P_{\text{PROCESSING}}$	is the average power measured in the operating state PROCESSING in [kW].

NOTE Time periods for P_{OFF}, $P_{\text{READY FOR PROCESSING}}$ and $P_{\text{PROCESSING}}$ are taken from Table 1.

For specific shift regimes the formula above shall be adjusted accordingly.

7.3 Simultaneous measuring

Simultaneous measurement ensures fast and reliable data acquisition. It shall be done by multi-channel measuring equipment, where the number of measuring channels corresponds to the number of relevant machine tool components to be measured plus one, to measure the energy supplied at the inlet point.

7.4 Quasi-simultaneous measuring

If less measurement channels than the ones required for simultaneous measurements are available, quasi-simultaneous measurement can be used. Compared to simultaneous measurement, quasi-simultaneous measurement ensures reliable data acquisition at the expense of time. It shall be done by measuring equipment with a minimum of two channels or two synchronized power meters and under stable conditions. While one channel shall measure without interruption the total power supplied to the machine tool during the measurement, the second channel shall be connected to the various machine tool components one after the other without interrupting their function. With advantage, this method can be used during regimes with clustered time shares with periodically repeated machine tool activities allowing stable conditions for longer time intervals. Care shall be taken since many components operate discontinuously on longer periods and expert judgment is necessary.

7.5 Measuring equipment

7.5.1 General requirements

The chosen measuring equipment shall be suitable (e.g. resolution and measuring range) to solve the current task. The equipment shall be calibrated and measurement uncertainty shall be stated (see Clause 8).

Measuring equipment shall suppress any influence of transients falsifying the measuring result. The sampling rate of the data acquisition system shall be suitable for correct measurement of the fluctuations of values within the measuring period. Equipment parameters influencing its accuracy due to other than nominal conditions (such as high-frequency distortion of measured signals) shall be reported. These are analog/digital converter sampling rate, anti-aliasing filter frequency or compliance with relevant standards (e.g. IEC 62053-22).

NOTE Integrated devices of the machine tool can serve as measuring equipment.

7.5.2 Equipment for electrical measurement

The equipment for electrical measurement shall be capable of providing the following data:

— active electrical power, i.e. wattmeter;

— electrical energy within the measuring period or average electrical power within the measuring period.

NOTE Any supplementary measurands such as peak power, apparent power (see [13]), etc. for purposes other than measuring energy supplied to the machine tool are not within the scope of this document.

7.5.3 Equipment for measuring fluids

Calorimetric measurement equipment is suitable for air and water. In order to determine the flow of fluids (e.g. mineral oil), measurement of other values and calculation may be done (see also Figure B.1).

Temperature of fluids shall be measured by sensors in the fluid or outside on the surface of a thermally non-insulated tube. See also Annex B.

7.6 Measurement units

All measurement results shall be reported in units of the measuring instrument and in the following way.

— Active electrical power shall be expressed in kW or in W. Electrical energy shall be expressed in kWh or in Wh.

— Pneumatic energy shall be measured as standard volume flow rate according to ISO 1217 at standard reference atmosphere according to ISO 8778, integrated over time and expressed as cubic meter at standard reference atmosphere [m^3 (ANR)] supplied at specified nominal pressure at the machine tool inlet point. Alternatively, the mass flow rate may be measured, integrated over time and converted into cubic meter at standard reference atmosphere [m^3 (ANR)].

— Liquid measurements shall include temperature in degree Celsius (°C), volume flow rate in litre per minute (l/m) integrated over time and expressed as volume in cubic meter (m^3) and pressure in Pascal (Pa).

7.7 Measurement period

The default measuring period is the evaluation period. Based on expert judgement or on monitoring of measuring results during the measurement, the measuring period can be shortened to a minimum of 5 min and the energy supplied shall be extrapolated to match the respective shift regime. The reason for the shortening shall be stated. Typical reasons for shortening are the observation of repetitive pattern or of a stabilization of power supplied after some time.

7.8 Conversion of measured values

In order to facilitate interpretation and comparison, all energy supplied to the machine tool shall be expressed in kWh or in Wh.

If the unit of the measuring instrument is other than electrical power or electrical energy, the value shall be converted into the electrical energy equivalent (see 7.9), i.e. in kWh or Wh necessary to provide the energy given in the machine tool's location or in a comparable industrial environment. The adopted conversion shall be stated in the report.

If the energy given is not or not primarily provided under the use of electrical energy, or if the conversion is not intended or not possible for other reasons, it shall be expressed in the unit of the measuring instrument and reported and interpreted separately.

7.9 Electrical energy equivalent

7.9.1 Standard conversion rates

For the electrical energy equivalent, preferably standard conversion rates are applied. They may be suggested by the manufacturer/supplier or result from an agreement between the manufacturer/supplier and the user. See also Annex A.

7.9.2 Determination of electrical energy equivalent

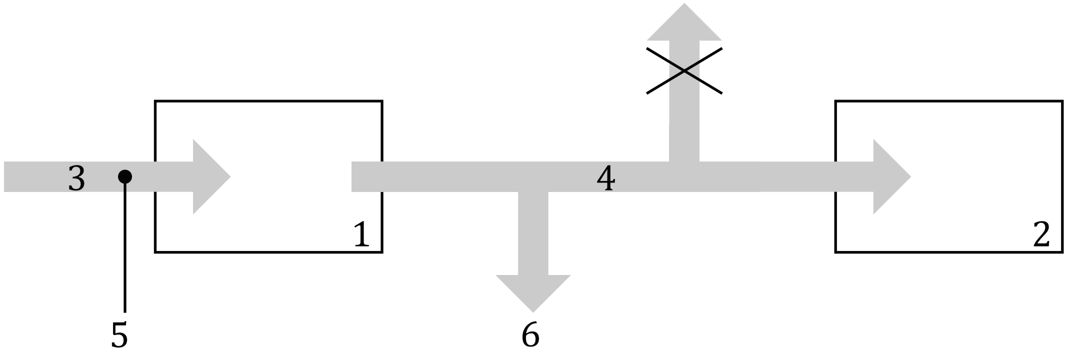
If suitable conversion rates for the electrical energy equivalent are unavailable, they may be determined by one of the two following methods.

— Determination according to method a): The factory installation for the energy supply is included in the system boundary and the electrical energy supplied to this factory installation is measured. This method is applicable only if there is no need to measure the energy supplied on component level (see 7.1).

— Determination according to method b): The energy supplied to the machine tool under test is quantified by measuring characteristic parameters, i.e. corresponding physical quantities (e.g. pressure, flow, temperature). The energy equivalent is then calculated by the application of a conversion rate on these characteristic parameters. This method requires a suitable set of characteristic parameters, constant conversion rates, i.e. a linear relation between the electrical energy equivalent and the energy supplied, and suitable measuring systems for the above characteristic parameters. Furthermore, the conversion rate shall be given or determined by method a).

As an example, the electrical energy equivalent of compressed air is determined by both ways.

— Determination according to method a): The machine tool is connected to the compressed air supply of the factory. Any other consumers bound to the same supply are either separated or kept stable during the measurement. The electrical energy supplied to the compressed air supply is measured with and without the machine tool under test (see Figure 8) at measuring point i. The energy equivalent is the difference of the electrical energy supplied to the compressed air supply with and without the machine tool under test. For reliable results, any other possible consumer of compressed air shall be examined carefully. The increase of the electrical energy supplied to the compressor when the machine tool is operating should be more than 50 % of the total electrical energy, as smaller increases of compressor power result in high uncertainty of results. The measuring period shall be at least 30 minutes. The operating cycle of the compressor shall be considered.

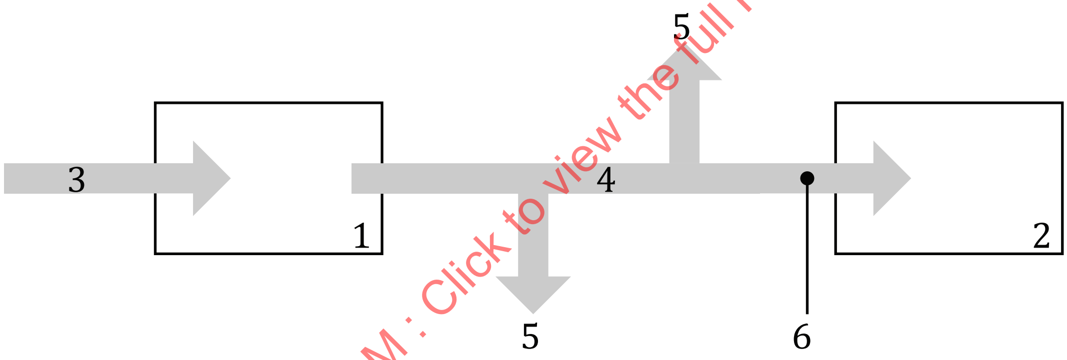


Key

1 compressed air supply
2 machine tool
3 electrical energy
4 compressed air
5 measuring point i
6 constant flow rate outlet

Figure 8 — Determining of electrical energy equivalent of compressed air by method a)

— Determination according to method b): First, the flow of compressed air to the machine tool under test is measured at measuring point ii, and integrated over time producing a value representing a compressed air volume (see Figure 9).

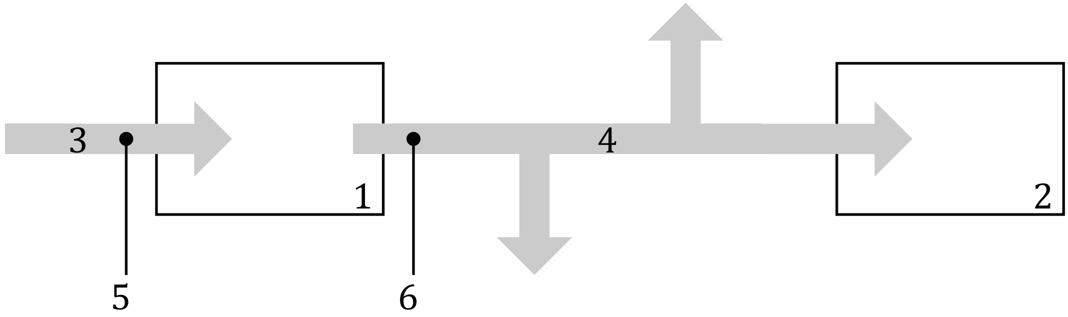


Key

1 compressed air supply
2 machine tool
3 electrical energy
4 compressed air
5 variable flow rate outlet
6 measuring point ii

Figure 9 — Measuring compressed air volume at machine tool inlet point for method b)

In separate measurement, at the outlet of the factory supply, the flow of compressed air is integrated over time at two different operating points, i.e. with a low and a high load (Figure 10, measuring point iii). Simultaneously, the electrical energy supplied to the factory supply is measured (Figure 10, measuring point i). The difference of electrical energy divided by the difference of mass flow integrated over the time of the two measurements is the value of the conversion rate.



Key

1	compressed air supply	4	compressed air
2	machine tool	5	measuring point i
3	electrical energy	6	measuring point iii

Figure 10 — Determination of the conversion rate by method b)

The difference in mass flow between low and high load should be more than 50 % of the nominal mass flow at the measuring point iii, the integrating time at least 30 min, and the pressure at the beginning and the end of integrating time should be the same.

The electrical energy equivalent is then calculated by multiplication of the two values.

Examples for conversion of energy values are given in Annex A. Examples of non-electrical energy measurements are given in Annex B.

8 Measurement uncertainty

Measurement uncertainty shall be evaluated for all measurements and shall be stated in the test report. At least the following measurement uncertainty contributors shall be considered:

— uncertainty of measuring equipment (see 7.5);

— uncertainty of measurement process mainly due to fluctuations of supplied power.

9 Reporting of results

9.1 Reporting of individual measurement results

9.1.1 System description

Each measurement shall be reported as follows:

a) kind of machining process;

b) manufacturer, machine type, serial number, year of construction of the machine tool, ancillary devices and peripherals within the system boundary;

c) nominal electrical power of machine tool;

d) nominal electrical power of peripherals and machine tool components, if measured individually.

9.1.2 Measurement setup description

a) Type of supplies measured other than electrical energy supply.

b) Type of measurement equipment and its measurement uncertainty.

c) Ambient conditions (If applicable, variation of ambient conditions).

d) Operating states (If applicable, variation of operating states).

e) Machine tool activity (If applicable, variation of machine tool activity).

f) Measuring points.

9.1.3 Measurement result description

a) Functional assignment of components.

b) Date, time and duration of measurement.

c) Energy supplied for each operating state.

d) If applicable, reason for choosing a measuring period shorter than the evaluation period.

e) Calculated average electric power = energy supplied/duration of measurement.

f) Power vs. time record is recommended.

Operating states and machine tool activities shall be stated in the test report.

An example of a measuring report is shown in Annex C.

9.2 Mapping of measured values and interpretation

Measured values shall be mapped to machine tool functions (ISO 14955-1:2017, 6.3.10) and relevant machine tool functions shall be identified (ISO 14955-1:2017, 6.4.1).

Each variety of ambient conditions, operating state and machine tool activity leads to a profile of energy supplied to the machine tool.

The application of a standard or specific shift regime leads to a global profile of energy supplied to the machine tool.

An example of mapping measured values to machine tool functions is shown in Annex C.

9.3 Measurement report

The measurement report shall describe:

a) the definition of test scenarios, see Clause 5;

b) if applicable, the electrical energy equivalent applied;

c) the quantitative functional mapping of machine tool components to machine tool functions according to ISO 14955-1:2017, 6.3.10;

d) the values for machine tool functions;

e) a bar chart is recommended, according to ISO 14955-1:2017, 6.4.1.

An example for the reporting of results is shown in Annex C.

Annex A
(informative)

Electrical energy equivalent

A.1 General

This annex gives a rule for determination of electrical energy equivalent, see 7.9.

A.2 Compressed air

The electrical energy equivalent of compressed air depends on the thermodynamic conditions, the efficiency of the compressor and losses for storage and distribution. The lowest value for the electrical energy equivalent is given by the ideal isothermic compression. For the case of adiabatic compression, the electrical energy equivalent is higher due to thermodynamic laws.

Based on field studies, the electrical energy necessary to supply 1 m^3 (ANR) of compressed air to the machine tool inlet point from a central factory supply typically lies between 0,11 kWh − 0,13 kWh[12].

Assuming a state-of-the-art medium size compressed air supply system with low leakage, modern compressors for oil-lubricated air and refrigerated dryer, minimum idling times and low pressure loss in the compressed air piping, significantly better equivalents can be achieved.

Waste heat utilization is a valuable tool used in many modern compressed air systems, using heat of compression to replace energy for heating or cooling, but it is not yet a standard in existing installations. Therefore, Table A.1 partly considers energy savings due to waste heat utilisation. The electrical energy equivalent is not the electrical energy supplied to the compressor, but an overall value considering savings of electrical or other forms of energy due to the average use of waste heat.

Table A.1 — Examples for electrical energy equivalents for 1 m^3 (ANR)

Nominal supply gauge pressure	Theoretical value for isothermic compression[14]	Theoretical value for adiabatic compression[14]	Best available technology with heat recovery[15]	Average industrial supply[12]
300 kPa	0,030 kWh	0,035 kWh	0,060 kWh	0,11 kWh to 0,13 kWh
600 kPa	0,050 kWh	0,067 kWh	0,085 kWh	
1 000 kPa	0,064 kWh	0,093 kWh	0,105 kWh	
1 600 kPa	0,077 kWh	0,120 kWh	0,145 kWh	

Other values than stated as best available technology with heat recovery in Table A.1 can be applied according to conditions specified in the following paragraphs, or to values based on measurements relevant for the machine tool under test, see 7.9.

The actual electrical energy equivalent for compressed air for a specific factory can deviate as much as −40 % for a very effective waste heat recovery to +40 % and more for not state-of-the-art compressed air systems, with over-compression, excessive idling times, high leakage and other deficiencies[15].

For special requirements related to certain applications, the following corrections of the values stated for best available technology with heat recovery can be applied as a rule of thumb:

— in case of oil-free air needed, the value is multiplied by 1,1;

— in case of a pressure dew point of less than 0 °C needed, it is additionally multiplied by 1,05;

— in case of a pressure dew point of less than −40 °C, by 1,1.

Values for gauge pressures other than those listed in Table A.1 are approximated by linear interpolation.

A.3 Contaminated air extraction

The electrical energy equivalent of contaminated air extraction is related to the electrical power used by the fan of the de-duster, which depends on extracted airflow $\left[\frac{\text{m}^3\,(\text{ANR})}{\text{h}}\right]$, aeraulic fan efficiency (%) and total pressure (Pa):

$$P_{\text{fan}} = \frac{Q \times p_t}{36 \times \eta_{\text{fan}}} \quad \text{(A.1)}$$

where

P_{fan} is the electrical power used by the fan of the de-duster for contaminated air extraction in W;

Q is the air flow in $\left[\frac{\text{m}^3\,(\text{ANR})}{\text{h}}\right]$;

p_{t} is the total pressure in Pa;

η_{fan} is the aeraulic fan efficiency in %.

$$p_t = p_s + p_d \quad \text{(A.2)}$$

where

p_{t} is the total pressure in Pa;

p_{s} is the static pressure in Pa;

p_{d} is the dynamic pressure in Pa.

The dynamic pressure is related to the required air velocity in the extraction system of the machine tool. It may be measured by a Pitot tube or calculated as follows:

$$p_{\text{d}} = 0{,}5 \times \rho \times v^2 \quad \text{(A.3)}$$

$$p_{\text{d}} = 0{,}625 \times v^2 \quad \text{(A.4)}$$

where

p_{d} is the dynamic pressure in Pa;

ρ is the density of contaminated air in $\left[\frac{\text{kg}}{\text{m}^3\,(\text{ANR})}\right]$, assumed as 1,25 $\left[\frac{\text{kg}}{\text{m}^3\,(\text{ANR})}\right]$;

v is the air velocity in m/s.

The static pressure is related with pressure losses caused by turbulences in extraction exhaust hoods and ducts installed at the machine tool side. It corresponds to the pressure drop between inlet of all devices and the connection to Chips And Dust Extraction System (CADES).

Based on field studies, the energy necessary to extract $1\frac{\mathrm{m}^3(\mathrm{ANR})}{\mathrm{h}}$ of contaminated air from the machine tool with centrifugal fans lies between 1,157 Wh and 2,083 Wh, assuming a typical pressure drop of 3 500 Pa with an air velocity in the ducts of 20 m/s.

NOTE Typical pressure drop of 3 500 Pa corresponds to 1 500 Pa of pressure drop at the machine extraction hoods plus 2 000 Pa at the CADES (de-duster included) to which the machine is connected.

More detailed values are provided in Table A.2 considering a typical air velocity in the ducts of 20 m/s. and different static pressures and aeraulic fan efficiencies.

Table A.2 — Examples for electrical energy equivalents for 1 m³ (ANR) of extracted contaminated air

Static pressure p_s	Dynamic pressure p_d	Electrical energy equivalent				
		η_{fan} = 0,5	η_{fan} = 0,6	η_{fan} = 0,7	η_{fan} = 0,8	η_{fan} = 0,9
500 Pa	250 Pa	0,417 Wh	0,347 Wh	0,298 Wh	0,260 Wh	0,231 Wh
1 000 Pa	250 Pa	0,694 Wh	0,579 Wh	0,496 Wh	0,434 Wh	0,386 Wh
1 500 Pa	250 Pa	0,972 Wh	0,810 Wh	0,694 Wh	0,608 Wh	0,540 Wh
2 000 Pa	250 Pa	1,250 Wh	1,042 Wh	0,893 Wh	0,781 Wh	0,694 Wh
2 500 Pa	250 Pa	1,528 Wh	1,273 Wh	1,091 Wh	0,955 Wh	0,849 Wh
3 000 Pa	250 Pa	1,806 Wh	1,505 Wh	1,290 Wh	1,128 Wh	1,003 Wh
3 500 Pa	250 Pa	2,083 Wh	1,736 Wh	1,488 Wh	1,302 Wh	1,157 Wh
4 000 Pa	250 Pa	2,361 Wh	1,968 Wh	1,687 Wh	1,476 Wh	1,312 Wh
4 500 Pa	250 Pa	2,639 Wh	2,199 Wh	1,885 Wh	1,649 Wh	1,466 Wh

Annex B
(informative)

Measuring of energy supplies (other than electrical)

B.1 Measuring of pneumatic energy

The gauge pressure of the air entering the system boundary corresponds to meet the minimal nominal value specified by the machine tool manufacturer.

Generally the volume is measured with an uncertainty of better than 6 % (coverage factor, $k = 2$), while the supply pressure oscillations should be within ±25 kPa.

NOTE As many compressed air consuming devices have a consumption proportional to absolute pressure, higher pressure deviations spoil the accuracy of the measurement.

Exception 1: If compressed air is more than 30 % of the energy supplied to the machine tool, it is advisable to measure the volume with an uncertainty of better than 3 % (coverage factor, $k = 2$), and to control the gauge pressure of the air entering the system boundary within ±10 kPa.

Exception 2: If compressed air is less than 10 % of the total energy supplied in the evaluation period, a volume measurement uncertainty of better than 15 % (coverage factor, $k = 2$) is sufficient. In this case, the following simplified measuring procedure may be applied:

— the compressed air should be supplied by a pressure tank solely connected to the machine tool;

— the tank should contain compressed dry air at a temperature of 20 °C ± 10 °C;

— the tank should be sufficiently large to ensure that the pressure at the end of the measuring period is higher than 50 % of the initial pressure;

— the pressure at the machine tool boundary should be kept constant at the required value by means of a pressure reducer;

— the difference between the initial pressure in the tank and the pressure at the end of the measuring period should be monitored.

Assuming isothermal expansion, the air volume is calculated as follows:

$$V = \Delta p \times V_{pt} \tag{B.1}$$

where

V is the air volume in [m^3(ANR)];

Δp is the pressure difference in kPa;

V_{pt} is the volume of the pressure tank in m^3.

B.2 Measuring of heat exchange

Two different heat exchange systems are generally used on machine tools:

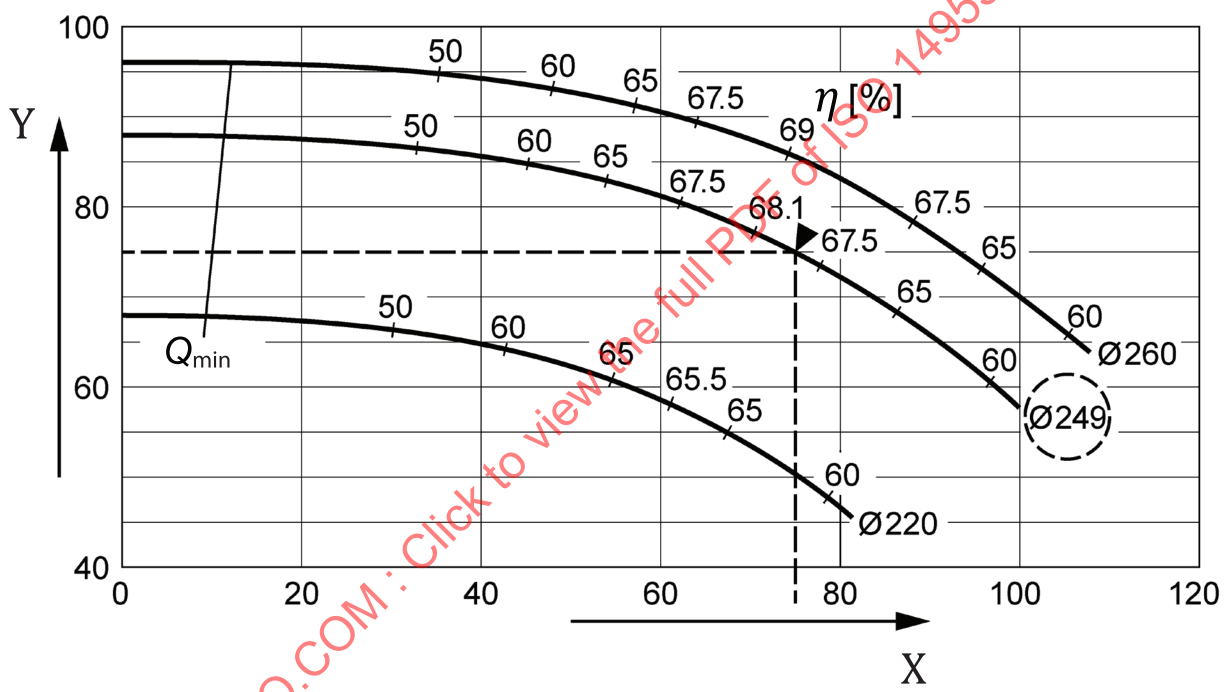
— Liquid/liquid (e.g. oil/water) heat exchangers;

— Liquid/air heat exchangers.

On both systems, the usable energy can be calculated by measuring the inlet and outlet temperature and flow (result is a power) and the time. Measuring of hydraulic fluids is described in relevant standards[4][5].

As a convention, the side of the heat exchanger connected to the liquid to be cooled is called the hot side; the side connected to the coolant is called the cold side.

If the heat capacity of the liquid on the hot side is less than the heat capacity of water (e.g. hydraulic oil), it leads to problems measuring the flow by regular industrial calorimetric sensors. Rotating flow metres are expensive and the long-term reliability is limited due to rotating parts. When these fluids are cooled, an auxiliary way of measuring the flow on the hot side is by measuring the pressure difference between the inlet and outlet on the circulation pump and taking the value from the pump characteristics given by the pump manufacturer (see Figure B.1). If the pump characteristic is based on a specific density (e.g. for impeller pumps), the density of the liquid should be taken into account. The pump speed taken into account should be the average between idling speed and nominal speed of the installed motor.



Key

Q_{min} minimum admissible flow (m³/h)

η pump efficiency (%)

X flow (m³/h)

Y pumping height (m)

Highlighted operating point for wheel diameter 249 mm; pressure equivalent to 75 m pumping height, the flow rate is 75 m³/h

NOTE The efficiency of the pump at the specified operating conditions is 67,8 %.

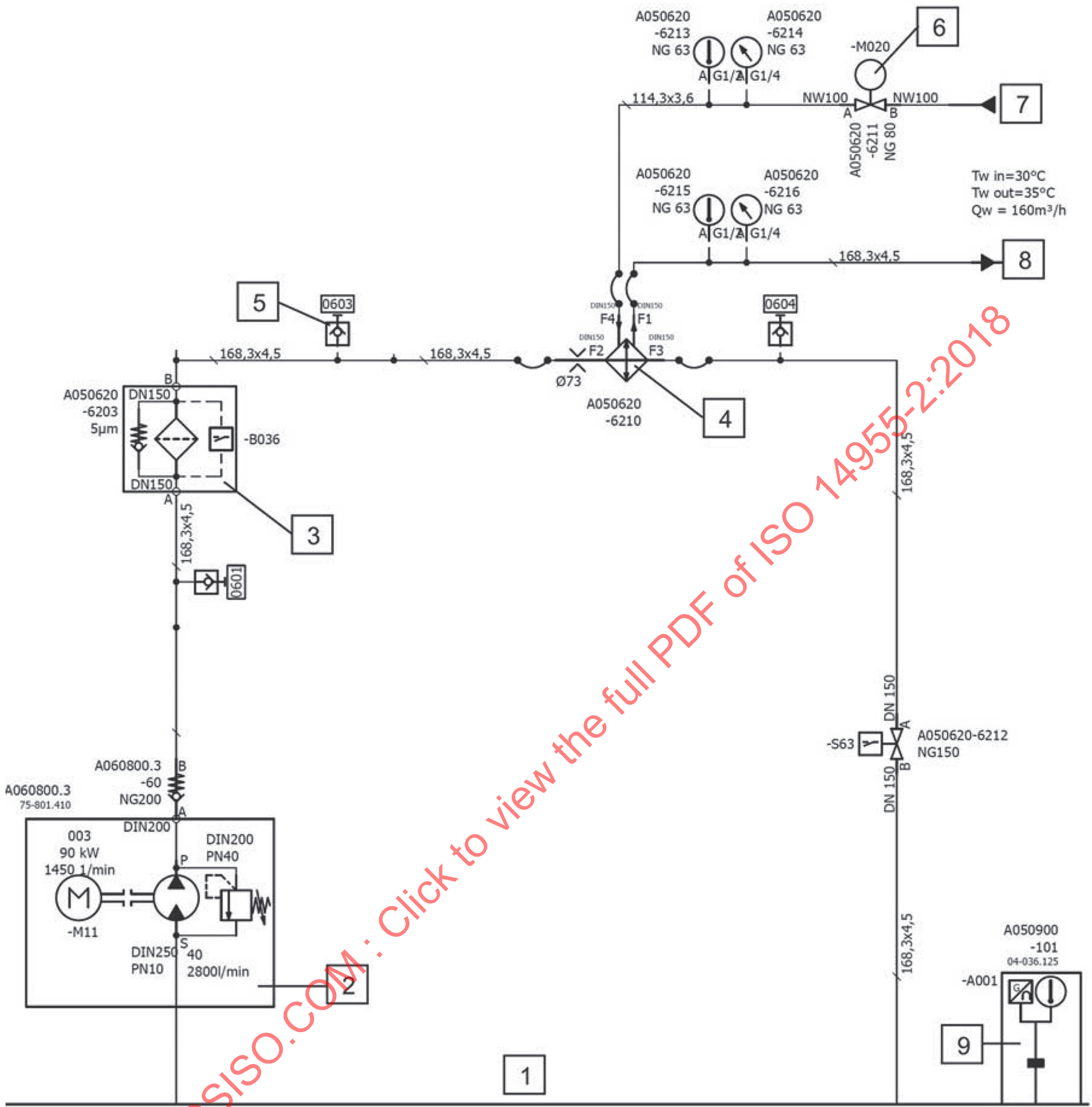
Figure B.1 — Example for impeller pumps characteristics with different wheel diameters at 2 900 min⁻¹

The temperatures should be measured with sensors mounted as close as possible at the ports of the heat exchanger.

On the hot side, in the power fed to the heat exchanger, the power required to achieve a flow is already included and no further measurement of this energy is necessary. The energy needed to generate an air flow or coolant liquid flow is added to the measured results.

At the cold side, on liquid/air heat exchangers the power needed to achieve an air stream through the heat exchanger is easy to measure (power supplied to the fan), the power needed to achieve a water flow for the particular machine tool in a real plant is out of the scope of the machine tool manufacturer. The method of measuring the useable energy shown above is usable for liquid/liquid heat exchangers as well as for liquid/air heat exchangers.

If a liquid/liquid heat exchanger is installed and reliable (e.g. calorimetric) sensors are available for measuring the coolant flow, cooling power can be measured by measuring coolant flow and temperature on the inlet and outlet ports on the cold side. Due to wear (e.g. calcination), it is possible that the coolant flow is reduced and needs to be measured.



Key

1 hydraulic fluid reservoir
2 motor-pump unit
3 filter unit
4 liquid/liquid heat exchanger
5 test ports, for pressure gauge
6 2/2 directional control valve for coolant flow
7 coolant feed line
8 coolant return line
9 contact thermometer or temperature sensor for hydraulic fluid temp

Figure B.2 — Example for a cooling circuit with oil/water heat exchanger

Hot hydraulic fluid is pumped out of the reservoir (1, Figure B.2) by motor-pump unit (2), passing a filter unit (3) and the liquid/liquid heat exchanger (4) and — now cooled — back to the reservoir (1).

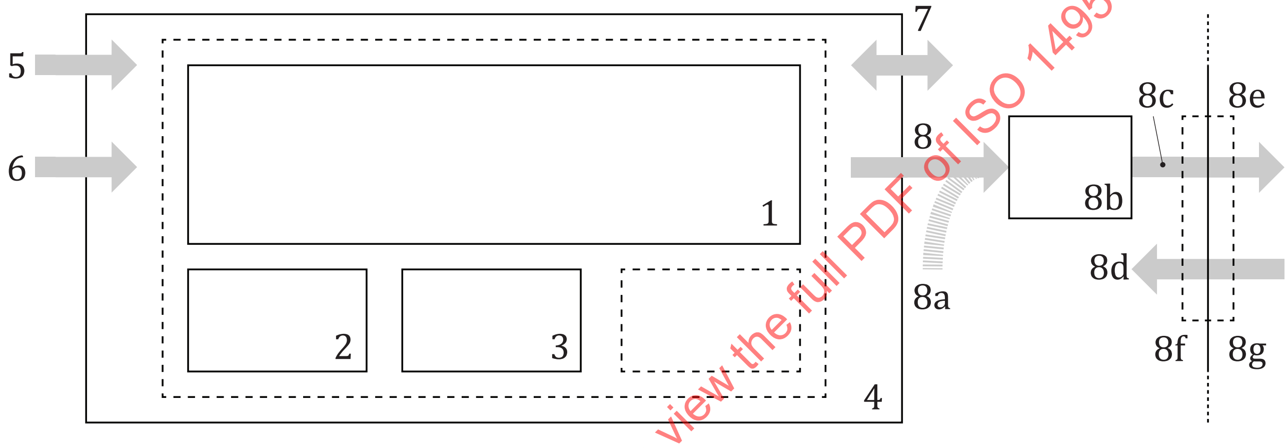
The hydraulic fluid temperature in the reservoir is measured by contact thermometer or temperature sensor (9).

The coolant is fed in coolant feed line (7), passing a 2/2 directional control valve (6) and the liquid/liquid heat exchanger (4) and then leaving in the coolant return line (8).

The motor-pump unit is running as soon as the standby state is reached to achieve filtering of the hydraulic fluid. The valve (6) is controlled to open as soon as a certain hydraulic fluid temperature [measured by (9)] exceeds a certain threshold and controlled to closed as soon as hydraulic liquid temperature is below this value (a hysteresis is not necessary due to thermal inertia).

B.3 Measuring of contaminated air flow and air exchange

The contaminated air flow and pressure are measured simultaneously at each suction pipe or in the main pipes connected to the Chips and Dust Extraction System (CADES).



Key

1 machine tool
2 peripheral A
3 peripheral B
4 system boundary
5 electrical energy
6 compressed air
7 heat exchange
8 contaminated air
8a contaminated air from other machine tools
8b contaminated air extraction and filtering
8c filtered air sent outdoor
8d clean replacement air from outdoor
8e optional heat exchanger
8f indoor (i.e. the shop floor)
8g outdoor

Figure B.3 — Centralized system for contaminated air management

The air flow at each contaminated (for example, by dust) air extraction connection outlet of the machine tool (flow 8 in Figure B.3) corresponds to meet the nominal value specified by the machine tool manufacturer at the declared pressure drop (static pressure).

Generally, the air flow is measured with an uncertainty of better than 5 % (coverage factor, $k = 2$).

Exception 1: If energy supplied related with contaminated air flow is more than 30 % of the energy supplied to the machine tool, the air flow should be measured with an uncertainty of better than 3 % (coverage factor, $k = 2$).

Exception 2: If energy supplied related with contaminated air flow is less than 10 % of the total energy supplied in the evaluation period of the sample shift regime, air flow measurement uncertainty of better than 15 % (coverage factor, $k = 2$) is acceptable.

Measurement according velocity-area method in circular ducts by means of Pitot static tubes is specified in ISO 7194.

$$Q = S \times V_a \qquad \text{(B.2)}$$

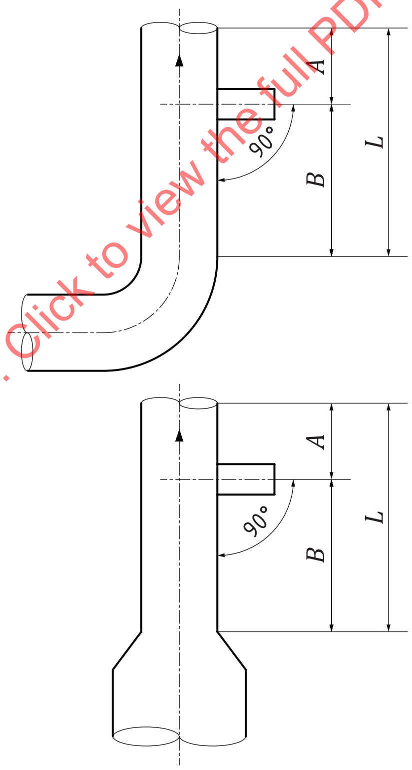
where

Q is the air flow in $\left[\frac{m^3(ANR)}{h}\right]$;

S is the duct cross section in m^2;

V_a is the average velocity in the duct cross section in m/h.

Actual velocity in a specific point inside the duct is related with dynamic pressure (velocity pressure) by the Bernoulli formula. In general, it is not constant within the duct cross section, changing from point to point where swirling, asymmetric and turbulent flow conditions occur. In order to minimize these effects, the measuring plane should be inserted in a straight duct having a total length not less than 11 duct hydraulic diameters (for circular ducts), 8 hydraulic diameters after (see Figure B.4, B) and 3 hydraulic diameters before (see Figure B.4, A) any air flow perturbing element.



Key

L straight duct length

A minimum distance between the measuring instrument and the end of the straight duct, $A = \frac{3}{11}L$

B minimum distance between the air flow perturbing element and the measuring instrument, $B = \frac{8}{11}L$

Figure B.4 — Correct positioning of measuring plane in order to minimize swirling, asymmetric and turbulent effects

In practical applications, it is acceptable to reduce *B* and *A* to minimum values, respectively 5 and 2 hydraulic diameters, for a resulting total straight length of 7 hydraulic diameters.

Hydraulic diameter is calculated as follows:

$$D_h = 4 \times \frac{S}{p} \tag{B.3}$$

where

D_h is the hydraulic diameter in m;

S is the duct section in m^2;

p is the duct perimeter in m.

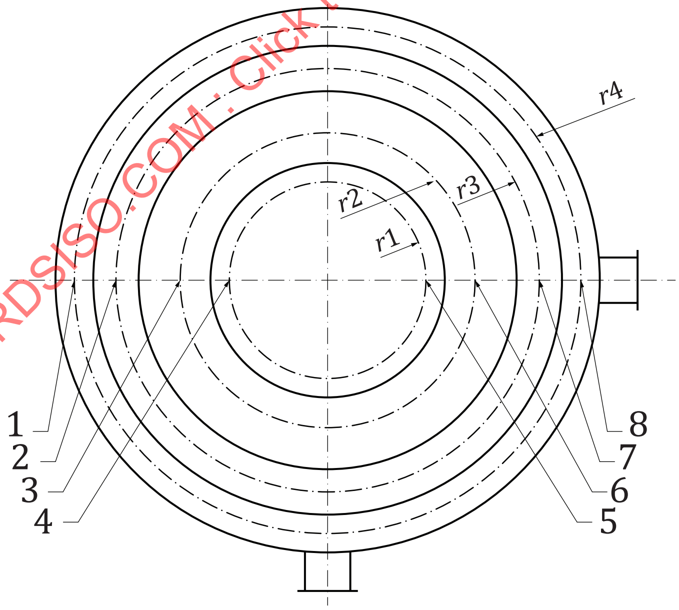
NOTE Hydraulic diameter corresponds to the geometrical diameter for circular ducts.

A device for improving flow conditions (straightener) should be installed, if possible, in order to eliminate flow swirl and/or asymmetry.

For ducts having a hydraulic diameter more than 0,1 m, average velocity should be calculated as the average of a series of velocity pressure readings taken at sensing points representative of equal areas. A formal pattern (traverse readings) of sensing points across the duct cross section is recommended.

Figure B.5 and Figure B.6 show an example of recommended Pitot tube locations for traversing round and rectangular ducts, respectively. Velocity measures shall be taken along one line for ducts with a cross section diameter up to 1 m (circular ducts) and minimum side of 0,5 m (rectangular ducts).

NOTE Velocity of the air stream is not uniform across the cross section of a duct due to friction that slows the air moving close to the walls, so the velocity is greater in the centre of the duct.

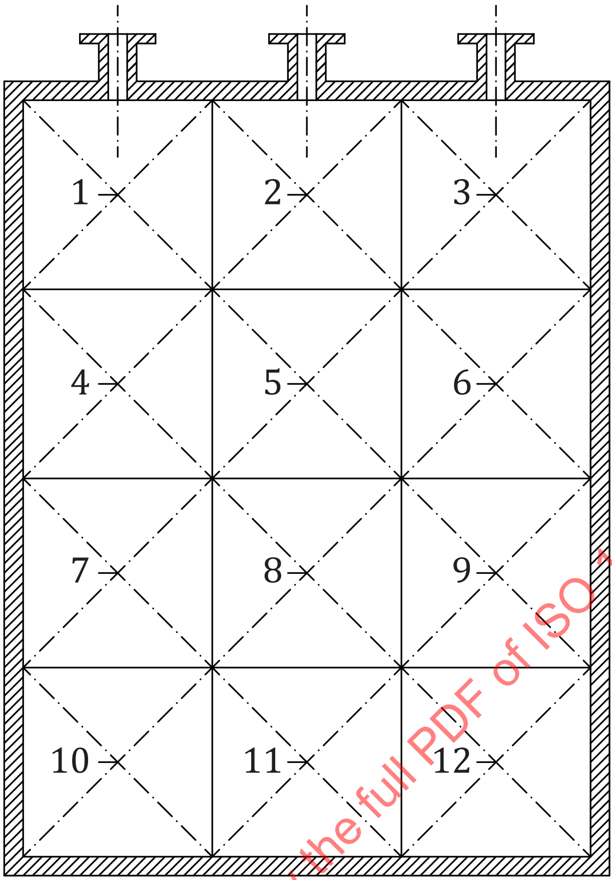


Key

r_i radius of ring i (from 1 to 4)

1, ..., 8 measuring points

Figure B.5 — Example of circular duct cross section divided in 4 equal concentric areas



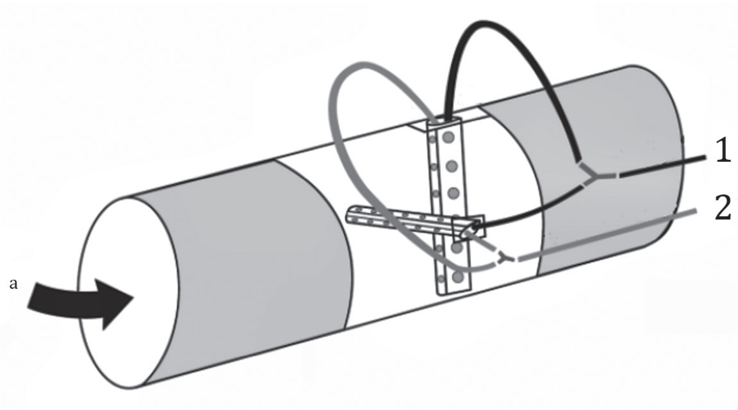
Key

1, ..., 12 measuring points

Figure B.6 — Example of rectangular duct cross section divided in 12 equal rectangular areas

In ducts having a diameter smaller than 0,1 m or where traverse operations are otherwise impossible, an accuracy of ±5 % can frequently be achieved by placing the Pitot tube in the centre. An approximate average is obtained by multiplying the velocity value in the centre by 0,9.

Flow measuring blades (see Figure B.7) represent a simple and cost-effective method of providing permanent air flow measurement in rectangular or circular ducts. When correctly placed in an air flow (see Figure B.8), an average differential pressure is generated, the square root of which is proportional to the air flow. Great care should be taken in choosing the differential pressure measuring instrument as it is mainly this instrument that determines the uncertainty of the air flow measurement.



Key

1 average static pressure

2 average dynamic pressure

a Air flow.

Figure B.7 — Example of flow measuring blade application

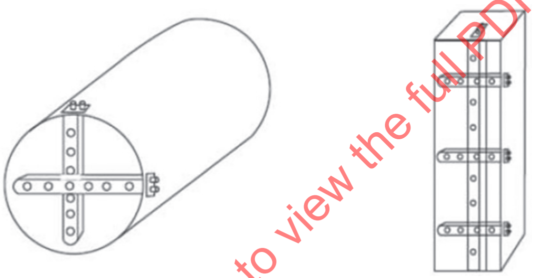


Figure B.8 — Example of flow measuring blade mounting in circular and rectangular ducts

The air flow is calculated as follows:

$$Q = K_L \times S \times 3\,600 \times \frac{\rho_t}{\rho_n} \times \sqrt{\frac{2 \times p_d}{\rho_t}} \quad \text{(B.4)}$$

where

K_L is the blade factor typical for the selected measuring blade;

p_d is the dynamic pressure (velocity pressure) average calculated as difference between total pressure average, p_t, and static pressure average, p_s, both in Pa.

Q is the air flow in $\left[\frac{m^3 (ANR)}{h}\right]$;

S is the duct section in m^2;

ρ_t is the air density under test conditions in kg/m^3;

ρ_n is the air density under normal conditions in kg/m^3;

NOTE ρ_t/ρ_n is the factor to transform the volume flow rate from test conditions into normal conditions.

Heat exchange is taken into account in winter time when outdoor air replacing contaminated air extracted from the machine tool is entered at the shop floor level (flux 8d in Figure B.3; i.e. not directly into the machine tool) and its electrical energy equivalent exceeds 10 % of the total energy supplied.

At constant pressure conditions (assuming negligible pressure fluctuations generated by the ventilation system), the energy necessary to warm up incoming outdoor air up to the shop floor temperature is calculated as the corresponding variation of enthalpy of dry air and water vapour, for the given air absolute humidity. The enthalpy variation can be estimated using the corresponding psychrometric chart (as the ASHRAE: Psychrometric Chart N.1) or, assuming average values, as:

$$\Delta h = (C_{\text{pa}} + x \times C_{\text{pw}}) \times \Delta T \quad \text{(B.5)}$$

where

C_{pa} is the specific heat capacity of dry air in kWh/kg°C (for air temperature between −100 °C to +100 °C it can be set to $2{,}79 \times 10^{-4} \dfrac{\text{kWh}}{\text{kg°C}}$;

C_{pw} is the specific heat of water vapour at constant pressure in kWh/kg°C (it can be set to $5{,}22 \times 10^{-4} \dfrac{\text{kWh}}{\text{kg°C}}$)[19];

x is the mass fraction of water vapour, also called "humidity ratio", [dimensionless];

Δh is the enthalpy variation in kWh/kg;

ΔT is the air temperature variation between outdoor and shop floor in °C.

To estimate the water vapour mass fraction, x, the following procedure is proposed. The water vapour pressure at a given temperature and relative humidity can be estimated by the following approximated formula:

$$p_v = \left(611{,}2 \times 10^{\frac{7{,}5 \times T}{237{,}7 + T}} \right) \times \frac{\varphi}{100} \quad \text{(B.6)}$$

where

p_{v} is the partial pressure of water vapour in Pa;

T is the air temperature in °C;

φ is the relative humidity in %.

The water vapour mass fraction equals:

$$x = \frac{m_{\text{v}}}{m_{\text{da}}} \quad \text{(B.7)}$$

$$x = \frac{M_{\text{v}}}{M_{\text{da}}} \times \frac{p_{\text{v}}}{p_{\text{da}}} \quad \text{(B.8)}$$

$$x = \frac{M_{\text{v}}}{M_{\text{da}}} \times \frac{p_{\text{v}}}{p_{\text{t}} - p_{\text{v}}} \quad \text{(B.9)}$$

$$x = 0{,}622 \times \frac{p_v}{p_t - p_v} \quad \text{(B.10)}$$

where

m_{da} is the mass of dry air in kg;

m_v is the water vapour mass in kg;

M_{da} is the dry air molar mass in g/mol;

M_v is the water vapour molar mass in g/mol;

p_v is the partial pressure of water vapour in Pa;

p_{da} is the partial pressure of dry air in Pa;

p_t is the total moist air pressure in Pa.

x is the mass fraction of water vapour, also called "humidity ratio", dimensionless;

With:

$$p_t = p_v + p_{da} \quad \text{(B.11)}$$

where

p_t is the total moist air pressure in Pa;

p_v is the partial pressure of water vapour in Pa;

p_{da} is the partial pressure of dry air in Pa.

Assuming a density of the contaminated air of 1,25 kg/m^3, the total equivalent electrical energy necessary to warm up an air flow, Q, from temperature T to $T + \Delta T$ is calculated as follows:

$$E_{eq} = \frac{Q \times 1{,}25 \times \left(2{,}79 \times 10^{-4} + x \times 5{,}22 \times 10^{-4}\right) \times \Delta T}{\eta_{hs}} \quad \text{(B.12)}$$

where

E_{eq} is the total equivalent electrical energy in kWh;

Q is the air flow of outdoor air at ambient pressure in m^3/h;

x is the mass fraction of water vapour, also called "humidity ratio", dimensionless;

ΔT is the temperature increase from outdoor to indoor in °C;

η_{hs} is the efficiency factor of the heating system, dimensionless.

Heat recovery from outgoing contaminated air flow (i.e. device 8e in Figure B.3), if any, is taken into account reducing accordingly the corresponding total energy supplied.

Annex C
(informative)

Measurement example

C.1 Machine tool description

Kind of machining process: Milling

List of machine tool and peripherals within the system boundary:

— machining centre with integrated lubricant supply system, total nominal power 86,5 kW;

— re-cooling system liquid/ambient air, nominal power 6,9 kW;

— chip conveyor (included in MT supply);

— mist extraction system (included in MT supply).

Working volume: 1 000 mm × 1 000 mm × 800 mm (X,Y,Z).

C.2 Measurement setup description

Type of supplies measures apart of electrical energy supply:

— Compressed air 600 kPa.

Type of measurement equipment and its instrument uncertainty (coverage factor, $k = 2$):

— Electrical power ≤10 kW, 3-phase power meter, instrument uncertainty 1,5 % of full scale;

— Electrical power >10 kW, 3-phase power meter with current transformer, instrument uncertainty 2 % of full scale;

— Compressed air flow $0\frac{\mathrm{m^3(ANR)}}{\mathrm{h}} - 150\frac{\mathrm{m^3(ANR)}}{\mathrm{h}}$, instrument uncertainty 3 % of full scale.

C.3 Ambient conditions

23,5 °C to 26,0 °C in workshop (temperature not controlled) during measurements.

C.4 Operating states

— READY FOR PROCESSING

— PROCESSING

— OFF

C.5 Machine tool activity

— READY FOR PROCESSING: Standby

— READY FOR PROCESSING: Spindle warm-up cycle

— PROCESSING: Reference process as defined by machine tool manufacturer

C.6 Measurement result description

Date and time: 2012-09-23 13:54/16:27

READY FOR PROCESSING, Standby, measuring stopped after 200 s due to stable power supply.

— Average electrical power 3,2 kW

— compressed air volume flow rate $10{,}7\frac{m^3(ANR)}{h}$

READY FOR PROCESSING, Spindle warm-up cycle, duration 480 s

— Average electrical power 5,2 kW

— compressed air volume flow rate $20{,}9\frac{m^3(ANR)}{h}$

PROCESSING, reference process with a duration of 1 250 s, three cycles

— Average electrical power 7,3 kW

— compressed air volume flow rate $17{,}7\frac{m^3(ANR)}{h}$

OFF, measuring stopped after 60 s due to stable power supply.

— Average electrical power 0 kW

— compressed air volume flow rate $0\frac{m^3(ANR)}{h}$

C.7 Results

C.7.1 Definition of relevant operating states

— Summary judgement of relevancy: READY FOR PROCESSING Spindle warm-up. Although the average electrical power in this operating state is higher than in Standby, this state is omitted. This operating state is used a few times per day only and lasts typically 360 s, whereas the average power for PROCESSING is significantly higher.

— Therefore, the sample shift regime is applied, with the operating states READY FOR PROCESSING and PROCESSING. OFF is part of the evaluation period, but not considered, as in this operating state no energy is supplied.

C.7.2 Electrical energy equivalent

— Electrical energy equivalent of compressed air is assumed with $0{,}13\frac{kWh}{m^3(ANR)}$, average industrial supply according to Table A.1.

C.7.3 Parameters for calculations

— OFF:

4 h, 0 kW electrical power, $0\frac{m^3(ANR)}{h}$

— READY FOR PROCESSING, Standby (time includes spindle warm-up):

4 h, 3,2 kW electrical power, $10,7 \frac{\mathrm{m}^3(\mathrm{ANR})}{\mathrm{h}}$

— PROCESSING:

16 h, 7,3 kW electrical power, $17,7 \frac{\mathrm{m}^3(\mathrm{ANR})}{\mathrm{h}}$

C.7.4 Calculation

Energy supplied within an evaluation period of 24 h with sample shift regime:

$$E = 3,2\ \mathrm{kW} \times 4\ \mathrm{h} + 10,7 \frac{\mathrm{m}^3(\mathrm{ANR})}{\mathrm{h}} \times 0,13 \frac{\mathrm{kWh}}{\mathrm{m}^3(\mathrm{ANR})} \times 4\ \mathrm{h} + 7,3\ \mathrm{kW} \times 16\ \mathrm{h} + 17,7 \frac{\mathrm{m}^3(\mathrm{ANR})}{\mathrm{h}} \times 0,13 \frac{\mathrm{kWh}}{\mathrm{m}^3(\mathrm{ANR})} \times 16\ \mathrm{h} \quad \text{(C.1)}$$

$$E = 172\ \mathrm{kWh} \quad \text{(C.2)}$$

where E is the electrical energy supplied in kWh.

C.7.5 Estimation of uncertainty

Only instrument uncertainty is taken into account. Influence of environment is assumed to be negligible, as well as any influences from power fluctuations.

Measuring time: 20 h(READY FOR PROCESSING and PROCESSING), instrument uncertainty for power measurement 0,15 kW (1,5 % of 10 kW full scale), for air flow measurement $4,5 \frac{\mathrm{m}^3(\mathrm{ANR})}{\mathrm{h}}$.

$$U(k=2) = 20\ \mathrm{h} \times \left(0,15\ \mathrm{kW} + 0,13 \frac{\mathrm{kWh}}{\mathrm{m}^3(\mathrm{ANR})} \times 4,5 \frac{\mathrm{m}^3(\mathrm{ANR})}{\mathrm{h}} \right) \quad \text{(C.3)}$$

$$U(k = 2) = 15\ \mathrm{kWh} \quad \text{(C.4)}$$

where $U(k = 2)$ is the measurement uncertainty in kWh.

C.7.6 Final result

$$E = 172\ \mathrm{kWh} \pm 15\ \mathrm{kWh}\ (k = 2) \quad \text{(C.5)}$$

C.8 Functional description

Energy supplied in READY FOR PROCESSING is <11 % of the energy supplied. Therefore, functional description is calculated for PROCESSING only.

The following components are measured separately:

— 24 V Supply;

— 230 V single phase supply;

— CNC with spindle and axis drives;

— Tool changer;

- Chip conveyor;
- Mist extraction system;
- Hydraulic pump;
- Pump for exterior lubricant supply;
- Pump for interior lubricant supply;
- Lubricant circulation pump;
- Re-cooling system liquid/air;
- Chip flushing pump;
- Lubricant band filtering system;
- Cooler for electrical cabinet.

The components are assigned to the functions according to Table C.1. Function “Part Handling” is omitted, because part handling is manual. Miscellaneous components with a minor share of energy supplied are not assigned to any machine tool function.

Table C.1 — Functional mapping for operating state PROCESSING

	Average power	Machine operation	Process conditioning	Tool handling	Waste handling	Machine tool cooling	Sum
24 V Supply	0,00 kW*	100 %					100 %
230 V single phase supply	0,07 kW*	100 %					100 %
CNC with spindle and axis drives	2,16 kW	100 %					100 %
Tool changer	0,02 kW*			100 %			100 %
Chip conveyor	0,04 kW*				100 %		100 %
Mist extraction system	0,75 kW		10 %		80 %	10 %	100 %
Hydraulic pump	0,18 kW*			100 %			100 %
Pump for exterior lubricant supply	0,23 kW*		80 %			20 %	100 %
Pump for interior lubricant supply	0,49 kW*		70 %		30 %		100 %
Lubricant circulation pump	0,20 kW*		90 %			10 %	100 %
Re-cooling system liquid/air	2,61 kW		20 %			80 %	100 %
Chip flushing pump	0,17 kW*				80 %	20 %	100 %
Lubricant band filtering system	0,00 kW*				100 %		100 %
Cooler for electrical cabinet	0,19 kW*					100 %	100 %
Miscellaneous components	0,17 kW	n. a.	n. a.	n. a.	n. a.	n. a.	

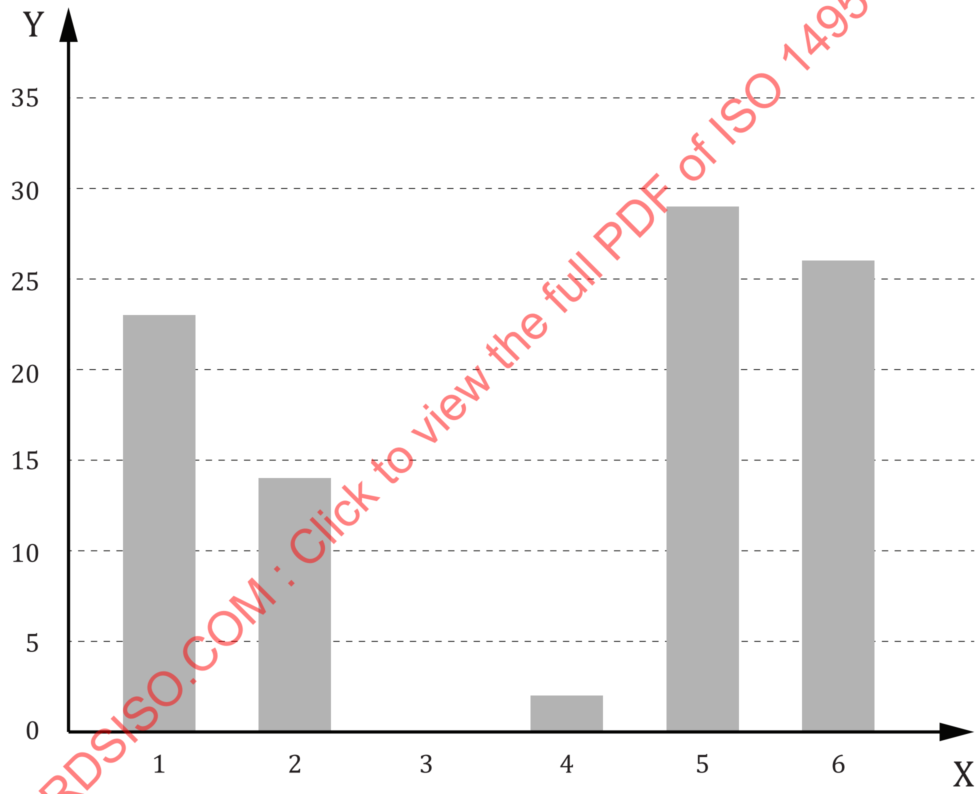
NOTE Components with average power marked with “*” are exempt from compulsory individual measurement according to 7.1.

Table C.1 *(continued)*

	Average power	Machine operation	Process conditioning	Tool handling	Waste handling	Machine tool cooling	Sum
Total average electrical power	7,29 kW						
Compressed air	2,28 kW				100 %		100 %
Total average power	9,58 kW	2,23 kW	1,30 kW	0,20 kW	2,77 kW	2,45 kW	
	100 %	23 %	14 %	2 %	29 %	26 %	

NOTE Components with average power marked with "*" are exempt from compulsory individual measurement according to 7.1.

Figure C.1 shows the share of energy supplied to different machine tool functions during processing.



Key

1 machine operation
2 process conditioning
3 part handling
4 tool handling
5 waste handling
6 machine tool cooling
X machine tool function
Y share of energy supplied (%)

Figure C.1 — Share of energy supplied to machine tool functions for a measurement example during processing

Annex D
(informative)

Equations for the calculation of energy supplied and energy efficiency

The energy efficiency factor of a machine tool during an activity is calculated as follows:

$$\eta_{\mathrm{MTa}} = \frac{W_{\mathrm{MTa}}}{W_{\mathrm{SysBoundMTa}}} \tag{D.1}$$

where

W_{MTa}	is the necessary energy supplied during a machine tool activity, see subsequent parts of ISO 14955;
$W_{\mathrm{SysBoundMTa}}$	is the energy supplied at the system boundary for a machine tool activity.
η_{MTa}	is the energy efficiency factor of a machine tool activity;

The energy supplied at the system boundary during a complete cycle is calculated as follows:

$$W_{\mathrm{SysBoundCycle}} = \sum_{\mathrm{MTa}_1}^{\mathrm{MTa}_n} W_{\mathrm{SysBoundMTa}} \tag{D.2}$$

$$W_{\mathrm{SysBoundCalc}} = \sum_{\mathrm{MTa}_1}^{\mathrm{MTa}_n} W_{\mathrm{MTa}} \tag{D.3}$$

where

W_{MTa}	is the necessary energy supplied during a machine tool activity, see subsequent parts of ISO 14955.
$W_{\mathrm{SysBoundCycle}}$	is the energy supplied at the system boundary for a machine tool cycle;
$W_{\mathrm{SysBoundMTa}}$	is the energy supplied at the system boundary for a machine tool activity;
$W_{\mathrm{SysBoundCalc}}$	is the necessary energy supplied for a machine tool cycle, see subsequent parts of ISO 14955;

The energy efficiency factor of a machine tool during this cycle is calculated as follows:

$$\eta_{\mathrm{MTCycle}} = \frac{W_{\mathrm{SysBoundCalc}}}{W_{\mathrm{SysBoundCycle}}} \tag{D.4}$$

where

η_{MTCycle}	is the energy efficiency factor of a machine tool cycle;
$W_{\mathrm{SysBoundCalc}}$	is the necessary energy supplied for a machine tool cycle, see subsequent parts of ISO 14955;
$W_{\mathrm{SysBoundCycle}}$	is the energy supplied at the system boundary for a machine tool cycle.

To determine the share of the machine tool components influencing the energy efficiency factor, the measured power loss can be taken into account.

It is calculated as follows:

$$W_{\mathrm{MTaCompLoss}} = \sum_{t_{\mathrm{MTaStart}}}^{t_{\mathrm{MTaEnd}}} P_{\mathrm{CompLossMTa}} \times \Delta t \tag{D.5}$$

where

$P_{\mathrm{CompLossMTa}}$	is the power loss of a machine tool component during a machine tool activity (e.g. $P_{\mathrm{SlPwrLossDesc.}}$, $P_{\mathrm{CuPwrLossLift.}}$);
t_{MTAStart}	is the starting time of a machine tool activity;
t_{MTAEnd}	is the end time of a machine tool activity;
$W_{\mathrm{MTACompLoss}}$	is the energy transferred into heat;
Δt	is the sampling rate of the measuring equipment.

The energy efficiency factor of a machine tool component is calculated as follows:

$$\eta_{\mathrm{MTaComp}} = 1 - \frac{W_{\mathrm{MTaCompLoss}}}{W_{\mathrm{MTaComp}}} \tag{D.6}$$

where

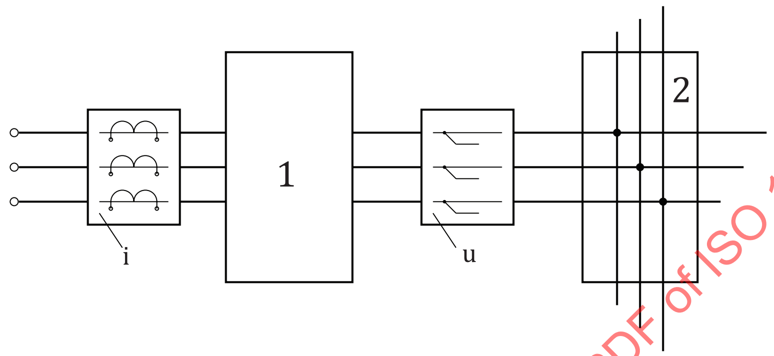
$W_{\mathrm{MTaCompLoss}}$	is the energy transferred into heat;
W_{MTaComp}	is the energy supplied to a machine tool component during a machine tool activity.
η_{MTaComp}	is the energy efficiency factor of a machine tool component;

NOTE Equations for calculation of the necessary energy supplied in operating state PROCESSING using nominal process values of different machine tool components are given in some of the annexes of the specific machine tools in the machine tool specific parts of ISO 14955.

Annex E
(informative)

Examples of power measurement setup

E.1 Single feeding point electrical power measurement



Key

1 main switch

2 power distribution

i current measuring point

u voltage measuring point

Figure E.1 — Setup for electric power measurement at a single feeding point

Single feeding point electrical power measurement is done at the system boundary as depicted in Figure E.1. Measurements of machine tool components are made accordingly.

If less than three phases are measured in a three-phase power system, the asymmetry shall be known during all machine tool activities and documented. The power factor shall be determined based on measured phase shift.

E.2 Power measurement at electric motors

E.2.1 General

The purpose of electric motors in machine tools is the conversion of electric power into force or torque and speed which is distributed to actuators, for example for workpiece processing or handling. Today, this conversion is mostly done by direct mechanical means (e.g. eccentric drive, belt, nut and spindle), fluidic means (e.g. compressed air, hydraulic fluids) or combination of both. Electric motors are controlled by starters or inverter systems.

For measurement of electrical power using actual values supplied by inverter systems, the measuring uncertainty of the values shall be known and the actual values shall

— be actualized with an effective sampling rate not less than 5 S/s,

— include the power loss of the inverter, filters and line reactor. If not, load-dependent efficiency factors for the inverter, filters and line reactor shall be given by the inverter manufacturer, and

— be recorded simultaneously or synchronized with the other measured values.