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Machine tools — Environmental evaluation of machine tools

Part 1: Design methodology for energy-efficient machine tools

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National foreword

This British Standard is the UK implementation of ISO 14955-1:2014.

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 39, *Machine tools*.

ISO 14955 consists of the following parts, under the general title *Machine tools — Environmental evaluation of machine tools*:

— *Part 1: Design methodology for energy-efficient machine tools*

The following parts are planned:

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

— *Part 4: Principles for testing metal-forming machine tools with respect to energy efficiency*

Introduction

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

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 being 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.

This part of ISO 14955 tries to overcome this deficiency by breaking down the machine tool to machine components which come closer to a functional unit for environmental evaluation. The machine components are objects of specific improvements keeping the application of the system in mind. These improvements are subject for quantification together with the overall system design to achieve a product with an improved environmental performance. The provisions and procedures specified in this part of ISO 14955 are also intended to allow the calculation of environmental improvements on a multi-national level and across different manufacturers/suppliers and users.

Based on a list of positive environmental features, which can be built into a machine tool, the performance of this product is intended to be evaluated in order to quantify the environmental improvements achieved over a defined period.

ISO 14955 takes care of relevant environmental impacts during the use stage. Aside from the design and engineering of machine tools, the utilization of these products is also addressed.

Machine tools as manufacturing devices might have a significant influence on the environmental performance of the products being manufactured together with their final use stage. This aspect has to be treated very sensitively and might produce quite different results when an assessment is made with a broader definition of the system boundaries.

Machine tools — Environmental evaluation of machine tools —

Part 1:
Design methodology for energy-efficient machine tools

1 Scope

This part of ISO 14955 constitutes the application of eco-design standards to machine tools, mainly for metal working numerically controlled (NC) machine tools.

This part of ISO 14955 addresses the energy efficiency of machine tools during the use stage, i.e. the working life of the machine tool. Environmental relevant stages other than the use stage and relative impacts other than energy supplied to machine tools are not within the scope of this part of ISO 14955 and need a special treatment (e.g. according to ISO/TR 14062).

Elements of eco-design procedure according to ISO/TR 14062 are applied to machine tools. Reporting of results to users and suppliers and monitoring of results are defined.

Evaluation of energy efficiency implies quantification of the resources used, i.e. energy supplied, and of the result achieved. This part of ISO 14955 provides guidance for a reproducible quantification of the energy supplied. It does not suggest a methodology for quantifying the result achieved due to the lack of universal criteria. The result achieved in industrial application being machined workpieces, their properties (e.g. material, shape, accuracy, surface quality), the constraints of production (e.g. minimum lot size, flexibility), and other appropriate parameters for the quantification of the result achieved are intended to be determined specifically for each application or for a set of applications.

This part of ISO 14955 defines methods for setting up a process for integrating energy-efficiency aspects into machine tool design. It does not support the comparison of machine tools. Also, this part of ISO 14955 does not deal with the effect of different user behaviours or different manufacturing strategies during the use phase.

Lists of environmentally relevant improvements and machine components, control of machine components, and combinations of machine components are given in two informative annexes, one for metal-cutting machine tools (Annex A) and one for metal-forming machine tools (Annex B). Annex C provides an example of application of the methodology. Other machine tools, e.g. laser-cutting machine tools, material additive machine tools, and woodworking machine tools are currently not covered by informative annexes.

NOTE Certain machining processes and specific machine tools can allow significant changes in the environmental impact of machined workpieces, e.g. material reduction for aluminium cans by application of special press technology, higher performance of compressors by machining on precision form grinders.[3][5] The environmental impact of such processes or machine tools might be less important compared to the environmental impact of the machined workpieces and their application. These changes in the environmental impact of machined workpieces are not subject of this part of ISO 14955 but might be important if different machining processes or different machine tools have to be compared related to environmental impact of products. For instance, the accuracy of a machined workpiece might be a significant parameter for the environmental impact of the workpiece in its use stage, and any attempt to compare machine tools is intended to take this into account necessarily.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14021:1999, *Environmental labels and declarations — Self-declared environmental claims (Type II environmental labelling)*

ISO 14031, *Environmental management — Environmental performance evaluation — Guidelines*

ISO/TR 14062:2002, *Environmental management — Integrating environmental aspects into product design and development*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 14062 and the following apply.

3.1

design and development
set of processes that transforms requirements into specified characteristics or into the specification of a product, process, or system

Note 1 to entry: The terms “design” and “development” are sometimes used synonymously and sometimes used to define different stages of the overall process of turning an idea into a product.

Note 2 to entry: Product development is the process of taking a product idea from planning to market launch and review of the product, in which business strategies, marketing considerations, research methods, and design aspects are used to take a product to a point of practical use. It includes improvements or modifications to existing products or processes.

Note 3 to entry: The integration of environmental aspects into product design and development may also be termed Design for Environment (DFE), eco-design, the environmental part of product stewardship, etc.

[SOURCE: ISO 9000:2005, 3.4.4]

3.2

environment
surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation

Note 1 to entry: Surroundings in this context extend from within an organization to the global system.

[SOURCE: ISO 14001:2004, 3.5]

3.3

environmental aspect
element of an organization’s activities, products, or services that can interact with the environment

Note 1 to entry: A significant environmental aspect is an environmental aspect that has or can have significant environmental impact.

[SOURCE: ISO 14001:2004, 3.6]

3.4

environmental impact
any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization’s environmental aspects

[SOURCE: ISO 14001:2004, 3.7]

3.5

life cycle

consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to the final disposal

Note 1 to entry: The stages of a product's life cycle are raw material acquisition, manufacture, distribution, use, and disposal (Introduction of ISO/TR 14062 based on 5.2.3 of ISO 14040:2006).

[SOURCE: ISO 14040:2006, 3.1]

3.6

mode of operation

type of operating and controlling a machine tool, whereby different modes of operation are defined by safety standards for machine tools

Note 1 to entry: Examples for modes of operation are manual mode, automatic mode, and setting mode.

Note 2 to entry: Different machine activities require certain modes of operation as laid down in safety standards for machine tools.

3.7

operating state

defined combination of ON, HOLD, OFF, etc., states of mains, peripheral units, machine control, machine processing unit, and machine motion unit including machine activities when operating state is other than OFF

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

Note 2 to entry: Machine 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, and draw cushions of a press.

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

Note 4 to entry: For measurement and testing energy efficiency of machine tools, operating states such as OFF, STANDBY, EXTENDED STANDBY, WARM UP, READY FOR OPERATION, PROCESSING, and CYCLING, have to be defined. An example for such a definition for a metal-cutting machine tool is given in Table D.1.

Note 5 to entry: Examples for machine 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 activities, a mode of operation is selected as defined by relevant safety standards of machine tools.

3.8

environmental claim

statement, symbol or graphic that indicates an environmental aspect of a product, a component or packaging

Note 1 to entry: An environmental claim may be made on product or packaging labels through product literature, technical bulletins, advertising, publicity, telemarketing, as well as through digital or electronic media such as the Internet.

[SOURCE: ISO 14021:1999, 3.1.3]

3.9

environmental claim verification

confirmation of the validity of an environmental claim using specific predetermined criteria and procedures with assurance of data reliability

[SOURCE: ISO 14021:1999, 3.1.4]

3.10
explanatory statement

any explanation which is needed or given so that an environmental claim can be properly understood by a purchaser, potential purchaser, or user of the product

[SOURCE: ISO 14021:1999, 3.1.6]

3.11
functional unit

quantified performance of a product system for use as a reference unit in a life cycle assessment study

[SOURCE: ISO 14021:1999, 3.1.7]

3.12
machine tool function

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

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

Note 2 to entry: Figure 7 shows an example relation between machine components and machine tool functions.

Note 3 to entry: Machine tool functions may be used for identifying machine components (3.13) relevant for energy supplied to the machine tool.

3.13
machine component

mechanical, electrical, hydraulic, or pneumatic device of a machine tool, or a combination thereof

3.14
qualified environmental claim

environmental claim which is accompanied by an explanatory statement that describes the limits of the claim

[SOURCE: ISO 14021:1999, 3.1.12]

3.15
self-declared environmental claim

environmental claim that is made, without independent third-party certification, by manufacturers, importers, distributors, retailers, or anyone else likely to benefit from such a claim

[SOURCE: ISO 14021:1999, 3.1.13]

3.16
machine tool

mechanical device which is fixed (i.e. not mobile) and powered (typically by electricity and compressed air), typically used to fabricate metal components by the selective removal or mechanical deformation

Note 1 to entry: Machine tools operation can be mechanical, controlled by humans or by computers. Machine tools have also a number of peripherals used for feeding, safety, waste and chip removal, lubrication, and other tasks connected to their main activities.

3.17
energy efficiency

relationship between the result achieved and the resources used, where resources are limited to energy input

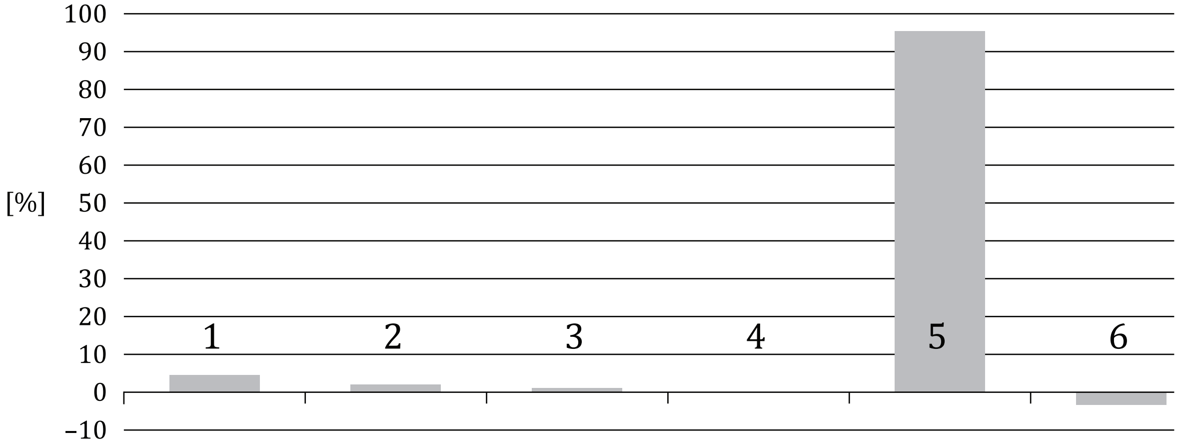
Note 1 to entry: Efficiency is defined as the relationship between the result achieved and the resources used (ISO 9000:2005, 3.2.15).

Note 2 to entry: Statements of energy efficiency can be given e.g. in cycle per total energy supplied, in workpiece per energy supplied. If machining of test pieces is involved, specification of workpiece machining and quality of workpiece are part of the definition of the result.

4 Restriction to energy efficiency during use stage

For the environmental impact of a machine tool, different stages of the product life cycle shall be investigated: acquisition of raw material for the machine tool, manufacturing of the machine tool, transportation of the machine tool, installation of the machine tool, use of the machine tool, and recycling of the machine tool (for more details on life cycle assessment, see ISO 14040).

If the environmental impacts are compared in the different stages of a machine tool, the typical profile is as shown in Figure 1, which gives the profile of an NC milling machine. The largest impact is in the use stage, and the largest contributor in the use stage is the energy supplied to the machine tool. This is the result of many life cycle assessments for machine tools [1][4][5][7] if the machine tool is used for 8 h a day/5 d a week or more, which is typical for the use of machine tools in an industrial manufacturing environment.



Key

1	raw material
2	production
3	transport
4	set-up
5	use
6	recycling

Figure 1 — Example of an eco-profile for a milling machine

Therefore, this part of ISO 14955 concentrates on the environmental impact, and specifically on the possibility of improving the energy efficiency during the use stage.

If the machine tool is not used in a typical industrial manufacturing environment, a complete life cycle assessment, e.g. according to ISO 14040, might be needed in order to identify the relevant environmental impacts. Measures other than increasing energy efficiency during the use stage to change the environmental impact might be of importance.

5 Integrating environmental aspects into machine tool design and development (design procedure for energy-efficient machine tools)

5.1 General

This is the application of ISO/TR 14062 for achieving energy-efficient machine tools in the use stage.

5.2 Goal and potential benefits

The goal of integrating environmental aspects into machine tool design and development is the reduction of adverse environmental impacts of machine tools, especially the increase of energy efficiency during the use stage of the average machine tool in an industrial manufacturing environment.

Benefits for the machine tool supplier/manufacturer and user may include the following:

- energy efficiency during use stage;
- cost reduction in machine tools operations;
- increased competitiveness of the metal working sector;
- stimulation of innovation and creativity;
- enhancement of organization image and/or brand;
- attraction of financing and investment, particularly from environmentally conscious investors;
- enhancement of employees' motivations;
- increased knowledge about the product;
- improved relations with regulators.

5.3 Strategic considerations

Strategic considerations that are taken into account for integration of environmental aspects into machine tool design and development may include the following:

- organizational issues (e.g. competitor's activities, machine tools user's needs, requirements and demands), organization's environmental aspects and impacts, activities of regulators and legislators, activities of industry associations;
- product-related issues such as early integration (i.e. addressing the environmental aspects early in the design and development process), functionality (i.e. how well the product suits the purpose of the machine tool user in terms of usability, useful lifetime, productivity, accuracy, etc.), multi-criteria concept (i.e. consideration of all relevant impacts and aspects), and trade-offs (i.e. seeking optimal solutions);
- communication (e.g. internal communication to employees on product-related environmental impacts, training courses on environmental issues, programmes, and tools, site-specific impacts on the environment, and feedback from employees), external communication on product properties (performance and environmental aspects), and proper use of machine tool.

5.4 Management considerations

Top management support and action should enable effective implementation of procedures and programmes to integrate environmental aspects in design and development of machine tools, including allocation of sufficient financial and human resources and time for the tasks involved. An effective programme should engage those involved in product design and development, marketing, production, environment, procurement, service personnel, and machine tool users. More detailed aspects on the multidisciplinary approach are given in ISO/TR 14062:2002, 6.5.

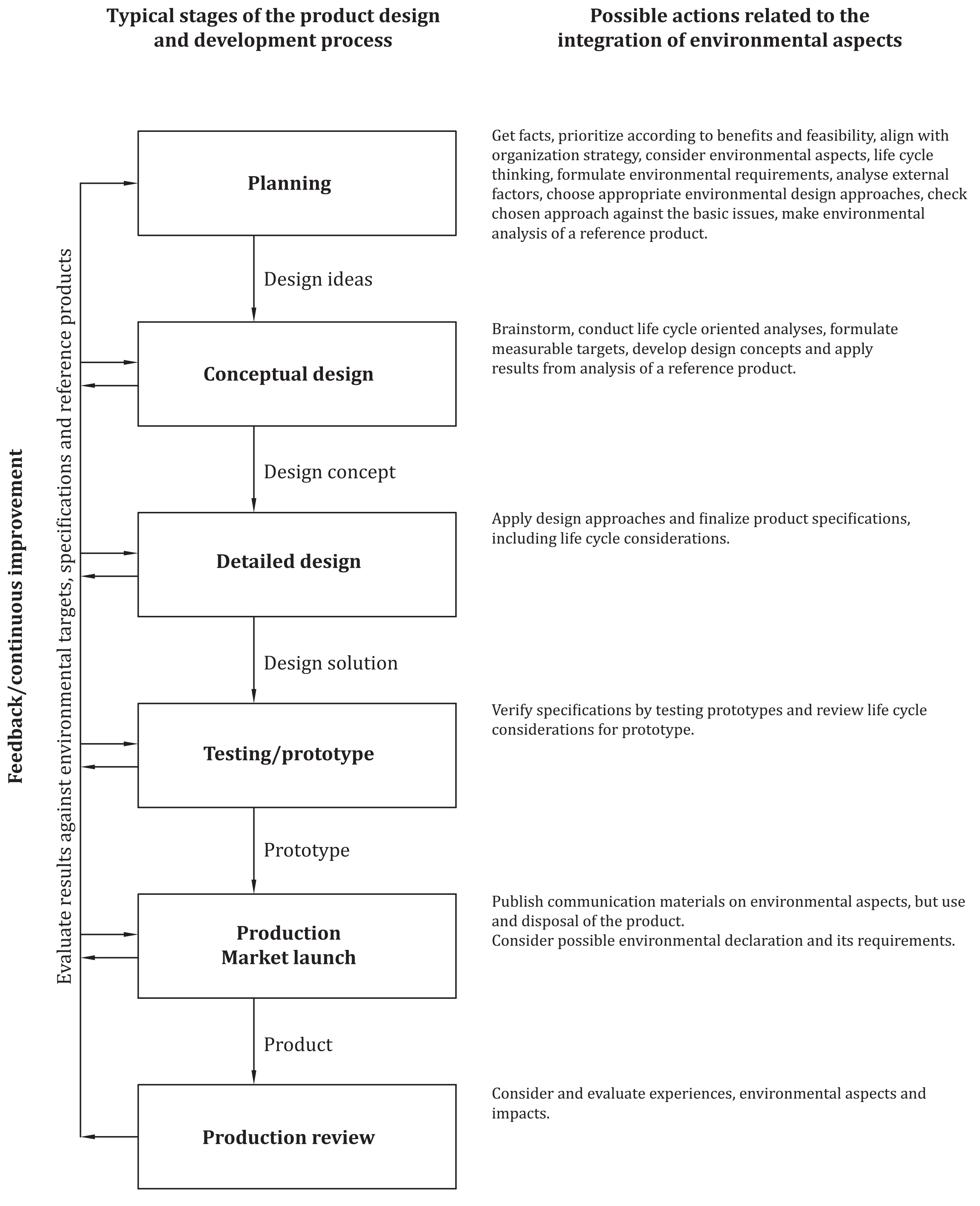
Details on how to formalize management's commitment and how to establish the organization's framework to integrate environmental aspects into machine tool design and development are given in ISO/TR 14062:2002, 6.2.

The integration of environmental aspects in machine tool design and management can be supported by existing management systems, e.g. management systems according to ISO 14001 or ISO 9001. This integration can also influence the supply-chain management; for details, see ISO/TR 14062:2002, 6.6.

5.5 Machine tool design and development process

An overview of integrating environmental aspects into the design and development process of machine tools is given in Figure 2.

NOTE Additional details are listed in ISO/TR 14062:2002, Clause 8. Eco-performance indicators, e.g. according to ISO 14031 might be rather useful for formulating measurable targets and transferring the targets into specifications.



Get facts, prioritize according to benefits and feasibility, align with organization strategy, consider environmental aspects, life cycle thinking, formulate environmental requirements, analyse external factors, choose appropriate environmental design approaches, check chosen approach against the basic issues, make environmental analysis of a reference product.

Brainstorm, conduct life cycle oriented analyses, formulate measurable targets, develop design concepts and apply results from analysis of a reference product.

Apply design approaches and finalize product specifications, including life cycle considerations.

Verify specifications by testing prototypes and review life cycle considerations for prototype.

Publish communication materials on environmental aspects, but use and disposal of the product.
Consider possible environmental declaration and its requirements.

Consider and evaluate experiences, environmental aspects and impacts.

Figure 2 — Example of a generic model of integrating environmental aspects into the machine tool design and development process (Source: ISO/TR 14062)

6 Machine tool and machine tool functions

6.1 General

The functional description of a machine tool (see 6.3) shall identify which machine tool function(s) are relevant for energy supplied to the machine. The functional description of machine tools is general and independent from the design of the machine tool and independent from the machining process implemented. Generalized functions of a machine tool, as given in 6.3, allow a general approach for identifying relevant energy flows of machine tools.

For a specific machine tool, the machine tool functions shall be assigned to machine components. This assignment is specific to each machine tool and corresponds to a transition from total energy supplied to the machine tool via machine tool functions and functional mapping to machine component level. This procedure is shown in an example in 6.3 and results in identifying energy relevant machine components (see 6.4).

Important parameters for this observation are the operating states of the machine tool and their duration in time, the accuracy of machined parts, and productivity of the machine tool, e.g. expressed by workpieces per hour. When comparing machine tools, these parameters shall be defined clearly.

Often measurement of power instead of energy is carried out. In these cases, times defined together with operating states have to be taken into account.

Some machine tools are equipped with internal compressors for pressurized air, hydraulic fluid, and/or for lubricant supply; other machine tools use centralized supply units for these. When comparing a machine tool using internal compressor(s) with a machine tool using centralized supplies, any comparison shall be made on the same basis, i.e. for both machine tools including all supplies. For this aim, system boundaries (see 6.2) shall be defined.

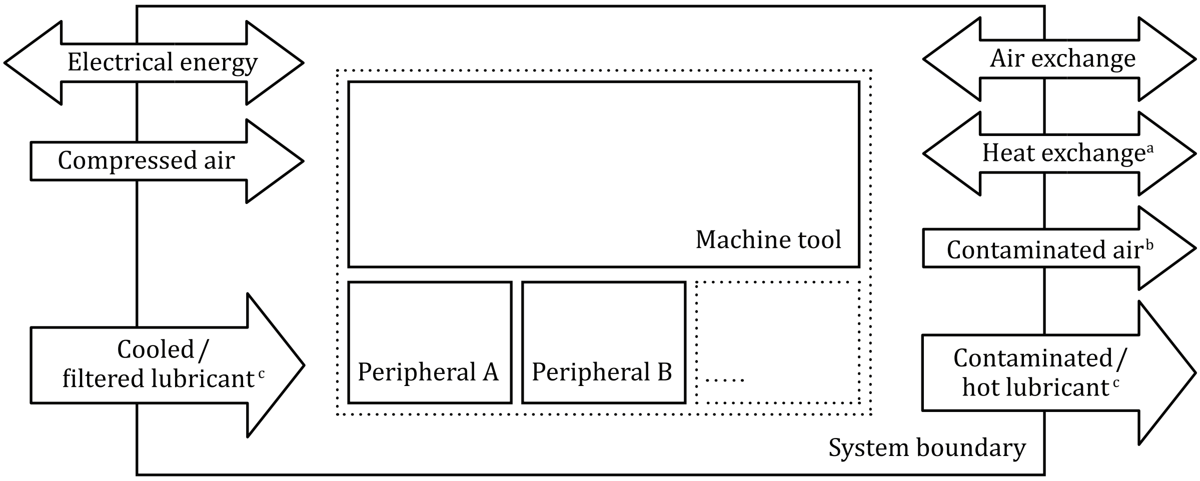
6.2 System boundaries

For evaluating the environmental impact of a machine tool, the machine tool is looked at, not the product(s) machined on the machine tool (see also Clause 4).

In this part of ISO 14955, the energy efficiency of machine tools in the use stage is addressed (see also Clause 4), whereas different forms of energy are looked at, e.g. electrical energy, pneumatic energy, hydraulic energy.

In order to deal with the energy efficiency of a machine tool during the use stage, system boundaries shall be defined in such a way that a system that is capable of a machining process is considered (see Figure 3). System boundaries are chosen in order to be able to measure energy flows with reasonable effort.

The machine tool and peripheral units are within the system boundaries. In general, electrical energy and compressed air are relevant energy inputs to the system. In some cases, air exchange is a relevant input and/or output. In cases where liquid heat exchangers are applied, heat exchange can be a relevant energy input and/or output of the system. If there is no mist filtering system within the system boundaries, any treatment of contaminated air will need energy that has to be considered, if relevant. If a centralized lubrication system is applied, cooled and filtered lubricant will be an input to the system and contaminated, hot lubricant will be an output; any energy used for lubricant treatment has to be considered, if relevant. Input of raw parts, new tools, new lubricant, auxiliary substances and output of machined parts, used tools, chips, and any other aspects do not have to be considered if it does not represent a relevant energy flow across the system boundary.



[a] Applies to cases with liquid heat exchangers.

[b] Applies to cases without internal mist filtering.

[c] Applies to cases with centralized lubricant management only.

Figure 3 — System boundaries related to relevant energy flows of a machine tool

6.3 Generalized functions of a machine tool

6.3.1 General

As metalworking machine tools cover a wide range of different types, subtypes, and sizes, a machine tool is described by its functions (see Figure 4), which might be realized by different machine components. This allows a generalized approach for a wide range of machine tools in order to evaluate environmental impacts of machine tools and the change of environmental impacts over time.

A machine tool should be described by the functions machine operation (machining process, motion and control), process conditioning and cooling, workpiece handling, tool handling or die change, recyclables and waste handling, and machine cooling/heating as shown in Figure 4, in relation to energy efficiency during the use stage. These generalized functions cover the vast majority of machine tools in a generalized view, independent from the implemented machining process and/or design of the machine tool.

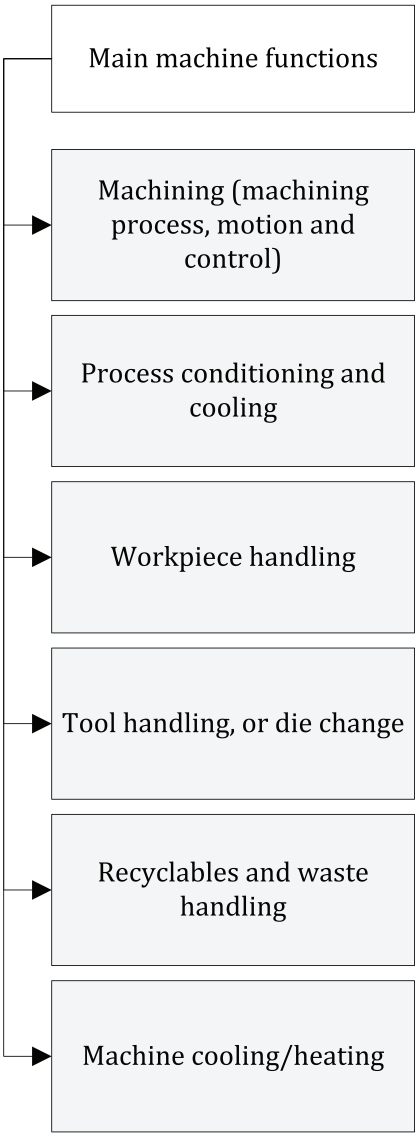


Figure 4 — Generalized functions of a machine tool in relation to energy efficiency, functional level, machine tool, and process independent

NOTE This functional description is a proposal to facilitate analysis and problem solving in relation to the energy efficiency of a machine tool during the use stage.

6.3.2 Machine operation (machining process, motion and control)

This function summarizes the target function of the machine tool, i.e. all energy supplied needed to realize the primary machining process.

6.3.2.1 Machining process

“Machining process” summarizes the realization of the machining processes, e.g. cutting velocity, electro-discharge process, laser beam for a cutting machine, process force, and working stroke of a press.

Typical components for the function “machining process” are the main spindle of a turning machine, the tool spindle of a machining centre, the generator of an electro-discharge machine, and the slide of a press.

6.3.2.2 Machining motion

“Machining motion” includes motions needed during machining a workpiece except machining process motions (see 6.3.2.1). Examples for “machining motion” are feed motion of a turning machine, positioning motion of a rotary table, feed motions of a laser cutting machine, and closing and opening of a press.

Typical components for the function “machining motion” are linear and rotary axes of a machining centre with their drives and power supply systems, rolling and sliding guideways, ball screws, bearings, gears, couplings, belts, pulleys, and axis clamping.

6.3.2.3 Machine control

“Machine control” summarizes the control of the machine, generally the numerical control, for automatic sequence control, monitoring systems, and measuring systems. “Machine control” may also contribute to non-machining functions, e.g. tool handling.

Typical components for the function “machine control” are the numerical control systems, PLC, displays, sensors, decoders and encoders, lighting of the work space, frequency converters, voltage transformers, relays, and touch probes.

6.3.3 Process conditioning and cooling

This function combines all cooling, heating, and conditioning that is process-related in order to keep the temperature and other relevant conditions of the working volume, the tools, the fixtures, and/or the workpieces within limits. Process conditioning may be seen as a value-adding function in order to achieve a constant machining process, e.g. lubrication for grinding, die lubrication for presses.

NOTE Process conditioning and cooling is sometimes combined with machine cooling/heating, see 6.3.8.

Typical machine components for the function “process conditioning and cooling” are cooling pumps related to process coolant, cutting/forming fluid cooler, die lubrication fluid cooler.

6.3.4 Workpiece handling

“Workpiece handling” may consist of workpiece changing, workpiece grasping, workpiece clamping, workpiece handling, workpiece lifting, in-feed of raw material, and measuring of workpieces on the machine tool.

Typical machine components for the function “workpiece handling” are pallet changer, workpiece handling robot, hydraulic clamping devices, and pneumatic chucks. On forming machines, “workpiece handling” is mostly done by destacker, centring stations, workpiece lifters in dies, workpiece ejectors, workpiece handling devices (e.g. robots, gripper bar transfer systems), and stacker.

6.3.5 Tool handling

“Tool handling” may consist of tool changing, tool grasping, tool clamping, tool storage, and probing of tools on the machine.

Typical machine components for the function “tool handling” are turret of a turning machine, hydraulic clamping devices, pneumatic chucks, tool changer, tool magazine, and system with compressed air to clean tool holder.

6.3.6 Die change

“Die change” may consist of die and automation tooling transport to/from interconnection points into machine tool, die clamping, die storage, preparation of tooling for automation systems, coupling/decoupling of energy needed for example part forming in hydro-forming processes or auxiliary die functions, such as lifters, coupling/decoupling of die lubrication supply.

Typical machine components for the function “die change” are moving bolster or die cart, die pusher/puller, die clamps (hydraulic or electric or electro-hydraulic or hydro-pneumatic or magnetic), manually operated mono-couplings, and automatically operated docking systems equipped with multi-couplings and/or electric plugs.

6.3.7 Recyclables and waste handling

This function summarizes handling of chips or scrap, handling of cutting fluids including separation and filtering, handling of dust and fumes, and handling of dirt.

Typical machine components for the function “recyclables and waste handling” are a chip conveyor or scrap conveyor, filter systems, exhaust systems, and systems with compressed air for chip transport.

6.3.8 Machine cooling/heating

This function summarizes all cooling and heating that is independent of the machining process. “Machine cooling/heating” does not add value to the machining process itself. Machine cooling/heating is applied in order to keep temperature within limits so that machine components are not damaged or distorted, e.g. keep the temperature of the control cabinet within operational limits, keep the temperature of a high-speed spindle within safety limits, keep the temperature of the machine tool within limits in order to prevent any thermal influences on the kinematic structure of the machine tool, keep oil temperature within operational limits.

Typical machine components for the function “machine cooling/heating” are fans, cooling system for control cabinet, water cooler, cooling pumps, and cooling/heating of guideways.

6.3.9 Subfunctions

The generalized functions may be divided into subfunctions in order to detect relevant energy flows. Figure 5 shows one possible division into subfunctions.

NOTE Generalized functions might be also called first-level functions (see Figure 4), subprocesses second-level, third-level, etc. functions (see Figure 5).

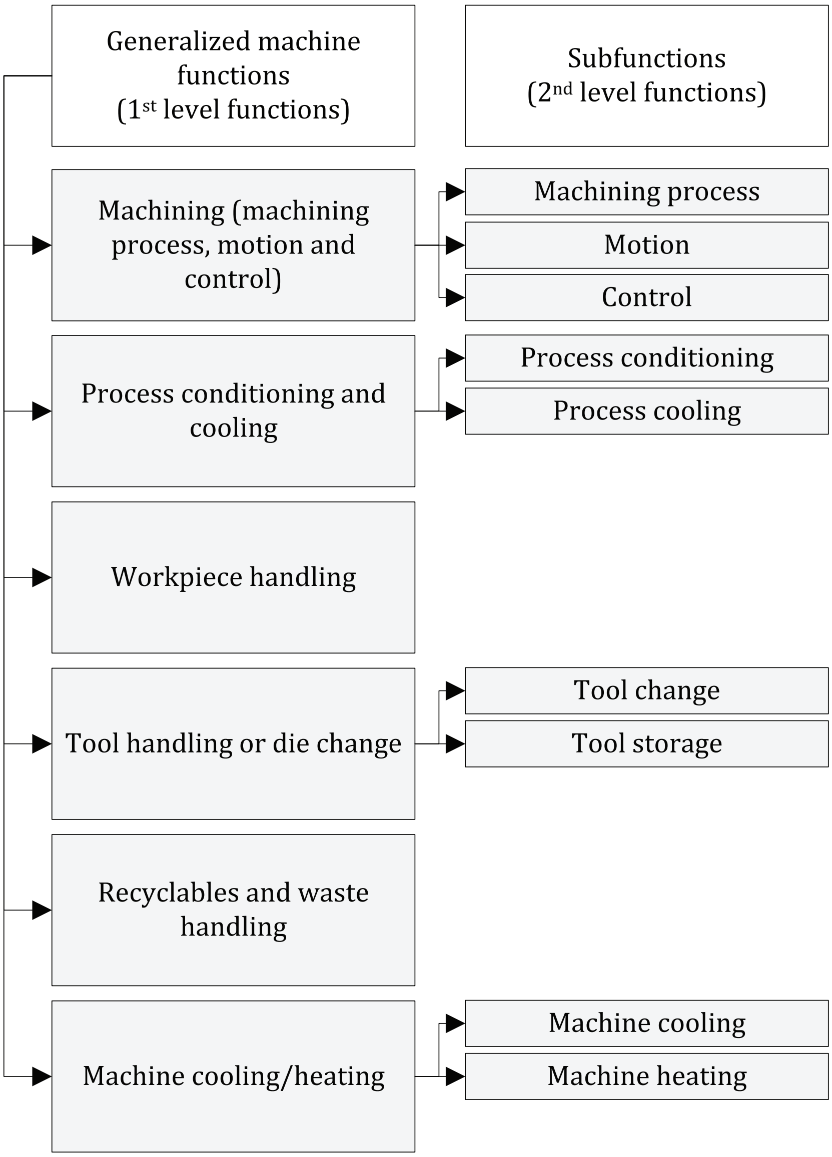


Figure 5 — Example of generalized machine tool functions and subfunctions in relation to energy efficiency (first- and second-level functions)

6.3.10 Machine tool functions and machine components

Sometimes machine components fulfil several functions, e.g. a coolant system is used for machine cooling (according to 6.3.8) and for process conditioning (according to 6.3.3). Then, the energy supplied to this machine component can be assigned to different generalized machine tool functions or subfunctions. Figure 6 gives an example of such assignments for a metal-cutting machine tool. Similar mapping can be performed for a metal-forming machine tool. For such mapping, the operating states of the machine tool and/or the specific test cycle shall be considered.

Significant exchange of energy in some operating states, e.g. during warm up, need corresponding time in those operating states in order not to influence other operating states.

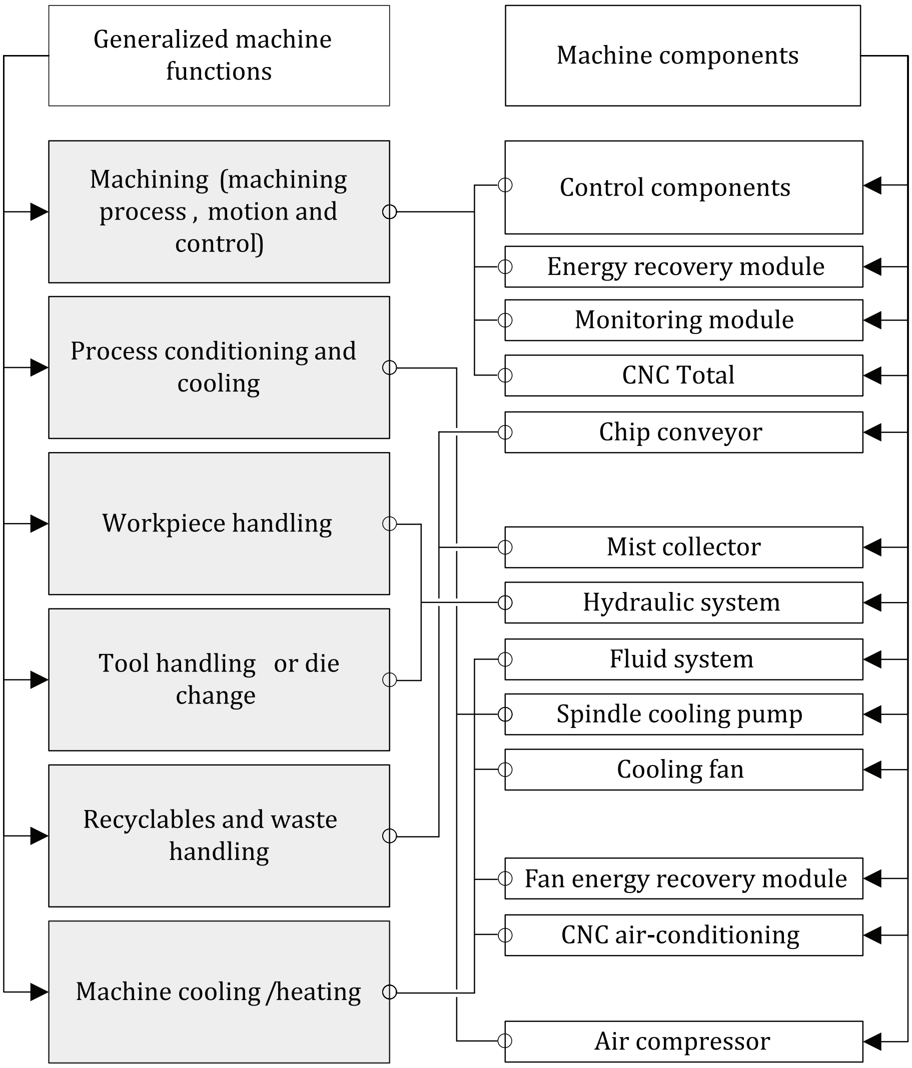
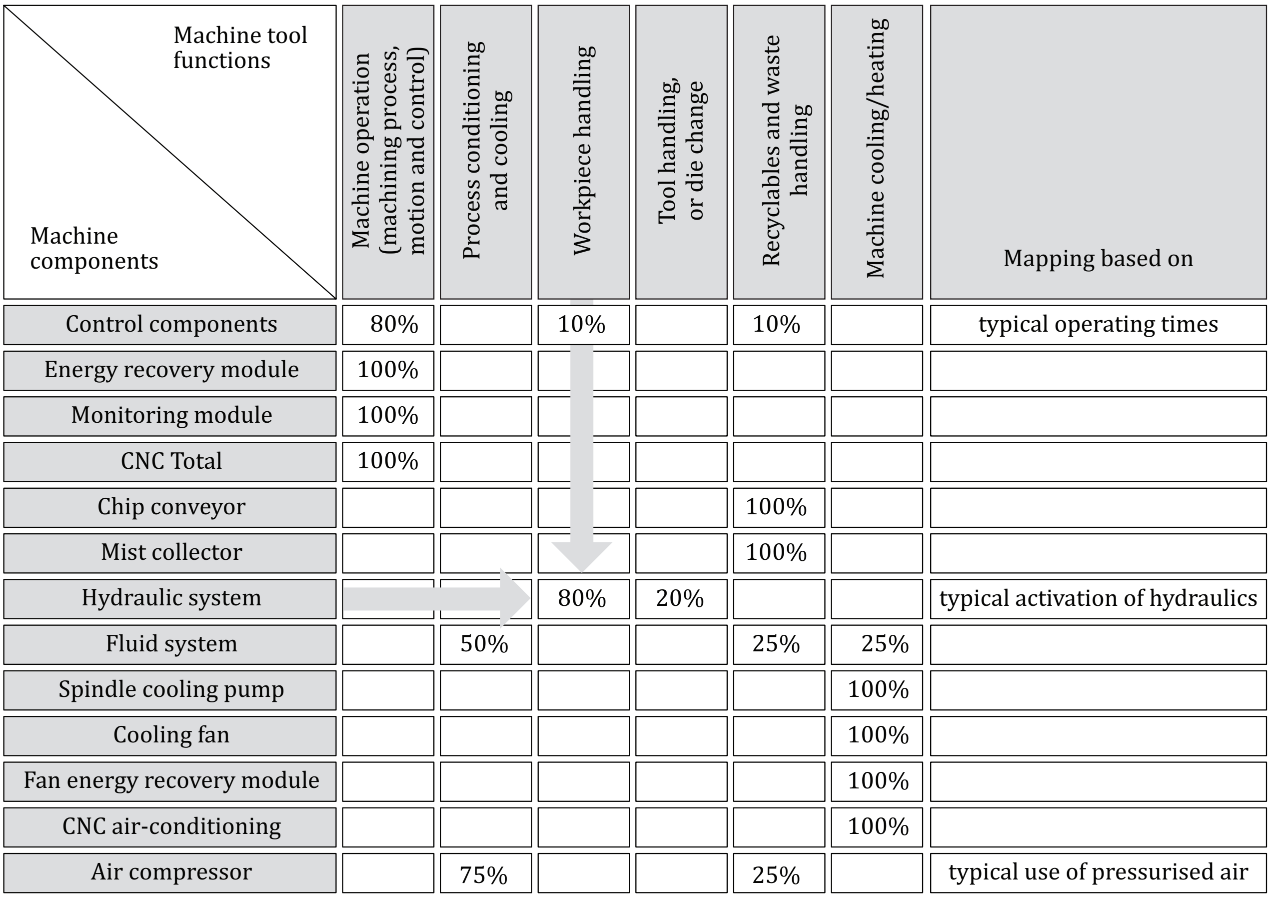


Figure 6 — Example of assigning machine components to machine tool functions (functional mapping) for a metal-cutting machine tool

This functional mapping finally has to be done quantitatively. An example is given in Figure 7, where the quantitative mapping is given in per cent (%) and where each line has to have a sum of 100 %.



Machine tool functions Machine components	Machine operation (machining process, motion and control)	Process conditioning and cooling	Workpiece handling	Tool handling, or die change	Recyclables and waste handling	Machine cooling/heating	Mapping based on
Control components	80%		10%		10%		typical operating times
Energy recovery module	100%						
Monitoring module	100%						
CNC Total	100%						
Chip conveyor					100%		
Mist collector					100%		
Hydraulic system			80%	20%			typical activation of hydraulics
Fluid system		50%			25%	25%	
Spindle cooling pump						100%	
Cooling fan						100%	
Fan energy recovery module						100%	
CNC air-conditioning						100%	
Air compressor		75%			25%		typical use of pressurised air

Figure 7 — Example for quantitative functional mapping, data given in %

NOTE When mapping machine components to more than one generalized function, the determination of the respective shares may appear as an imprecise procedure. However, the assignment of machine components to a single generalized function does not allow an appropriate system analysis if machine components are linked with more than one generalized function. In lack of measurement data and/or scientific grounds, an educated guess still gives a better insight for the system analysis than ignoring the complex dependencies between machine components and generalized functions.

6.4 Relevant machine tool functions and relevant machine components

6.4.1 Relevant machine tool functions

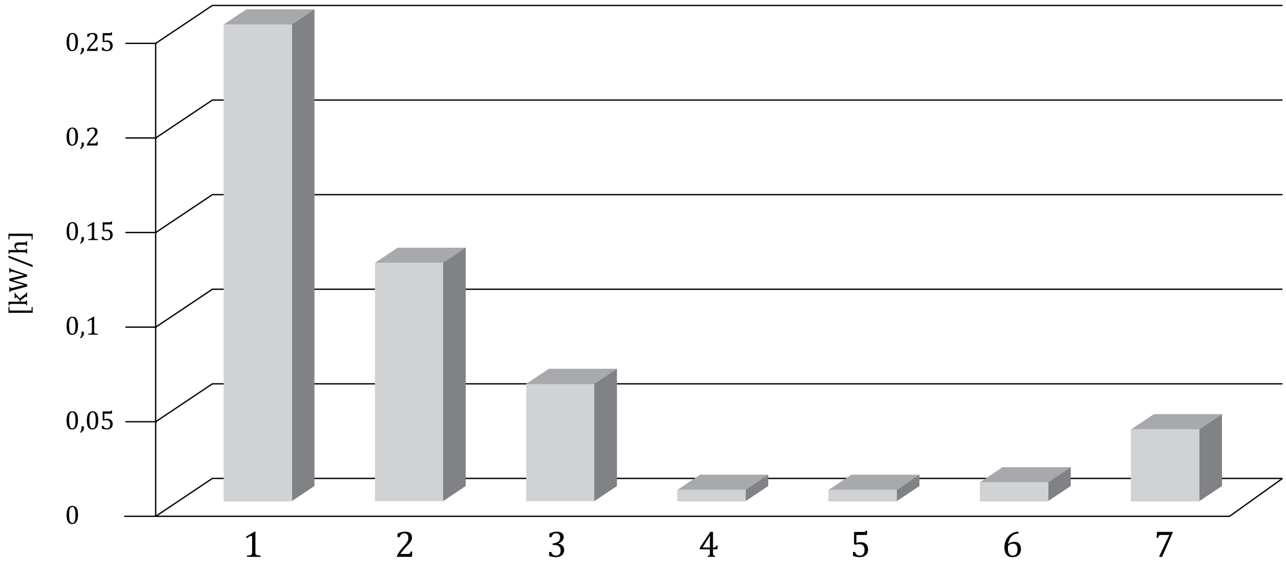
By examining the energy supplied for the different machine tool functions or subfunctions, the function(s) most relevant for energy supplied during use stage of a machine tool shall be identified. Most relevant functions for energy supplied to the machine tool are those sorted in descending order, which are on top of this sorted list, and whose cumulative total accounts for at least 80 % of total energy supplied to the machine.

NOTE The limit of 80 % is chosen due to available information and due to measurement uncertainties for measurement of energy or power.

Energy supplied to the machine tool shall be measured. During the design phase, energy supplied to the machine tool might be also calculated or simulated. A profile of the energy supplied to the machine as shown in Figure 8 can be used for presenting the results of this examination. Such profiles shall be presented together with a statement on the operating state(s) and/or the test cycle of the machine tool under test and/or the test piece machined; operating state(s) and test cycles and/or workpieces shall be specified by standards or shall be agreed upon between manufacturer/supplier and user of machine tool.

For comparisons, operating states and test cycles or test pieces shall be comparable, including additional parameters such as environmental conditions, operating times, and accuracy of test piece.

It is recommended to measure power instead of energy, so that the statistical duration of time spent in the different operating states (according to 3.7) can be taken into account. For this purpose, however, a time study is required. For this purpose, time studies compiling statistical distributions of time spent in the respective states can be used as statistics that are based on observations of machine tools in industrial use environments (e.g. according to Reference [4]). Even with such statistics available, it is still required to determine the total period over which the energy use is to be determined. A total period of use or a total period of effective machining can be examples of functional units (according to 3.11) to be used for this purpose.



Key

1 total energy
2 machining (machining process, motion, control)
3 process conditioning and cooling
4 workpiece handling
5 tool handling
6 recyclables and waste handling
7 machine cooling

Figure 8 — Example presentation of profile of energy supplied to the machine tool when cutting a specified test piece with specified machining parameters (turning of steel, cutting speed 180 m/min, feed speed 0,35 mm/rev, volume cut 1 564 331 mm^3, cutting time 440 s)

6.4.2 Relevant machine components

The most relevant functions and the components related to these are the first targets for improvement related to energy efficiency of machine tools. They should be furthermore evaluated in respect of their value added to the machining process, their relative improvement potential through measures such as listed in Annexes A and B, their state as compared to the state of the art, and the impact of modification of the component on the machine tool as a whole.

6.5 Result achieved

For the evaluation of energy efficiency, quantification of the “result achieved” is a prerequisite. It shall be quantified by observation (e. g. unit on or off), by counting (e. g. number of tool changes), by time measurement (e g. cycle time, machining time), or by other measurements (e. g. feed speed of axis or flow and pressure of lubricant supplied).

When measuring of energy efficiency includes machining of workpieces, the machining time, workpiece accuracy, and any other workpiece characteristics produced by the machining process shall be defined. Workpieces not complying with the requirements shall not be counted as result achieved, but the energy assigned to these workpieces (e.g. energy content in material, energy content to pre-machining) shall be considered as resources used.

6.6 Efficiency evaluation

Statements of energy efficiency shall be given in result per energy supplied to the machine tool, e.g. in cycles per energy supplied, in workpieces per energy supplied.

Any statement of energy efficiency shall be accompanied with information on operating states, machine activities, and environmental conditions during the test procedure. Measurement uncertainties should be stated with the test results.

7 Evaluation of design procedure for energy-efficient machine tools

In order to fulfil design procedures for energy-efficient machine tools, as shown in Figure 9, the following requirements shall be satisfied:

- the machine tool is described in its generalized functions or subfunctions, and machine components are assigned to generalized functions or subfunctions according to 6.3;
- function(s) relevant for energy efficiency during the use stage are identified (see 6.4.1);
- relevant function(s) is (are) assigned to machine components (see 6.4.2);
- relevant machine components, their control, and their combinations are compared to the state of the art (see Annexes A and B) or to the previous generation of that machine component, control, and/or combination (see Clause 8);
- relevant machine components and/or function(s) are monitored (see Clause 8).

NOTE 1 If a machine tool under investigation has other relevant environmental impact than the energy supplied to the machine during use stage, this is not addressed by this part of ISO 14955. Other publications, such as ISO/TR 14062, could be of guidance.

If declarations of energy efficiency are made, requirements of ISO 14021 shall be fulfilled.

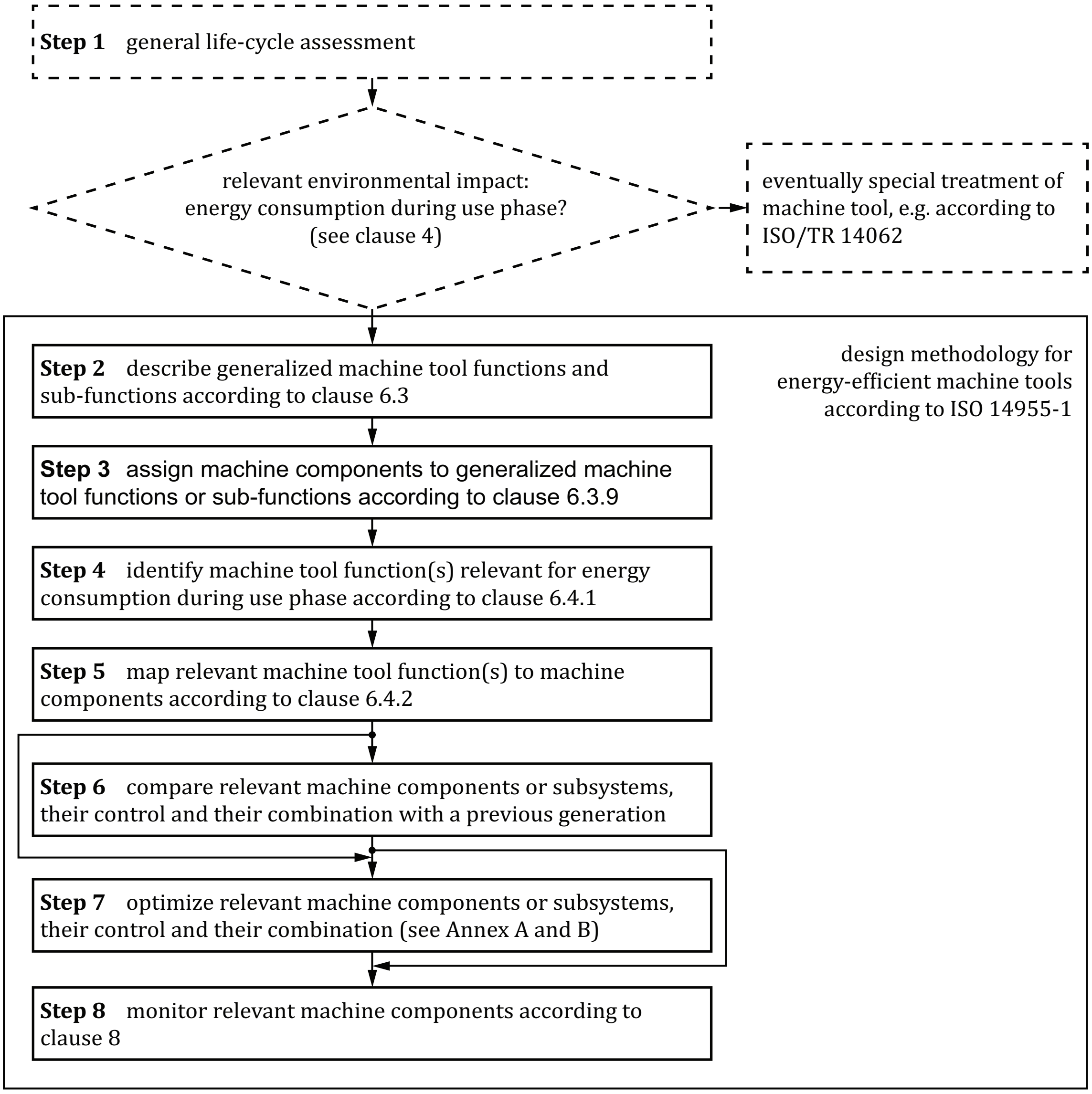


Figure 9 — Design methodology for energy-efficient machine tools

8 Reporting and monitoring of results

Reporting and monitoring of results shall include one of the following options:

- comparison with state of the art (e.g. qualitative comparison based on Annexes A and B);
- comparison with previous generation of machine tool of similar functionality (performance, productivity, accuracy);
- monitoring of results, including parameters covering higher productivity, higher accuracy, higher functionality of new generation machine tools.

Principally, the evaluation is done by the machine tool manufacturer. This enables the manufacturer to monitor their individual improvements with special attention to the most relevant machine tool function(s) and machine component(s).

If results are reported in the form of an environmental claim or a qualified environmental claim, the following requirements shall be fulfilled:

- the claimant shall be responsible for evaluation and provision of data necessary for the verification of the claim;
- prior to making the claim, evaluation measures shall be implemented to achieve reliable and reproducible results necessary to verify the claim.

More details are given in ISO 14021:1999, especially to topics such as evaluation of comparative claims, selection of methods, access of information (see Clause 6 of ISO 14021:1999), recovered energy (see 7.6 of ISO 14021:1999), and reduced energy supplied to machine tool (see 7.9 of ISO 14021:1999).

NOTE Some machine tools and their applications can require a temperature-controlled environment outside the machine components. The introduction of the closed-loop process control has, in some cases, eliminated this requirement, with consequent environmental energy savings which might not be directly accounted for by a measurement of the energy supplied to the machine tool. The energy saved would depend on the factory location and local climate. In such cases, it is legitimate to include a qualifying statement to avoid an over-simplistic interpretation of any energy figures quoted.

Annex A
(informative)

List of energy-efficiency improvements for metal-cutting machine tools

Table A.1 is a non-exhaustive checklist of energy-efficiency improvements for metal-cutting machine tools. Although the measures are generally apt to improve energy efficiency, their implementation should be considered within the given circumstances, the system design, the technologies used, and the application of the machine tool under investigation. Decisions about their implementation might be further subject to consideration of multiple criteria including functionality, standardization, reliability, cost, and others.

Table A.1 — Well-tried design principles for machine components, control components, and combinations of machine components for energy-efficient metal-cutting machine tools

No.	Feature for improvement	Description
1	**Overall machine concept**	
1–1	Minimization of moved masses	
1–2	Reduction of friction	Reduction of friction means less mechanical wear and higher quality and also should lead to energy reduction; various types of bearing possible (rolling bearing, sliding bearing, hydrostatic bearing, magnet bearing); ecological aspect has to be considered by the choice of bearings as well.
1–3	Optimization of the electrical design	Check if the machine tool has been designed according to customer requirements and operational range has been specified close to optimal working point; avoid adding up spare capacities (avoid oversizing/over-engineering).
1–4	Design for instant machining without warm-up	Provisions for automatic temperature compensation.
1–5	Work piece clamping and tool clamping	Use best efficient technology.
1–6	Multi-spindle/multi-work pieces machining	
1–7	Complete machining all sides	
1–8	Combination of various technologies (turning + milling + laser + grinding, etc.)	Combination of technologies in one machine, one-time mounting and adjusting may result in higher quality and higher yield and also causing less energy consumption.
1–9	Axis clamping	Usage of axis clamping instead of active motor brake (see 1–5).
1–10	Redundant axis	High acceleration with short-stroke axis reducing acceleration for long-range, heavy axis.
1–11	Increase output	Without utilization (production) or low output, the efficiency will be degraded.
1–12	Provide customer interaction to reduce consumption of resources	Give the operator provisions to interact when he expects downtime.
1–13	Tool change during running spindle (milling machine tools used in a way to change tools very frequently)	Provision to allow a tool change during running spindle to avoid deceleration and acceleration of spindle.

Table A.1 *(continued)*

No.	Feature for improvement	Description
2	**Drive units**	
2–1	Regenerative feedback of inverter system (servo motor/ spindle)	The in-feed unit is capable to feed back the braking energy to the main power supply.
2–2-1	Use of energy-efficient motors for auxiliary units	Use of an energy-efficiency class according to IEC 60034–30 and size of the motors (IE/capacity).
2–2–2	Use of energy-efficient motors for intelligent magnetic flux control	Magnetic flux to be controlled on asynchronous motors to reduce losses.
2–3	Use of high-quality reducers	- Use of gears sets quality as defined in International Standards (ISO 1328). - Use of low-friction seals. - Optimize lubrication.
2–4	Mass-free compensation of load for vertical axes	In case of vertical spindle, compensation of weight (mass) (e.g. spring-type mounting).
2–5	Use of brake for non-moving axes	The feed axes that are not involved in the interpolation during the part program are switched off (pulses deleted) and clamped by a brake, swivel head or swivel table, and auxiliary axes.
2–6	Inverter system with highly efficient power device	Usage of inverter system with highly efficient power device. Substituting line-connected motors by inverter motors.
2–7	Higher voltage inverter systems (e.g. 400 V) to substitute 200 V systems (where applicable)	Higher voltage inverter systems (e.g. 400 V) leads to a higher energy efficiency due to reduced ohmic losses.
2–8	DC voltage link to balance the energy between different drives	The DC voltage link balances the energy between different drives and may reduce the size of the in-feed unit.
3	**Hydraulic systems**	
3–1	Selection of optimal drive subsystem (motor-pump system)	- Different function sequences create the need for pump system which match the requirements profile. - Power on demand depending on the load cycle. - Select the correct size and type of motor and pump to avoid over dimensioning and to operate the pump in the optimal efficiency range. - Temporary storage of hydraulic energy (e.g. accumulator charging operation) to achieve the best possible match between the pump drive and the load cycle and to compensate for demand peaks (potential downsizing). - Speed-controlled pumps allow pressure control with variable speed instead of control valve. - Use switching valves with optimized technology (e.g. alternative control via Pulse Width Modulation or use of low-power solenoids when applicable).
3–2	Reduce hydraulic losses/leakage	- Use displacement control systems instead of throttle control systems. - Reduce internal leakage (e.g. seat valves in the accumulator charging unit or the clamping hydraulics). - Consider distributed supply strategies. - Apply leakage monitoring.

Table A.1 *(continued)*

No.	Feature for improvement	Description
3–3	Match the pressure level to the load cycle and to the different actuators on the machine	- Pressure adjustment using adjustable pressure relief valves or zero-pressure circulation. - Use actuators which are designed to operate at the same pressure level (less losses). - Pressure adjustment using pressure-controlled drive systems (variable speed drives, etc.). - Use pressure intensifiers for individual actuators which requires higher pressure. - On/Off or stand-by mode giving due consideration to safety criteria.
3–4	Dimensioning of tubes and pipes	- Optimize the design of piping (length, diameter, etc.) and reduce flow resistance. Tubes and pipes cause friction losses and thus energy losses. Finally, the tube or pipe causes a pressure drop which negatively affects the energy balance of the machine tool. Length, inner diameter, flowrate, and installation radius of tubes, pipes, and fittings shall be optimized to the application. Functions shall be identified and described where this requirement is applicable.
3–5	Overall system	Optimization of total hydraulic system.
4	**Pneumatic systems**	
4–1	Optimized compressed air system with minimum losses (differentiation between sealing air and pneumatic drives)	Allow for different kind of measures: - Single master switch-off. - Individual switch-off capability for specific modules. - Intelligent shut down procedures.
4–1–1	On-demand operation	Check if all branches of pneumatic circuits need to be pressurized in all operating states of the machine tool. If not, consider measures to switch these branches off.
4–1–2	Leak	Leak indicator, on demand monitoring. One of the main avoidable causes of energy dissipation is leakage in pressure piping and tubes. Leakage and condition monitoring systems as part of the control system of the machine tool shall be implemented in order to easily locate leakage and eliminate leakage directed. Functions shall be identified and described where this requirement is applicable.
4–1–3	Reduction of dead volume (V_{cut})	Distance between valve and cylinder shall be kept as short as possible. Long tubes are dead volumes which cause a major loss of energy in each switching cycles as they have to be pressurized and exhausted. This amount of compressed air will be wasted. Functions shall be identified and described where this requirement is applicable.
4–1–4	Directed switch-off of not needed branches.	It shall be verified if all branches of pneumatic circuits need to be pressurized in all modes of the machine tool. If not, take measures to switch these branches off in order to prevent energy losses caused by unneeded volume. Functions shall be identified and described where this requirement is applicable.

Table A.1 *(continued)*

No.	Feature for improvement	Description
4–1–5	Dimensioning of tubes and pipes	Optimize the design of piping (length, diameter, etc.) and reduce flow resistance. Tubes and pipes cause friction losses and thus energy losses. Finally, the tube or pipe causes a pressure drop which negatively affects the energy balance of the machine tool. Length, inner diameter, flowrate, and installation radius of tubes, pipes, and fittings shall be optimized to the application. Functions shall be identified and described where this requirement is applicable.
4–1–6	Correct layout of pneumatic drives	Pneumatic drives, e.g. cylinder forces, shall not be oversized. Unneeded air consumption and thus loss of energy were the result. The layout of the pneumatic system and its components shall be tailored to suit of the machine tools need.
4–1–7	Reduction of pressure	The interaction of pressure supply reduction to machine tool performance shall be verified. (Depending on the application, 1 bar reduction can result in up to 10 % increased efficiency). The reduction of pressure shall not have any negative influence on the correct function of the machine. Functions shall be identified and described where this requirement is applicable.
4–2	Directed switch off	Check if all branches of pneumatic circuits need to be pressurized in all operating states of the machine tool. If not, take measurements to switch these branches off.
4–3	Optimize cylinder force for the required function.	
4–4	ISO 4414 shall be applied	
4–5	Sealing air	When larger lots of sealing air (P < 0,2 MPa) are needed (more than 0,3 m^3/min), a small low-pressure compressor or similar means usually gives a much better efficiency than compressed air from a pressure-reducing regulator.
5	**Electric systems**	
5–1	Minimize energy losses in power supplies	Usage of high-efficiency transformer or voltage-proof converters instead of conventional transformers (e.g. controlled switching power for auxiliary power 24 V).
5–2	Converter with power factor correction	Power factor in the in-feed unit for feed operation and regenerative feedback saves energy losses.
5–3	Thermal management regarding control cabinet	Optimized concept for thermal management of the control cabinet: 1. Minimization of waste heat. 2. If waste heat is not avoidable, it has to be dissipated (air cooling or water cooling); for reuse of thermal energy, water is given a preference compared to air; further use of waste heat has to be checked/discussed with customer. 3. Controlled ventilation (fan).
6	**Cooling lubrication system**	
6–1	Discontinuous operating pumps, adjustable pressure for cooling lubrication, controlled flow rate	Active mode of cooling lubricant system depends on demand.
6–2	Minimal quantity lubrication (MQL) when advantageous	Consider energy consumption of compressed air.

Table A.1 *(continued)*

No.	Feature for improvement	Description
7	**Cooling system**	
7–1	Thermal management of machine tool and all components (cooling devices, etc.)	Optimized concept for thermal management of all machine tool components regarding the following: 1. Minimization of thermal power losses. 2. If thermal power loss is not avoidable, it has to be dissipated by air or water cooling; for reuse of thermal energy, water is given a preference compared to air; further reuse of thermal energy has to be checked/discussed with customer (e.g. via standardized interface). 3. Controlled ventilation (fan).
7–2	Apply direct cooling of components depending on process (cooling at the source)	Temperature controlled.
7–3	Demand-dependent cooling	e.g. substituting line-connected motors by inverter motors
7–4	Consideration of applied subsystems with regard to synergies	To obtain the maximum possible energy savings, it is often not sufficient to only look at the individual components and modules that are used for the individual functions. In addition, it has be checked if it is possible to extend the use of a supply unit (e.g. hydraulic), particularly during idle periods where other machine functions could be supplied or driven by it. In addition to the increase in the total efficiency of the supply unit due to the improved utilization, a complete drive unit can be omitted (e.g. generation of high-pressure coolant) and a large part of the previous energy requirement saved (avoidance of electrical, mechanical, and volumetric losses).
8	**Peripheral devices**	
8–1	Demand depending controlled peripherals (devices, e.g. mist extraction and chip conveyor)	Active mode of oil mist exhaust system depends on operating mode.
9	**Guidance for energy-efficient use**	
9–1	Optimization of work piece processing by simulation off-machine; avoidance of inefficient operating time	Work piece processing by simulation off-machine; avoidance of inefficient operating time; use also possible in conceptual phase of machine tool production. Non-productive time can be minimized if a simulation environment is provided for virtual setup allowing for simulative exclusion of possible collisions and simulative optimization of tool paths.
9–2	Minimize non-productive time	Without utilization (production) the efficiency will be degraded.
10	**Control systems**	

Table A.1 *(continued)*

No.	Feature for improvement	Description
10–1	Control parameters for different operating conditions	A method for minimising energy consumption by adapting control parameters to the active type of processing is provided. The type of method can follow different concepts or a combination of these concepts: A) Static Methods for manual selection of a parameter set of control parameters (e.g. including velocity limits, acceleration limits, feed forward, and feedback control coefficients) according to a target application (e.g. different parameter sets for roughing and finishing). B) Dynamic Methods for automated adaptation of control parameters to process conditions on a dynamic basis (e.g. by applying adaptive feed control, advanced position control). C) Methods by adapting control parameters based on energy-efficiency commands in the part program (e.g. STEP-based, such as roughing, finishing, boring, thread cutting). A provision to configure conditions for automatic switch over between different operating conditions.
10–2	Automatic operating state switching	A method for automated by switching of operating states to different levels is provided. Possible operating states are the following: - Switched off; - Standby, ready to be started (mains on, controls running, auxiliary and peripheral units stopped); - Halted, ready for production (auxiliary and peripheral units running); - Production. The method should apply different states automatically with respect to the current machining situation, order schedule, and user preferences.
10–3	Optimization of manufacturing process depending on manufacturing conditions	Provision of motion control features for minimization of energy usage (e.g. time-optimized manufacturing vs. energy-efficient manufacturing, accuracy-optimized manufacturing vs. energy-efficient manufacturing).
10–4	Recording or monitoring of current energy consumption together with energy relevant production data	

Annex B
(informative)

List of energy-efficiency improvements for metal-forming machine tools

Tables B.1 and B.2 are non-exhaustive checklists of energy-efficiency improvements for hydraulic presses (Table B.1) and mechanical servo presses and mechanical presses (Table B.2). Although the measures are generally apt to improve energy efficiency, their implementation should be considered within the given circumstances, the system design, the technologies used, and the application of the machine tool under investigation. Decisions about their implementation might be further subject to consideration of multiple criteria including functionality, standardization, reliability, cost, and others.

Table B.1 — Well-tried design principles for machine components, control components, and combinations of machine components for energy-efficient hydraulic presses

No.	Features for improvement	Description
1	**Overall machine concept**	
1–1	Minimization of moved masses	Moved masses have to be accelerated and the energy required for acceleration is dependent on the mass ($E = 1/2 \cdot m \cdot v^2$). Even if some part of the energy is recovered during braking, this recovery is with an efficiency factor below 1. The best way to reduce energy needed for acceleration is mass reduction.
1–2	Reduction of friction	Reduction of friction means less mechanical wear and higher quality and also should lead to energy reduction; various types of bearings possible (rolling bearing, sliding bearing, hydrostatic bearing, magnet bearing); ecological aspect has to be considered by the choice of bearing as well. Reduction of speed-dependent friction should be optimized with respect to the characteristic of the chosen drive technology.
1–3	Optimization of the overall machine design	Check if the machine tool has been designed according to customer requirements; operational range been specified close to optimal working point; avoid adding up spare capacities (over sizing).
1–4	Counterbalance system for vertical axes	Counterbalancing systems reduces the potential energy in vertical moving systems. Additional reduction of accelerating and decelerating.
1–5	Highly efficient cushion	Cushions are needed for restraining material flow. Without energy efficiency means the energy required is mostly transferred into heat. Use cushion control system with low-energy consumption or regenerative feedback
1–6	Use regenerative circuit for differential cylinders	Reduction of pressure drop on control valves.
1–7	Die clamping	Choose a clamping system with the best efficient technology.
2	**Drive units**	
2–1	Regenerative feedback of inverter system (e.g. servo motor, AFE- technology)	The in-feed unit is capable to feed back the braking energy to the mains power supply.
2–2	Optimization of the dynamic parameters	Option to limit the acceleration in the set point signal results in a better exploitation of the motors' efficiency. In this case, the overload capability of the motor is not utilized.

Table B.1 *(continued)*

No.	Features for improvement	Description
2–3	Optimization of installed motor power	Select motor operating close to optimum of efficiency factor, oversizing and overloading creates energy losses.
2–4	Use of energy-efficient motors	Use of an energy-efficiency class according to IEC 60034–30 and size of the motors (IE/capacity).
2–5	Provide most efficient drive system	Provide most efficient drive system for operating conditions in which the machine tool is mostly working. Compare energy efficiency of different types of drive systems (e. g. direct pump drive for processes with short cycle time, accumulator drive for processes with long cycle time). See also 3–1.
2–6	Use of multi-pressure accumulator system for main axis	Multi-pressure accumulator systems reduces pressure drop between accumulator and actuator.
2–7	Use of energy-efficient pump-motor units	Either pump principle and sizing in combination with the electrical motor influences the efficiency of the unit. Pump principle, size, and speed shall be selected so that the pump system operates near to its optimum efficiency for as long as possible. See also 3–1.
2–8	Direct coupled energy-storing drive systems for main drives	Direct coupled energy storage support (e.g. flywheel) may reduce installed power of main motors.
2–9	Indirect coupled energy-storing drive systems for main drives	Indirect energy storing drive systems such as electrically coupled flywheel, capacitor banks, etc. reduces load peaks.
2–10	Intelligent drive management	Intelligent drive management turns off energy consumers (e.g. electric motors) when not needed.
2–11	Highly efficient power devices for inverter systems	Usage of inverter system with highly efficient power device. Substituting line-connected motors by inverter motors.
3	**Hydraulic systems**	
3–1–1	Selection of the optimal drive sub-system (motor-pump system)	
3–1–2		Different functions/sequences create the need for pump systems which match the required profile (pump combinations, e.g. high pressure/low pressure, variable or fixed-displacement pumps).
3–1–3		Power on demand depending on the load cycle (constant speed in intermittent operation, variable speed (pole change, speed control/regulation with servo motors or asynchronous motors).
3–1–4		Select the correct size pump to avoid over-dimensioning, and operate the pump in the optimal efficiency range.
3–1–5		Temporary storage of hydraulic energy to achieve the best possible match between the pump drive (e.g. accumulator charging circuits) and the load cycle, and to compensate for demand peaks (so that drives and pumps with a lower output rating can be used).
3–2	Match the pressure level to the load cycle and to the different actuators on the machine	
3–2–1		Pressure adjustment using adjustable pressure relief valves or zero-pressure circulation.
3–2–2		Use actuators which are designed to operate at the same pressure level (no pressure reduction losses).
3–2–3		Pressure adjustment using pressure-controlled drive systems (e.g. variable speed drives, adjustable-pressure variable capacity pumps).
3–2–4		Use pressure intensifiers for individual actuators which require higher pressure.
3–2–5		On/Off or stand-by mode, giving due to consideration to safety criteria.
3–3	Reduce hydraulic losses	
3–3–1		Use displacement control systems instead of throttle control systems.

Table B.1 *(continued)*

No.	Features for improvement	Description
3–3–2		Reduce internal leakage, for example, through the use of seat valves in the accumulator charging circuit or the clamping hydraulics.
3–3–3		Optimize the design of the hydraulic lines and reduce hydraulic resistance.
3–3–4		Consider distributed supply strategies.
3–3–5		Use of pilot-operated valves with low-pilot oil consumption.
3–4	Reduce power consumption on solenoid operated valves	
3–4–1		Use pulse valves (with detent) which only draw power during switching.
3–4–2		Reduce power consumption by using valve connectors with built-in automatic reduction of holding current.
3–4–3		Reduce power consumption for valve actuation. Reduce power consumption by using valves with 8 W solenoids when applicable. The possible use of low Watt solenoids is dependent on the function because of reduced switching forces.
3–5	Leakage monitoring	Internal leakage (e.g. loose fittings in reservoir, worn valves or pumps) leads to energy dissipation. Leakage monitoring detects exceeding flow.
3–6	Low flow resistance	Avoid losses caused by flow resistance e.g. by choosing valve dimension and spring characteristics in respect to optimized pressure drop.
3–7	Highly efficient auxiliary pressure generation	Avoid pressure relief valves or pressure reducing valves for pressure adjustment, generate pressure at appropriate level e.g. by speed controlled pumps, pumps with variable flow, discontinuously operating pumps (see 3–1).
3–8	Warm-up cycle	End warm-up cycle as soon as possible, use actual oil temperature to control warm-up. If applicable, change to hydraulic heating instead of electrical heaters with respect to start temperature.
3–9	Oil temperature	Operate in optimal temperature range. Select oil viscosity grade suitable for the expected ambient temperature range.
3–10	Oil cooling	Use water cooling instead of air cooling. Water cooling is more efficient and warm water may be used in facility for other purposes.
3–11	ISO 4413 shall be applied	
4	**Pneumatic systems**	
4–1	Optimized compressed air system with minimum losses (differentiation between sealing air and pneumatic drives)	
4–1–1		Single master switch-off.
4–1–2		Individual switch-off capability for specific modules.
4–1–3		Intelligent shut down procedures.
4–1–4		Leak indicator, on demand monitoring. One of the main avoidable causes of energy dissipation is leakage in pressure piping and tubes. Leakage and condition monitoring systems as part of the control system of the machine tool shall be implemented in order to easily locate leakage and eliminate leakage directed. Functions shall be identified and described where this requirement is applicable.

Table B.1 *(continued)*

No.	Features for improvement	Description
4–1–5	Reduction of dead volume (V_{cut})	Distance between valve and cylinder shall be kept as short as possible. Long tubes are dead volumes which cause a major loss of energy in each switching cycles as they have to be pressurized and exhausted. This amount of compressed air will be wasted. Functions shall be identified and described where this requirement is applicable.
4–1–6	Directed switch off of not needed branches.	It shall be verified if all branches of pneumatic circuits need to be pressurized in all modes of the machine tool. If not, take measures to switch these branches off in order to prevent from energy losses caused by unneeded volume. Functions shall be identified and described where this requirement is applicable.
4–1–7	Dimensioning of tubes and pipes	Optimize the design of piping (length, diameter, etc.) and reduce flow resistance. Tubes and pipes cause friction losses and thus energy losses. Finally, the tube or pipe causes a pressure drop which effects negatively to the energy balance of the machine tool. Length, inner diameter, flow-rate, and installation radius of tubes, pipes, and fittings shall be optimized to the application. Functions shall be identified and described where this requirement is applicable.
4–1–8	Correct layout of pneumatic drives	Pneumatic drives shall not be oversized. Unneeded air consumption and thus loss of energy were the result. The layout of the pneumatic system and its components shall be tailored to suit of the machine tools need. Functions shall be identified and described where this requirement is applicable.
4–1–9	Reduction of pressure	The interaction of pressure supply reduction to machine tool performance shall be verified. (Depending on the application, 1 bar reduction can result in up to 10 % increased efficiency). The reduction of pressure shall not have any negative influence on the correct function of the machine. Functions shall be identified and described where this requirement is applicable.
4–2	Directed switch off	Check if all branches of pneumatic circuits need to be pressurized in all operating states of the machine tool. If not, take measurements to switch these branches off.
4–3	Optimize cylinder force for the required function.	
4–4	ISO 4414 shall be applied	
4–5	Overall system	Optimization of total pneumatic system
5	**Electric systems**	
5–1	Avoidance energy losses of power supplies	Avoid power losses in the transformer by use of e.g. voltage-proof converter, controlled switching power supply for 24 V control voltage
5–2	High efficiency transformer	Load requirement of a machine tool is not constant during the cycle. Therefore, it is more efficient to install transformers optimized on low Fe-losses instead of transformers optimized on low Cu-losses.
5–3	Apply the simultaneity factor when designing the power system	Avoid oversizing of power supply leads to lower absolute energy losses. Avoid overload as well.
5–4	Converter/inverter with power factor correction	Power factor in the in-feed unit for feed operation and regenerative feedback saves power losses.
5–5	Thermal management regarding control cabinet	Optimized concept for thermal management of the control cabinet:
5–5–1		Minimization of waste heat;
5–5–2		If waste heat is not avoidable, it has to be dissipated (air cooling or water cooling);

Table B.1 *(continued)*

No.	Features for improvement	Description
5–5–3		Controlled ventilation (fan);
5–5–4		Low-maintenance air conditioner (no air filter) and thermostatic air conditioning with open-door-shutoff.
6	**Die cooling/lubrication system**	
6–1	Thermal management of all cooling devices including cooling device for machine tool and/or its modules	Optimized concept for thermal management of all cooling devices:
6–1–1		Minimization of thermal power losses;
6–1–2		If thermal power loss is not avoidable, it has to be dissipated by air or water cooling; for reuse of thermal energy has to be checked/discussed with customer;
6–1–3		Controlled ventilation (fan).
6–2	Apply direct cooling of components depending on process	Temperature controlled
6–3	Apply demand depending cooling	E.g. substituting line-connected motors by inverter motors, temperature-controlled coolant water flow
7	**Machine Tool lubrication system**	
7–1	Lubrication flow depending on demand	Active mode of cooling and lubrication system. E.g.: - discontinuous operating pumps - controlled flow rate - adjustable pressure
7–2	Low flow rate for lubrication pump	Install not more than sufficient pump flow and distributor instead of orifices
8	**Peripheral devices**	
8–1	Controlled peripheral devices such as mist extraction, and scrap conveyor.	Active mode of devices, dependent on mode of operation
9	**Guidance for energy-efficient use**	
9–1	Optimization of work piece processing by die tryout	Workpiece processing by tryout off-machine; avoidance of inefficient operating time; use also possible in conceptual phase of machine tool production.
9–2	Provisions to reduce scrap production	Die monitoring, in-process control, optimized use of raw material, minimize waste, zero-defect production.
9–3	Provide customer information to reduce consumption of resources	Training of operators leads to energy-sensitive handling of the machine tool.
9–3–1	Information to user on energy-efficient use of the machine e.g. on/off programming of auxiliary devices (users manual, instruction)	Give the operator information e. g. how to interact when he expects downtime.
9–3–2	Information to user on optimized movements of axis	Means for optimization of movements of multiple axis systems (feeders, robots) to follow energy-optimized moving curves
9–3–3	Information to user on usable exergy	Provide information about type of exergy carrier (e.g. water) and temperature of medium to choose optimal means for recovery.
9–4	Minimize non-productive time	Without utilization (production) or low output the efficiency will be degraded. Means of improving output may be automatic die change systems, condition monitoring to prevent component failures, good diagnostic for quick trouble shooting etc.
9–5	Optimize productivity by reducing cycle time per part	An improved productivity reduces the portion of required basic load per part.

Table B.1 *(continued)*

No.	Features for improvement	Description
10	**Control systems**	
10–1	Energy optimized default setting for operating condition -energy level- (customer specific drive management)	possible operating conditions -energy levels- e.g.: - switched off - standby - ready to be started (mains on, controls running, auxiliary and peripheral units stopped) - halted - ready for production (auxiliary and peripheral units running) - production possible means depending on mode of operation: - screen saver for operating terminal and lighting - intelligent drive management
10–2	Automatic operating state switching	Switching between different operating states helps drive management to choose most efficient mode.
10–3	Recording or monitoring of current energy consumption together with energy relevant production data	The knowledge of the machine energy consumption under different operating conditions helps the user to follow ISO 50001.

Table B.2 — Well-tried design principles for machine components, control components and combinations of machine components for energy-efficient mechanical servo presses and mechanical presses

No.	Feature for Improvement	Description
1	**Overall machine concept**	
1–1	Minimization of moved masses	Moved masses have to be accelerated and the energy required for acceleration is depending on the mass ($E = 1/2 \cdot m \cdot v^2$). Even if some part of the energy is recovered during braking, this recovery is with an efficiency factor below 1. The best way to reduce energy needed for acceleration is mass reduction.
1–2	Reduction of friction	Reduction of friction means less mechanical wear and higher quality and also should lead to energy reduction; various types of bearing possible (rolling bearing, sliding bearing, hydrostatic bearing, magnet bearing); ecological aspect has to be considered by the choice of bearing as well. Reduction of speed dependent friction should be optimized in respect to the characteristic of chosen drive technology.
1–3	Optimization of the overall machine design	Check if the machine tool has been designed according to customer requirements; operational range been specified close to optimal working point; avoid adding up spare capacities (oversizing)
1–4	Counterbalance system for vertical axes	Counterbalancing systems reduces the potential energy in vertical-moving systems. Additional reduction of accelerating and decelerating.
1–5	Highly efficient cushion	Cushions are needed for restraining material flow. Without energy efficiency means the energy required is mostly transferred into heat. Use cushion control system with low-energy consumption or regenerative feedback.
1–6	Die clamping	Choose a clamping system with the best efficient technology.
2	**Drive units**	
2–1	Regenerative feedback of inverter system (e.g. servo motor, AFE-technology)	The in-feed unit is capable to feed back the braking energy to the main power supply.
2–2	Optimization of the dynamic parameters	Option to limit the acceleration in the set point signal results in a better exploitation of the motors' efficiency. In this case, the overload capability of the motor is not utilized.
2–3	Minimization of spare capacity/customer specific layout of motors	Select an appropriate motor: - select motor operating close to optimum of efficiency factor; - oversizing and overloading can create energy losses.
2–4	Minimization of spare capacity/customer specific layout of inverter system	Select an appropriate inverter: - select inverter close to motor size; - oversizing can create energy losses.
2–5	Optimized axis servo motors	Optimized regarding energy efficiency.
2–6	Use of energy-efficient motors for auxiliary units	Use of an energy-efficiency class according to IEC 60034–30 and size of the motors (IE/capacity).
2–7	Use of high-quality reducers	- Use of gears sets quality as defined in International Standards (ISO 1328). - Use of low-friction seals. - Optimize lubrication.

Table B.2 *(continued)*

No.	Feature for Improvement	Description
2–8	Inverter-controlled motors for auxiliary units	Substitution of line-connected motors by inverter motors.
2–9	Indirect coupled energy-storing drive systems for main drives	Use of energy-storing drive systems to reduce cyclic power peaks.
2–10	Optimization of installed motor power	Select motor operating close to optimum of efficiency factor; oversizing and overloading creates energy losses.
2–11	Use of energy-efficient motors	Declaration of energy-efficiency class and size of the motors (IE/capacity).
2–12	Use of energy-efficient pumps	Different pump principles lead to different pump efficiencies.
2–13	Intelligent drive management	Intelligent drive management turns off energy consumers (e.g. electric motors) when not needed.
2–14	Use of energy-efficient pump-motor units	Either pump principle and sizing in combination with the electrical motor influences the efficiency of the unit. Pump principle, size, and speed shall be selected so that the pump system operates near to its optimum efficiency for as long as possible. See also 3–1.
2–15	Highly efficient power devices for inverter systems	Usage of inverter system with highly efficient power device. Substituting line-connected motors by inverter motors.
3	**Hydraulic systems**	
3–1	Selection of the optimal drive subsystem (motor-pump system)	
3–1–1		Different function sequences create the need for pump systems which match the requirements profile (pump combinations, e.g. high pressure/low pressure, variable or fixed-displacement pumps).
3–1–2		Power on demand depending on the load cycle [constant speed in intermittent operation, variable speed (pole change, speed control/regulation with servo motors or asynchronous motors)]
3–1–3		Select the correct size pump to avoid over dimensioning, and operate the pump in the optimal efficiency range
3–1–4		Temporary storage of hydraulic energy to achieve the best possible match between the pump drive (e.g. accumulator charging circuits) and the load cycle, and to compensate for demand peaks (so that drives and pumps with a lower output rating can be used).
3–2	Match the pressure level to the load cycle and to the different actuators on the machine	
3–2–1		Pressure adjustment using adjustable pressure relief valves or zero-pressure circulation.
3–2–2		Use actuators which are designed to operate at the same pressure level (no pressure reduction losses).
3–2–3		Pressure adjustment using pressure-controlled drive systems (e.g. variable speed drives, adjustable-pressure variable capacity pumps).
3–2–4		Use pressure intensifiers for individual actuators which require higher pressure.
3–2–5		On/Off or stand-by mode, giving due consideration to safety criteria.
3–3	Reduce hydraulic losses	
3–3–1		Use displacement control systems in place of throttle control systems.
3–3–2		Reduce internal leakage, for example, through the use of seat valves in the accumulator charging circuit or the clamping hydraulics.

Table B.2 *(continued)*

No.	Feature for Improvement	Description
3–3–3		Optimize the design of the hydraulic piping and reduce hydraulic resistance.
3–3–4		Consider distributed supply strategies.
3–3–5		Use of pilot-operated valves with low-pilot oil consumption.
3–4	Reduce power consumption on solenoid-operated valves	
3–4–1		Use pulse valves (with detent) which only draw power during switching.
3–4–2		Reduce power consumption for valve actuation. Reduce power consumption by using valve connectors with built-in automatic reduction of holding current.
3–4–3		Reduce power consumption by using valves with 8 W solenoids when applicable. The possible use of low Watt solenoids is depending on the function, because of reduced switching forces.
3–5	Leakage monitoring	Internal leakage (e. g. loose fittings in reservoir, worn valves or pumps) leads to energy losses. Leakage monitoring detects exceeding flow.
3–6	Low flow resistance	Avoid losses caused by flow resistance e.g. by choosing valve dimension and spring characteristics in respect to optimized pressure drop.
3–7	Highly efficient auxiliary pressure generation	Avoid pressure relief valves or pressure reducing valves for pressure adjustment, generate pressure at appropriate level e.g. by speed controlled pumps, pumps with variable flow, discontinuously operating pumps (see 3–1).
3–8	Warm-up cycle	End warm-up cycle as soon as possible, use actual oil temperature to control warm-up. If applicable, change to hydraulic heating instead of electrical heaters with respect to start temperature.
3–9	Oil temperature	Operate in optimal temperature range. Select oil viscosity grade suitable for the expected ambient temperature range.
3–10	Oil cooling	Use water cooling instead of air cooling. Water cooling is more efficient and water may be used in facility for other purposes. Recovering cooling energy can be used for e.g. floor heating or warm water supply.
3–11	ISO 4413 shall be applied	
4	**Pneumatic systems**	
4–1	Optimized compressed air system with minimum losses (differentiation between sealing air and pneumatic drives)	Allow for different kind of measures:
4–1–1		- Single master switch-off.
4–1–2		- Individual switch-off capability for specific modules.
4–1–3		- Intelligent shut down procedures.

Table B.2 *(continued)*

No.	Feature for Improvement	Description
4–1–4		Leak indicator, on demand monitoring. One of the main avoidable causes of energy dissipation is leakage in pressure piping and tubes. Leakage and condition monitoring systems as part of the control system of the machine tool shall be implemented in order to easily locate leakage and eliminate leakage directed. Functions shall be identified and described where this requirement is applicable.
4–1–5	Reduction of dead volume (Vcut)	Distance between valve and cylinder shall be kept as short as possible. Long tubes are dead volumes which cause a major loss of energy in each switching cycles as they have to be pressurized and exhausted. This amount of compressed air will be wasted. Functions shall be identified and described where this requirement is applicable.
4–1–6	Directed switch off of not needed branches.	It shall be verified if all branches of pneumatic circuits need to be pressurized in all modes of the machine tool. If not, take measures to switch these branches off in order to prevent from energy losses caused by unneeded volume. Functions shall be identified and described where this requirement is applicable.
4–1–7	Dimensioning of tubes and pipes	Optimize the design of piping (length, diameter, etc.) and reduce flow resistance. Tubes and pipes cause friction losses and thus energy losses. Finally, the tube or pipe causes a pressure drop which effects negatively to the energy balance of the machine tool. Length, inner diameter, flow-rate, and installation radius of tubes, pipes, and fittings shall be optimized to the application. Functions shall be identified and described where this requirement is applicable.
4–1–8	Correct layout of pneumatic drives	Pneumatic drives shall not be oversized. Unneeded air consumption and thus loss of energy were the result. The layout of the pneumatic system and its components shall be tailored to suit of the machine tools need. Functions shall be identified and described where this requirement is applicable.
4–1–9	Reduction of pressure	The interaction of pressure supply reduction to machine tool performance shall be verified. (Depending on the application, 1 bar reduction can result in up to 10 % increased efficiency). The reduction of pressure shall not have any negative influence on the correct function of the machine. Functions shall be identified and described where this requirement is applicable.
4–2	Directed switch off	Check if all branches of pneumatic circuits need to be pressurized in all operating states of the machine tool. If not, take measurements to switch these branches off.
4–3	Optimize cylinder force for the required function	
4–4	ISO 4414 shall be applied	
4–5	Overall system	Optimization of total pneumatic system
5	**Electric systems**	

Table B.2 *(continued)*

No.	Feature for Improvement	Description
5–1	Avoidance of energy losses of power supplies	Avoid power losses in the transformer by use of e.g. voltage-proof converter, controlled switching power supply for 24 V control voltage.
5–2	High-efficiency transformer	Load requirement of a machine tool is not constant during the cycle. Therefore, it is more efficient to install transformers optimized on low Fe- losses instead of transformers optimized on low Cu- losses.
5–3	Apply the simultaneity factor when designing the power system	Avoid oversizing of power supply leads to lower absolute energy losses. Avoid overload as well.
5–4	Converter/inverter with power factor correction	Power factor in the in-feed unit for feed operation and regenerative feedback saves power losses.
5–5	Thermal management regarding control cabinet	Optimized concept for thermal management of the control cabinet:
5–5–1		Minimization of waste heat.
5–5–2		If waste heat is not avoidable, it has to be dissipated (air cooling or water cooling); for reuse of thermal energy, water is given a preference compared to air; further use of waste heat has to be checked/discussed with customer.
5–5–3		Controlled ventilation (fan).
5–5–4		Low-maintenance air conditioner (no air filter) and thermostatic air conditioning with open-door-shutoff.
6	**Die cooling/lubrication system**	
6–1	Thermal management of all cooling devices including cooling device for machine tool and/or its modules	Optimized concept for thermal management of all cooling devices:
6–1–1		Minimization of thermal power losses.
6–1–2		If thermal power loss is not avoidable, it has to be dissipated by air or water cooling; for reuse of thermal energy, water is given a preference compared to air; further reuse of thermal energy has to be checked/discussed with customer.
6–1–3		Controlled ventilation (fan).
6–2	Apply direct cooling of components depending on process	Temperature controlled.
6–3	Apply demand depending cooling	E.g. substituting line-connected motors by inverter motors, temperature controlled coolant water flow
7	**Lubrication system**	
7–1	Lubrication flow depending on demand	Active mode of cooling and lubrication system. E.g. - discontinuous operating pumps - controlled flow rate - adjustable pressure
7–2	Low flow rate for lubrication pump	Install not more than sufficient pump flow and distributor instead of orifices.
8	**Peripheral devices**	

Table B.2 *(continued)*

No.	Feature for Improvement	Description
8–1	Controlled peripheral devices such as mist extraction and scrap conveyor	Active mode of devices, dependent on mode of operation.
9	**Guidance for energy-efficient use**	
9–1	Optimization of work piece processing by die tryout	Work piece processing by tryout off-machine; avoidance of inefficient operating time; use also possible in conceptual phase of machine tool production.
9–2	Provisions to reduce scrap production	Die monitoring, in-process control, optimized use of raw material, minimize waste, zero-defect production.
9–3	Provide customer information to reduce consumption of resources	Training of operators leads to energy-sensitive handling of the machine tool.
9–3–1	Information to user on energy-efficient use of the machine e.g. on/off programming of auxiliary devices (user manual, instruction)	Give the operator information e. g. how to interact when he expects downtime.
9–3–2	Information to user on optimized movements of axis	Means for optimization of movements of multiple axis systems (feeders, robots) to follow energy-optimized moving curves.
9–3–3	Information to user on usable energy	Provide information about type of exergy carrier (e.g. water) and temperature of medium to choose optimal means for recovery.
9–4	Minimize non-productive time	Without utilization (production) or low output, the efficiency will be degraded. Means of improving output may be automatic die change systems, condition monitoring to prevent component failures, good diagnostic for quick trouble shooting, etc.
9–5	Optimize productivity by reducing cycle time per part	An improved productivity reduces the portion of required basic load per part.
10	**Control systems**	
10–1	Energy optimized default setting for operating condition -energy level- (customer specific drive management)	possible operating conditions -energy levels- e.g.: - switched off - standby - ready to be started (mains on, controls running, auxiliary and peripheral units stopped) - halted - ready for production (auxiliary and peripheral units running) - production possible means depending on mode of operation: - screen saver for operating terminal and lighting - intelligent drive management
10–2	Automatic operating state switching	Switching between different operating states helps drive management to choose most efficient mode.
10–3	Recording or monitoring of current energy consumption together with energy relevant production data	The knowledge of the machine energy consumption under different operating conditions helps the user to follow ISO 50001.

Annex C
(informative)

Example of how to apply the methodology on a machine tool

Specific machine under test:

machine type: 5-axis machining centre;

machine travel: X: 1 000; Y: 1 000; Z:800 mm;

machine mass: 14 t;

spindle power: 35 kW nominal;

auxiliary machine accessory: integrated tool changer.

The following steps refer to the design methodology as shown in Figure 9.

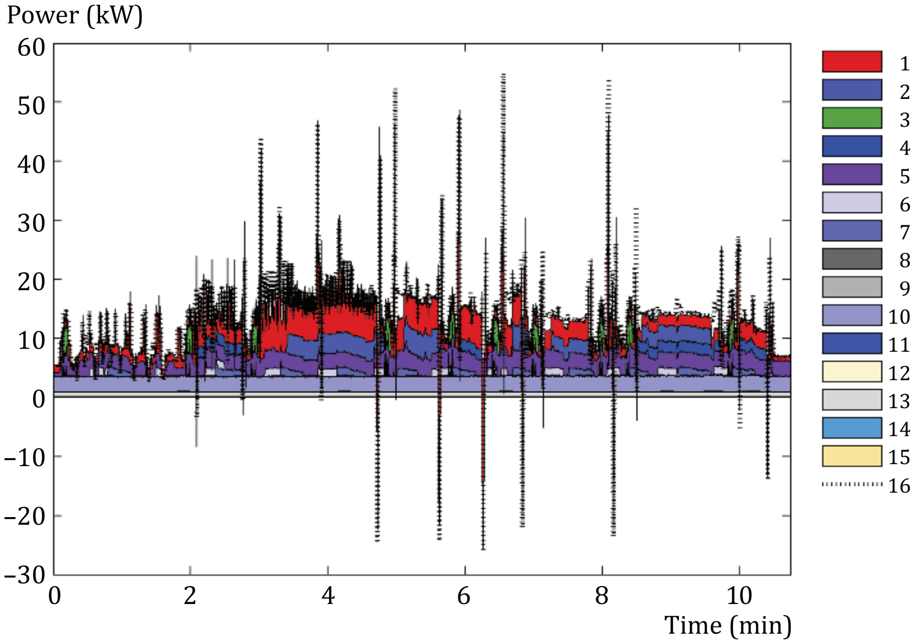
Step 1: Energy consumption during use phase is the most relevant environmental impact

Step 2: Describe generalized machine tool functions and subfunctions

- Machine operation: spindle and axis; 230 V AC and 24 V DC supply
- Process conditioning and cooling: interior and exterior lubricant supply, re-cooling of lubrication, air convection by mist extraction
- Workpiece handling: manual loading → no machine tool function
- Tool handling or die change: tool changer, hydraulic clamping
- Recyclables and waste handling: chip purging, chip conveyor, chip filtering, seal air, mist extraction
- Machine cooling/heating: lubricant supply, electrical cabinet cooling

Step 3: Assign machine components to generalized machine tool functions or subfunctions

For the example given, an area plot on component level for a reference process is established.



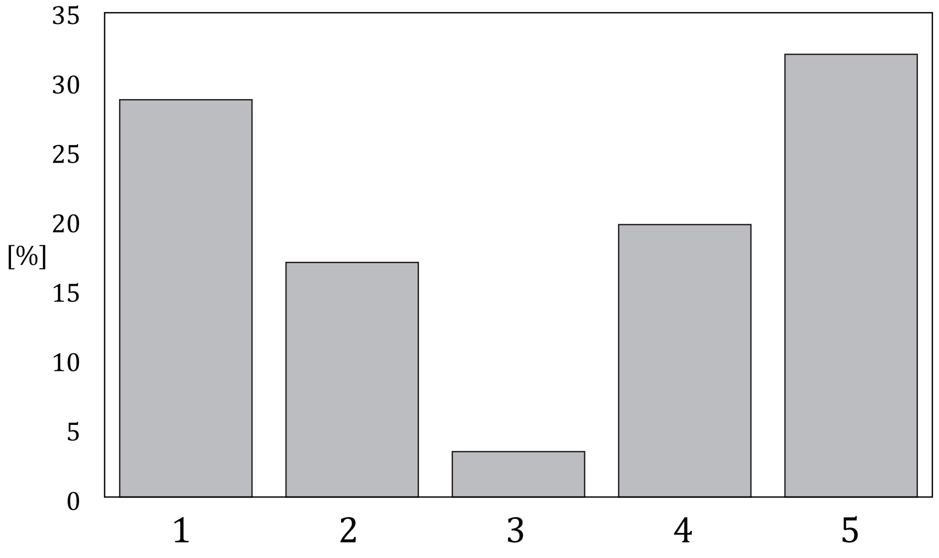
Key

1	spindle + Axis
2	pump/tool interior cooling
3	hydraulics
4	pump/tool exterior cooling
5	compressed air
6	chip removal pump
7	lubricant circulation pump
8	tool changer
9	chip conveyor
10	re-cooling devices
11	chip filtering device
12	supply 230 V AC
13	mist extraction
14	cooler for electrical cabinet
15	supply 24 V DC
16	total power

Figure C.1 — Area plot on component level

Table C.1 — Components list

	Machining	Process cond. + cool.	Work-piece handling	Tool handling	Recycl. + Waste handling	Machine cooling	Comment
CNC: spindle + axis	100 %						
Pump/ tool interior cooling		70 %			30 %		Reason for high pressure are chips
Hydraulic pump				100 %			
Pump/ tool exterior cooling		80 %				20 %	Mostly for process
Compressed air					100 %		No lubricant, no need
Chip removal pump					100 %		No chips, no need
Lubricant circulation pump		90 %				10 %	Mostly for process
Tool changer				100 %			
Chip conveyor					100 %		
Re-cooling devices		20 %				80 %	Permanent load for spindle cooling
Chip filtering device					100 %		
Supply 230 V AC	100 %						Arbitrary assignment due to small share
Mist extraction		10 %			80 %	10 %	Air convection is by-product of mist extraction
Cooler for electrical cabinet						100 %	
Supply 24 VD	100 %						Arbitrary assignment due to small share



Key

1 machining
2 process cooling and conditioning
3 tool handling
4 machine cooling
5 waste handling

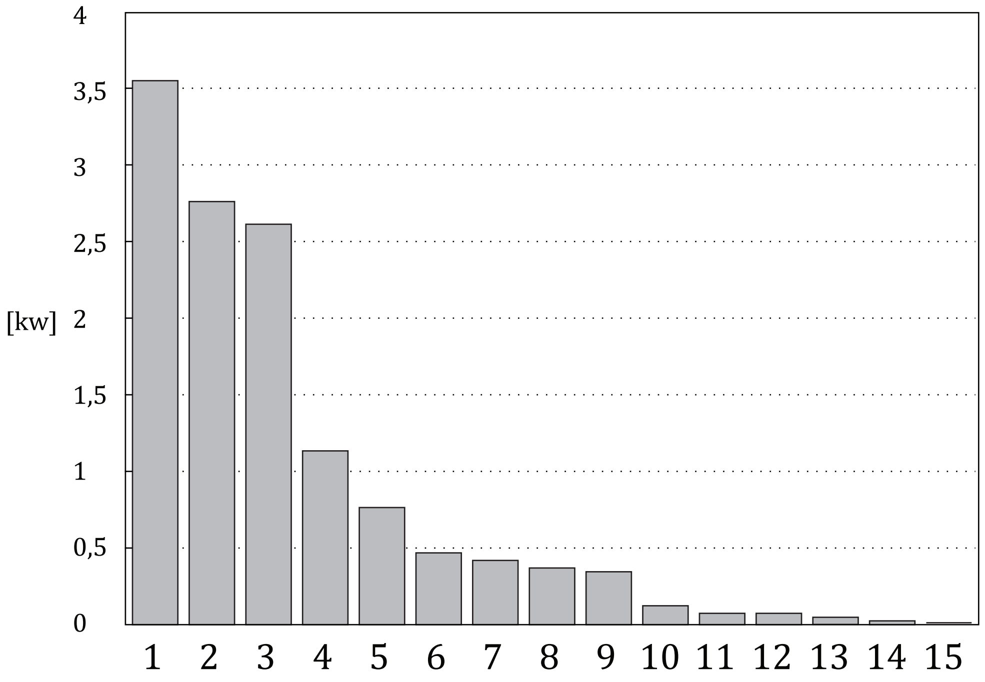
Figure C.2 — Share of energy for reference process (%)

The functional view suggest focus on (in priority order)

- waste handling and machining,
- machine cooling and process cooling and conditioning, and
- tool handling.

Step 4: Identify machine tool functions relevant for energy consumption during use phase

Calculation of average power from above measurements.



Key

1	cnc: spindle + axis	9	chip removal pump
2	compressed air	10	cooler for electrical cabernet
3	re-cooling devices	11	chip conveyor
4	pump/tool interior cooling	12	supply 230 V AC
5	mist extraction	13	tool changer
6	pump/tool exterior cooling	14	chip filtering device
7	lubricant circulation pump	15	supply 24 V DC
8	hydraulic pump		

NOTE Items 10 to 15 are of minor importance.

Figure C.3 — Average power in reference process (kW)

Step 5: Map relevant machine tool functions to machine components

Tool handling is neglected due to the small share according to step 4.

Table C.2 — Mapping of machine tool functions to machine components

Decreasing priority →	Recycling and waste handling	Machining	Machine cooling	Process conditioning and cooling
CNC: spindle + axis		100 %		
Compressed air	100 %			
Re-cooling device			80 %	20 %
Pump/tool interior cooling	30 %			70 %
Mist extraction	80 %		10 %	10 %
Pump/tool exterior cooling			20 %	80 %
Lubricant circulation pump			10 %	90 %
Chip removal pump	100 %			

Step 6: Compare relevant machine components, their control and their combination in the state of the art/to previous generation

For guidance, consult Annex A.

Table C.3 — Comparison of machine components

	Technology	System design: Component sizing	Demand-dependent control	Comparison with previous generation
Taxonomie/Metrics				
+	Best available technology	correct and/or no base load	Closed loop control	Efficiency improved > 20 %
0	Standard	oversized < 20 % and/or moderate base load	Open loop control	Efficiency improved > 0 %...20 %
–	Basic technology Low quality, below market average	oversized > 20 % and/or high base load	No control	No improvement, or deterioration
Components				
CNC: spindle + axis	+	0	+	0
Compressed air	0	–	–	–
Re-cooling device	0	–	+	0
Pump/tool interior cooling	+	0	0	0
Mist extraction	+	–	0	0
Pump/tool exterior cooling	+	–	0	0
Lubricant circulation pump	0	0	0	0
Chip removal pump	–	0	0	–

Step 7: Monitor relevant machine components

Considering share of energy (step 4 and step 5) and improvement potential (step 6), further efforts of improvement for this specific case are grouped as follows in decreasing priority:

- compressed air;

- re-cooling device;
- pump/tool interior cooling;
- mist extraction;
- pump/tool exterior cooling;
- chip removal pump;
- CNC: spindle + axis.

NOTE As this is just one example, the order will differ with other machine tools.

Step 8: Optimization of the machine tool

Optimization based on Annex A considering the findings of step 6 and step 7.

Annex D
(informative)

Operating states

Table D.1 — Example operating states for a metal-cutting machine tool

Examples of operating states	Mains	Machine control	Peripheral units	Machine processing unit	Machine motion unit	Machine axes
OFF	OFF	OFF	OFF	OFF	OFF	NOT MOVING
STAND BY WITH PERIPHERAL UNITS OFF	ON	ON	OFF	OFF	OFF	NOT MOVING
STAND BY WITH PERIPHERAL UNITS ON	ON	ON	ON[a]	OFF	OFF	NOT MOVING
READY FOR OPERATION	ON	ON	ON[a]	HOLD	HOLD	NOT MOVING
WARM UP	ON	ON	ON[a]	ON NO MACHINING	ON	MOVING
PROCESSING	ON	ON	ON[a]	ON MACHINING	ON	MOVING

[a] ON for peripheral unit might be just the state ENABLED because the operation of a peripheral unit might depend on additional conditions, e.g. operation of workspace cooling unit might depend on environmental temperature.

Bibliography

[1] ISO/TC 39/WG 12 N 022, Eco-design potential in Swiss industry, English translation from:

Züst R., Züst S., Studer S. Eco-design-Potenzialanalyse in der Schweizer MEM-Industrie — eine explorative Studie (2009), swissmem

[2] Massachusetts University Centre for Energy Efficiency and Renewable Energy (US Department of Energy). http://www.ceere.org/iac/assessment%20tool/ARC2420

[3] Sauls J., & Powell G. Ingersoll Rand/Trane, La Crosse, WI, US. *Influence of Manufacturing and Operational Effects on Screw Compressor Rotor Pair Clearances.* Schraubenmaschinen 2010 (Dortmund Compressor Conference), VDI, October 2010

[4] *Methodology for systematic analysis and improvement of manufacturing unit process life cycle inventory (UPLCI) Part 1*: Methodology Description- Kellens, K., Dewulf, W., Overcash, M., Hauschild, M. and Duflou, J.R. (2011), The International Journal of Life Cycle Assessment. DOI: . http://www.springerlink.com/content/ygn87mq1x217752w/ doi:10.1007/s11367-011-0340-4

[5] *Methodology for systematic analysis and improvement of manufacturing unit process life cycle inventory (UPLCI) Part 2*: Case Studies, Kellens, K., Dewulf, W., Overcash, M., Hauschild, M. and Duflou, J.R. (2011). The International Journal of Life Cycle Assessment. DOI: . http://www.springerlink.com/content/36851182732548u6/ doi:10.1007/s11367-011-0352-0

[6] Helu M. Vijayaraghavan, Dornfeld, D., 2011. *Evaluating the relationship between use phase environmental impacts and manufacturing process precision*, CIRP Annals – Manufacturing Technology 60(2011) 49-52

[7] Kellens K., Dewulf W., Duflou J.R. *Machine tool oriented eco-design perspectives based on systematic manufacturing process impact assessment*, Proceedings of 6th International Symposium on Environmentally Conscious Design and Inverse Manufacturing, Sapporo, 7-9 December 2009, ISBN978-4-88898-192-7, pp. 741-746

[8] Dahmus J.B., & Gutowski T.G. An environmental analysis of machining. *Proceedings of IMRCEE*. 2004, **2004** (November) pp. 13–19 [Anaheim, California, USA]

[9] Gontarz A., Weiss L., Wegener K. *Evaluation Approach with Function-Oriented Modelling of Machine Tools. Proceedings of Sustainable and Intelligent Manufacturing SIM*. IST PRESS, Leiria, Portugal, 2011, pp. 61–8.

[10] prEN 50598-1/-2, *Ductile iron pipes, fittings, accessories and their joints for sewerage application - Requirements and test methods*

[11] ISO 1328, *Cylindrical gears - ISO system of accuracy*

[12] ISO 4413, *Hydraulic fluid power — General rules and safety requirements for systems and their components*

[13] ISO 4414, *Pneumatic fluid power — General rules and safety requirements for systems and their components*

[14] IEC 60034-40, *Rotating electrical machines, Part 40*

[15] ISO 50001, *Energy management systems — Requirements with guidance for use*

[16] ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

[17] ISO 11011, *Compressed air — Energy efficiency — Assessment*

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