INTERNATIONAL STANDARD

ISO 14955-4

First edition
2019-07

Machine tools — Environmental evaluation of machine tools —

Part 4:
Principles for measuring metal-forming machine tools and laser processing machine tools with respect to energy efficiency

Machines-outils — Évaluation environnementale des machines-outils —

Partie 4: Principes de mesurage de l'efficacité énergétique des machines-outils de formage des métaux et des machines-outils à laser

Reference number
ISO 14955-4:2019(E)

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Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

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

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

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

Introduction

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

Machine tools are complex products for used by industry to manufacture workpieces ready for use or semi-finished products. Their environmental impact includes waste raw material, use of auxiliary substances such as lubricants and other material flows as well as the conversion of electrical energy into heat, the dissipation of heat to the atmosphere or heat exchange by fluids and eventually the use of other resources such as compressed air.

Based on relevance considerations, the ISO 14955 series is focussed on environmental impacts during the use phase.

The performance of a machine tool as key data for investment is multi-dimensional regarding its economic value, its technical specification and its operating requirements, which are influenced by the specific application. The energy supplied to the same machine tool can vary depending on the workpiece manufactured and the conditions under which the machine tool is operated. Therefore, the environmental evaluation of a machine tool cannot be performed without considering of these aspects.

Machine tools — Environmental evaluation of machine tools —

Part 4: Principles for measuring metal-forming machine tools and laser processing machine tools with respect to energy efficiency

1 Scope

This document specifies technical requirements and measures for testing procedures for evaluation of energy required to be adopted by persons undertaking the design, manufacture and supply of metal forming and laser processing machine tools in order to achieve reproducible data about the energy supplied under specified conditions. Furthermore, it provides methods for quantifying the energy supplied to components in order to assign their share to generalized machine tool functions as described in ISO 14955-1.

Along with ISO 14955-1 and ISO 14955-2, it covers all significant energy requirements relevant to hydraulic (servo) and mechanical (servo) presses, turret punch presses and press brakes, pipe benders, laser processing machine tools, when they are used as intended and under the conditions foreseen by the manufacturer. Examples of how to perform energy evaluation on metal-forming machine tools are given in the annexes.

This document is applicable to machine tools which transmit force mechanically or transmit energy by laser light to cut, form, or work metal or other materials by means of dies attached to or operated by slides, punches or beams as well as to lasers ranging in size from small high speed machine tools producing small work-pieces to large relatively slow speed machine tools and large work-pieces. This document covers machine tools whose primary intended use is to work metal, but which can be used in the same way to work other materials (e.g. cardboard, plastic, rubber, leather, etc.).

It also applies to auxiliary devices supplied as an integral part of the machine tool and to machine tools which are part of an integrated manufacturing system where the energy required is comparable to those of machine tools working separately.

This document does not give test procedures for the energy requirements of tools or dies attached to the machine tools.

It is not applicable to machine tools whose principal designed purpose is:

— metal-cutting by milling, drilling or turning;

— metal-cutting by oxygen or water cutting;

— attaching a fastener, e.g. riveting, stapling or stitching;

— bending or folding by folding machine tools;

— straightening;

— extruding;

— drop forging or drop stamping;

— compaction of metal powder;

— single purpose punching machine tools designed exclusively for profiles, e.g. used in the construction industry;

— working by pneumatic hammer;

— working by pneumatic presses.

NOTE Mechanical servo presses are also known as servo electric presses.

2 Normative references

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

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14955-1 and ISO 14955-2 and the following apply.

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

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

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

3.1
press
machine tool designed or intended to transmit energy to a tool/punch for the purpose of the working (e.g. forming or shaping) of metal or other material worked in the same way between the tools

3.2
hydraulic press
hydraulic servo press
press (3.1) designed or intended to transmit energy by linear movement between closing tools by hydraulic means

[SOURCE: ISO 16092-1:2017, 3.1.4, modified — The Note 1 to entry has been deleted.]

3.3
mechanical press
press (3.1) designed or intended to transmit energy from a prime mover to a tool/punch by mechanical means using a clutch mechanism which transmits torque to impart motion of the flywheel to the slide

[SOURCE: ISO 16092-1:2017, 3.1.2, modified — The Note 1 to entry has been deleted.]

3.4
mechanical servo press
press (3.1) designed or intended to transmit energy to a tool/punch by mechanical means using a servo drive mechanism without clutch mechanism to generate torque to impart motion to the slide

[SOURCE: ISO 16092-1:2017, 3.1.3, modified — The Note 1 to entry has been deleted.]

3.5
double action press
press (3.1) containing a die cushion for deep drawing purposes

3.6
press brake
machine tool designed or intended to transmit energy to the moving part of the tools by hydraulic means and/or mechanical means with or without using a servo drive mechanism, principally for the purpose of bending between narrow forming tools along straight lines

3.7
pipe bender
machine tool designed or intended to transmit energy to constrain or strain to tension by bending pipes

3.8
turret punch press
type of *press* (3.1) used to cut holes in material, which can be small and manually operated holding one simple die set, or very large and NC controlled with a single or multi-station turret holding a much larger and complex die set

3.9
laser processing machine tool
machine tool in which (an) embedded laser(s) provide(s) sufficient energy/power to melt, evaporate, or cause a phase transition in at least a part of the workpiece, and which has the functional and safety completeness to be ready-to-use

[SOURCE: ISO 11553-1:2005, 3.2 modified — "machine" is substituted by "machine tool"]

3.10
slide/ram
main reciprocating *press* (3.1) member which holds the tool/punch

[SOURCE: ISO 16092-1:2017, 3.2.12]

3.11
beam
main reciprocating press brake member which normally holds the punch on a down-stroking press brake, and which normally holds the die on an up-stroking press brake

[SOURCE: EN 12622:2009, 3.1.1]

3.12
die cushion
accessory for a die which accumulates and releases, or absorbs, force as required in some *press* (3.1) operations

[SOURCE: ISO 16092-1:2017, 3.2.6]

3.13
tool/die
device for imparting a desired shape, form, or finish to a material

EXAMPLE Hardened steel forms for producing the patterns on coins and medals by pressure, and the hollow moulds into which metal or plastic is forced.

3.14
moving bolster
movable plate carrying the *tools or dies* (3.13) and moving during tool change

3.15
automation system
system for loading and/or unloading of workpieces by highly automatic means, reducing human process intervention to a minimum

3.16
spacer
device to hold a space open [e.g. between slide and moving bolster or between slide and *die cushion* (3.12)] on hydraulic or mechanical presses

3.17
regenerative circuit
shaft side of a double action cylinder connected to the head side, so that fluid exiting the shaft side is added to the fluid entering the head side

3.18
total power
power applied to a machine tool component at the feeding point of the machine tool component

3.19
power loss
loss of power applied to a machine tool component, mostly transferred to heat (e.g. due to friction or throttle losses)

3.20
inverter system
system generating variable frequency to energize electric motors for variable speed, consisting of line reactor and/or line filter and the inverter itself

3.21
dead centre
point at which the tool/punch, during its travel, is:

— either nearest/closest to the die (generally, it corresponds to the end of the closing stroke), known as bottom dead centre (BDC);

— or furthest from the die (generally, it corresponds to the end of the opening stroke), known as top dead centre (TDC)

[SOURCE: ISO 16092-1:2017, 3.2.4]

4 Operating states for measurement procedure

4.1 Operating state OFF

The main switch shall be turned off during measurement.

4.2 Operating state MAIN SWITCH ON

Main switch and control voltage are turned on. The power measured is mainly the power applied to the control system and includes the power applied in operating state OFF.

The power needed for air conditioning of the control cabinets depends on ambient conditions during measurement.

4.3 Operating state AUXILIARY DRIVES ON

The auxiliary drives shall be turned on and the average power shall be measured over a time of at least 15 min. If auxiliary drives are used to charge accumulators for control pressure and an on/off-charging mode is used, the measurement shall be done at least for the time specified in the shift regime and at least 5 charging cycles. If an auxiliary drive is charging an accumulator system, the measurement shall cover at least five charging cycles.

The power measured includes the power applied to the control system when the main switch is on. The difference to the applied power in operating state “MAIN SWITCH ON” is the power applied to the auxiliary drives.

In laser processing machine tools, the oscillator and the chiller are turned on and the warm-up is performed until the heat generated by the oscillator and the heat dissipated by radiation/cooling is balanced.

NOTE The warm-up time can vary between different types of oscillators.

4.4 Operating state MAIN DRIVES ON

The main drives shall be turned on and the average power shall be measured over a time specified in the shift regime.

If the main drives are controlled by inverters (e.g. servo motor) and a rotating drive leads directly to a movement (e.g. of the slide or die cushion), MAIN DRIVES ON is when main drives are powered with rotation speed zero.

The power measured includes the power applied when auxiliary drives are on. The difference to the applied power in operating state AUXILIARY DRIVES ON is the idling power applied to the main drives.

4.5 Operating state READY TO RUN IN PRODUCTION MODE

The power measured includes the power applied to auxiliary functions, e.g. automation systems. The difference to the applied power in operating state MAIN DRIVES ON is the power applied to automation systems.

4.6 Operating state PROCESSING

As this is the operating state the machine tool is designed for, the energy shall be determined by measurement at the system boundary.

The efficiency factor shall be calculated as described in Clause 5 for the different types of machine tools.

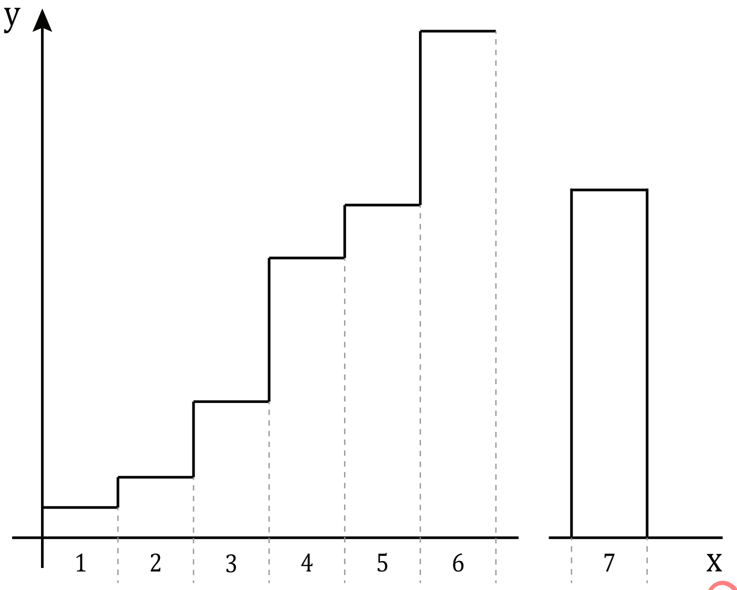
4.7 Operating state TOOL CHANGE

Due to the fact that the tool change sequence is different from production cycle, TOOL CHANGE is seen as a separate operating state and the energy supplied in this state shall be measured. This measurement should be done using tools/dies with a mass typical for the press size and agreed upon between manufacturer and user.

The energy supplied during TOOL CHANGE may be determined using the methodology as described in ISO 14955-2.

4.8 Typical result of power measurement

Figure 1 shows the result of a power measurement supplied in different operating states.



Key

x operating states
y power [kW]
1 OFF
2 MAIN SWITCH ON
3 AUXILIARY DRIVES ON
4 MAIN DRIVES ON
5 READY TO RUN IN PRODUCTION MODE
6 PROCESSING
7 TOOL CHANGE

Figure 1 — Typical average power supplied in different operating states

5 Evaluation of energy supplied to different types of machine tools

5.1 General

Measuring equipment installed shall not reduce the level of safety of the machine tool[1][2][3].

NOTE This reduction can occur, for example, by bypassing of interlocking guard(s), modifications in the safety-related control system or installing stroke-initiating devices in place of two hand control devices.

5.2 Energy supplied to presses

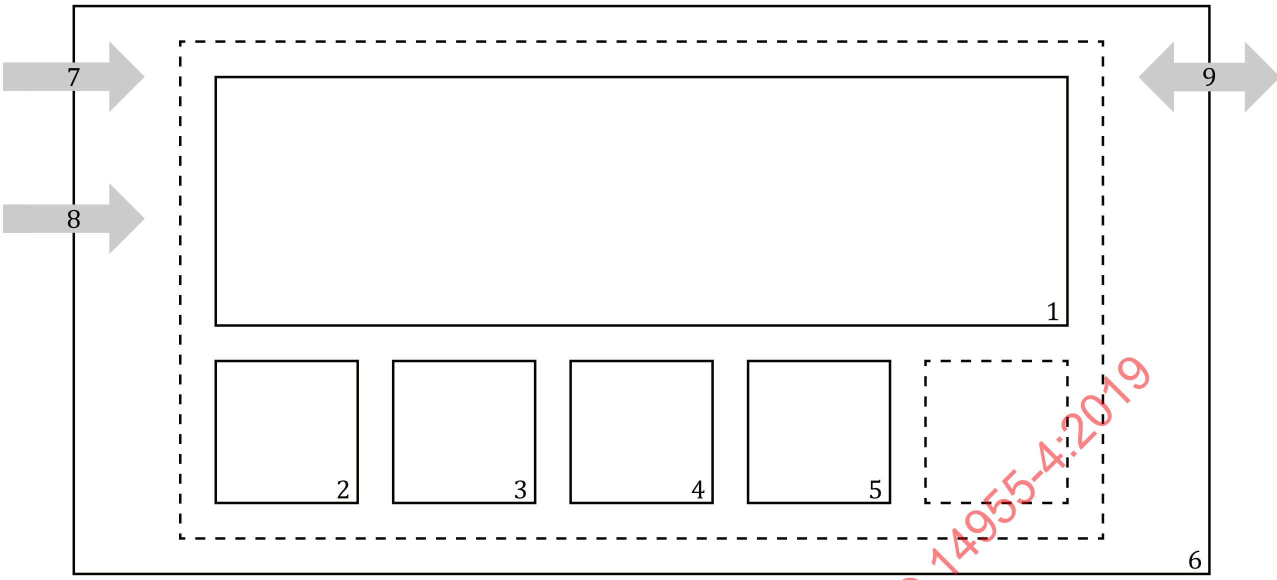
5.2.1 General

Examples for hydraulic and mechanical presses are given in Annex A and Annex B.

5.2.2 System boundary

The energy flow at the system boundary during test-run shall be as close as possible to the energy flow at the system boundary during production.

Figure 2 shows an example for the system boundary of a hydraulic (servo) and mechanical (servo) press.



Key

1	machine tool	6	system boundary
2	machine tool component A, e.g. slide	7	electrical energy
3	machine tool component B, e.g. die cushion	8	compressed air
4	machine tool component C	9	heat exchange
5	machine tool component D		

Figure 2 — System boundary of hydraulic (servo) and mechanical (servo) presses

The system boundary during the test-run does not include energy required for dies and/or die functions (e.g. workpiece lifters, die heating in cure processes, die cooling in hot forming processes). These die functions have a broad variety in terms of the type of energy required (e.g. electrical energy, hydraulic energy, steam, die coolant, workpiece lubricant flow) and the amount. Die functions depend on the process and the die itself and not on the machine tool.

5.2.3 Shift regime

As shift regimes are dependent on the equipment (e.g. equipped with automatic or manual tool change) and therefore can be different for each machine tool and machine tool user (e.g. number of tool changes per shift), a specific shift regime according to ISO 14955-2:2018, 5.2.2, can be set up for measurement. The shift regime and the clustered shift regime shall be reported.

5.2.4 Minimum measuring period

The default measuring period is the observation period. During measurement it can be decided to shorten the measuring period. In this case the energy supplied shall be extrapolated to match the respective shift regime. The reason for the shortening shall be stated, e.g. observation of a repetitive pattern or stabilization of power supplied after some time.

In a specific shift regime, the measuring periods for each operating state under stable conditions are at least as given in Table 1.

Table 1 — Minimum measuring periods in specific shift regime

Operating state	Measuring period
1: OFF	5 min
2: MAIN SWITCH ON	5 min

Table 1 *(continued)*

Operating state	Measuring period
3: AUXILLIARY DRIVES ON	10 min
4: MAIN DRIVES ON	10 min
5: READY TO RUN IN PRODUCTION MODE	10 min
6: PROCESSING: INTERMITTENT RUN	30 min and 10 cycles
7: PROCESSING: CONTINOUS RUN (Presses with automatic feeding only)	30 min and 10 cycles
8: TOOL CHANGE	1 complete tool change sequence

The measuring time in operating state processing shall be at least 30 min. If less than 10 cycles are performed during this time (e.g. in presses for curing processes), the measuring shall continue until 10 complete cycles are performed.

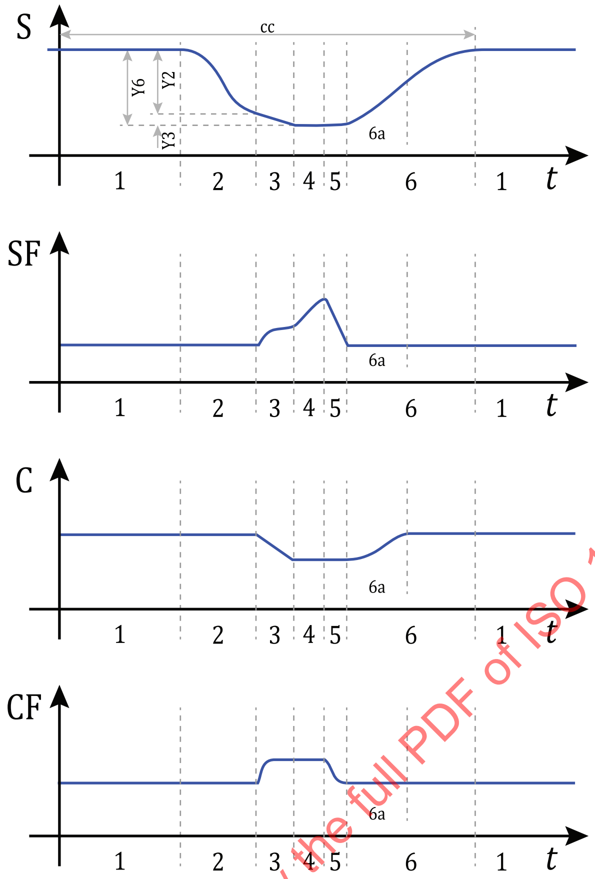
In operating state processing, measurement shall be made on a cycling machine tool. Interruptions (e.g. by failure) leading to a total time of measurement interruption longer than 10 % of the scheduled measuring time requires a restart of the measurement. A total interruption time less than or equal to 10 % of the scheduled measuring time shall prolong the measuring period.

5.2.5 Typical press cycle diagram

Due to the fact that deep drawing processes are one of the most run processes on presses worldwide, this example reflects a typical deep drawing process on a double action downstroking press (on upstroking presses, slide stroke is upside down and formulae are to be matched to this situation). Even if processes other than deep drawing or other presses than double action have different cycle diagrams, the principle of this cycle diagram remains valid.

If an energy recovery/energy saving feature can be disabled by the user, the measurement shall be performed having the energy recovery/energy saving feature engaged as well as disengaged.

In order to obtain detailed information about energy supplied and energy efficiency in the operating state PROCESSING, the press cycle shall be broken down in machine tool activities, see Figure 3.



Key

S slide stroke
SF slide force
C cushion stroke
CF cushion force
t time

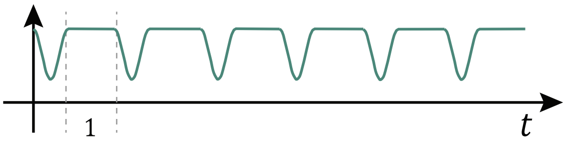
1	machine tool activity 1: slide waiting in TDC:	Slide is waiting for start signal while workpiece is loaded into die.
2	machine tool activity 2: slide close:	Slide is closing the die.
3	machine tool activity 3: forming:	Slide is forming the workpiece and the cushion is displaced by the slide
4	machine tool activity 4: embossing:	Slide applies set-force in BDC and starts BDC dwell time.
5	machine tool activity 5: decompression:	Decompression of press frame, die cushion and slide cylinder (hydraulic press)/gear and drive mechanism (mechanical press). Decompression is not adjustable by the user.
6	machine tool activity 6: slide return:	Slide moves back to TDC.
6a	machine tool activity 6a: workpiece ejection:	Die cushion lifts workpiece for unloading.

cc complete cycle
Y2 slide stroke between TDC and workpiece contact
Y3 distance the cushion is displaced
Y6 complete slide stroke

Figure 3 — Typical press cycle diagram with machine tool activities for a downstroking press

5.2.6 Reference and test cycle for hydraulic (servo) presses in PROCESSING

The press shall be measured in intermittent run and continuous run (press with automatic feeding) for a time period given in the shift regime, see Figure 4.



Key

1 TDC dwell time

t time

Figure 4 — Typical press cycles for hydraulic presses

Table 2 shows set-values for test cycle (if adjustable by the user, values in % are related to nominal value).

Table 2 — Settings for test cycle of hydraulic presses

Machine tool component	Machine tool activity	Parameter	Set-value
Slide	Waiting in TDC (1)	TDC dwell time for manual fed presses with a nominal cycle time of less than 5 s	1 s
		TDC dwell time for manual fed presses with a nominal cycle time of equal or more than 5 s but less than 30 s	4 s
		TDC dwell time for manual fed presses with a nominal cycle time of equal or more than 30 s	8 s
	Closing (2)	Closing stroke (Y2, % of nominal value)	60 %
		Closing speed (% of nominal value)	100 %
	Working (3)	Working stroke (Y3, % of closing stroke)	20 %
		Working speed (% of nominal value)	70 %
	BDC dwell time (4)	Force (% of nominal value)	70 %
		Presses with a nominal cycle time of less than 5 s	0,3 s
		Presses with a nominal cycle time of equal or more than 5 s but less than 30 s	1 s
		Presses with a nominal cycle time of equal or more than 30 s	20 s
	Return (6)	Return stroke (Y6, % of nominal value)	80 %
		Return speed (% of nominal value)	100 %
Die cushion(s)	Die cushion stroke (Y3, % of nominal value)		80 %
	Die cushion force (% of nominal value)		80 %
	Die cushion force (% of nominal value)		80 %
Automation system	Moving speed of all axis		80 %

The press cycle shall take into account the intended manufacturing process (e.g. stamping, forging, curing) to allow realistic energy evaluation. If a press is designed for more than one manufacturing process (e.g. stamping and curing), energy evaluation shall be done for all processes the press is designed for.

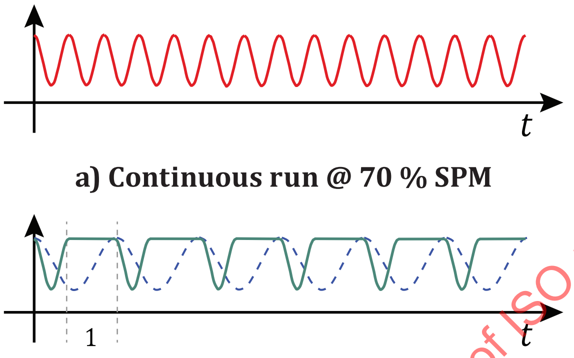
On manually fed presses, the test cycle shall include the time needed for manual feeding (TDC dwell time). On presses with automatic loading/unloading, the test cycle shall imply the operation of the automation system and the TDC dwell time is depending on the cycle time of the automation system.

If energy recovery/conservation means are selectable by the user, measurement shall be made with and without energy recovery/conservation means active.

To allow repetitive measurement under reproducible conditions, the energy relevant process data shall be documented in the report.

5.2.7 Reference and test cycle for mechanical (servo) presses in PROCESSING

Figure 5 shows typical press cycles for mechanical (servo) presses.



Key

1 TDC dwell time

t time

Figure 5 — Typical press cycles for mechanical (servo) presses

The press shall be measured in continuous run and intermittent run for a time period given in 5.2.4.

Tables 3 and 4 show set-values for test cycle (if adjustable by the user, values in % are related to nominal value).

Table 3 — Settings for test cycle of mechanical presses

Machine tool component	Parameter	Set-value
Slide	Flywheel speed	70 %
	TDC dwell time for intermittent run of presses with a nominal SPM of equal or more than 12 SPM	1 s
	TDC dwell time for intermittent run of presses with a nominal SPM of less than 12 SPM	2 s
Stroke length adjustment	Stroke length (Y6)	≥80 %
Die cushion(s)	Die cushion force at 25 % cushion stroke (% of nominal value)	30 %
	Die cushion force at 40 % cushion stroke (% of nominal value)	10 %
	Die cushion ejection speed (if adjustable, % of nominal value)	80 %
Automation system	Moving speed of all axis	80 %

Table 4 — Settings for test cycle of mechanical servo presses

Machine tool component	Machine tool activity	Parameter	Set-value
Slide	Waiting in TDC (1)	TDC dwell time for intermittent run of presses with a nominal SPM of equal or more than 12 SPM	1 s
		TDC dwell time for intermittent run of presses with a nominal SPM of less than 12 SPM	2 s
	Closing (2)	Closing stroke (Y2, % of nominal value)	70 %
		Closing speed (% of nominal value)	100 %
	Working (3)	Working stroke (Y3, % of nominal value)	70 %
		Working speed (% of nominal value)	70 %
	Return (6)	Return stroke continous run (Y6, % of nominal value)	100 %
		Return stroke intermittent run (Y6, % of nominal value)	50 %
		Return speed (% of nominal value)	100 %
Stroke length adjustment	Stroke length (Y6)		≥80 %
Die cushion(s)	Die cushion force at 25 % cushion stroke (% of nominal value)		30 %
	Die cushion force at 40 % cushion stroke (% of nominal value)		10 %
	Die cushion ejection speed (if adjustable, % of nominal value)		80 %
Automation system	Moving speed of all axis		80 %

5.2.8 Use of spacers instead of a die during test-run

Workpieces being formed on presses covered by this document require individual dies. These dies are made solely for this workpiece and are recycled or sold as soon as the production of this product is stopped or sourced out.

The energy supplied to form a workpiece is mainly depending on type of material (e.g. steel, stainless steel, high alloy steel, aluminium), degree of shaping, workpiece temperature (e.g. hot/cold), friction of the workpiece in the die (mainly influenced by tribology) and die wear.

If a test-run for energy evaluation is done using a specific die, it cannot be guaranteed that the same measurement condition can be found for a repetitive measurement after a longer period of time (e.g. one year). A practicable way to achieve reproducible conditions for the test-run for energy evaluation is to use spacers which allow a realistic (production) cycle.

NOTE These spacers are mostly made out of solid steel blocks with top and bottom side machined. The number of spacers installed depends on their size and force applied during test-run.

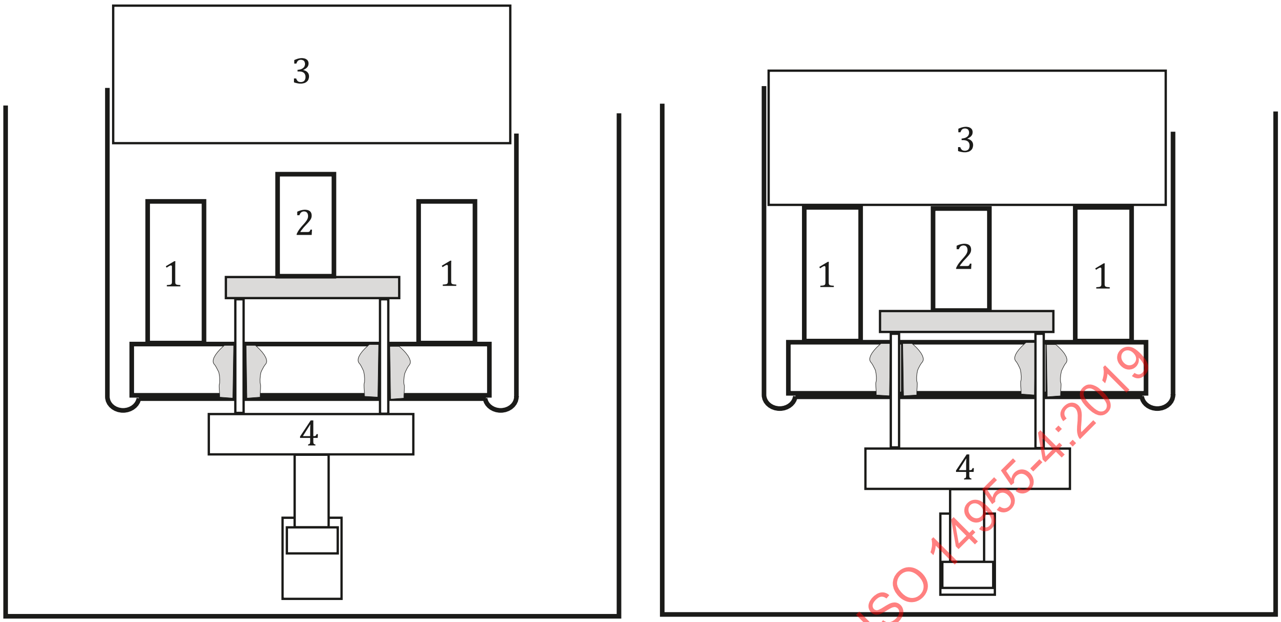
These spacers shall:

— allow a test-cycle according to the reference cycle;

— withstand all forces and velocities applied during measurement; and

— be kept at user site or be easy to rent or purchased in an acceptable time.

Figure 6 shows an example of a hydraulic or mechanical double action press with spacers installed.



a) Slide at top dead centre

b) Slide at bottom dead centre (end of closing stroke)

Key

1 spacers for slide
2 spacer for die cushion
3 slide
4 die cushion

Figure 6 — Example of a hydraulic or mechanical double action press with spacers installed

If no die cushion is installed in the press, springs can be used as spacers on presses with spring decompression feature. In other cases, the measurement shall be done with the slide force generated on spacer(s).

The technical data and dimensions of the spacer(s) shall be reported and given to the user to allow reproducible measurements at a later date.

5.3 Energy supplied to press brakes

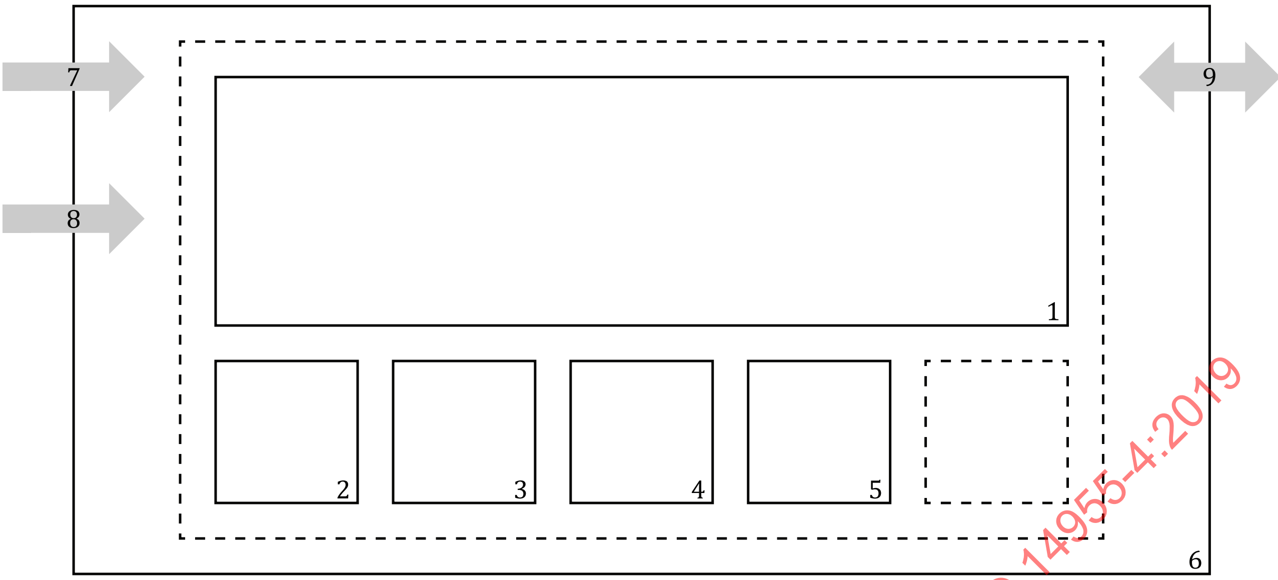
5.3.1 General

An example for a hydraulic press brake is given in Annex C.

The type of press brakes dealt with in this document is driven by hydraulic means (including hybrid systems) and direct electric means.

5.3.2 System boundary

The energy flow at the system boundary during test-run test shall be as close as possible to the energy flow at the system boundary during production, see Figure 7.



Key

1 machine tool
2 machine tool component A, e.g. beam
3 machine tool component B, e.g. back gauge
4 machine tool component C, e.g. feed unit
5 machine tool component D
6 system boundary
7 electrical energy
8 compressed air
9 heat exchange

Figure 7 — System boundary of press brakes

The system boundary during test-run does not include energy required for specific auxiliary functions (e.g. follow-up device and support robot), automatic tool change systems and process accuracy improvement devices (bending indicator, etc.).

5.3.3 Shift regime

As shift regimes are dependent on the equipment (e.g. NC unit, die layout and die equipment) and, therefore, can be different for each machine tool and machine tool user, a specific shift regime according to ISO 14955-2:2018, 5.2.2, can be set up for measurement. The shift regime and the clustered shift regime shall be reported.

5.3.4 Minimum measuring period

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

In a specific shift regime, the measuring periods for each operating state under stable conditions shall be at least as given in Table 5.

Table 5 — Minimum measuring periods in specific shift regime

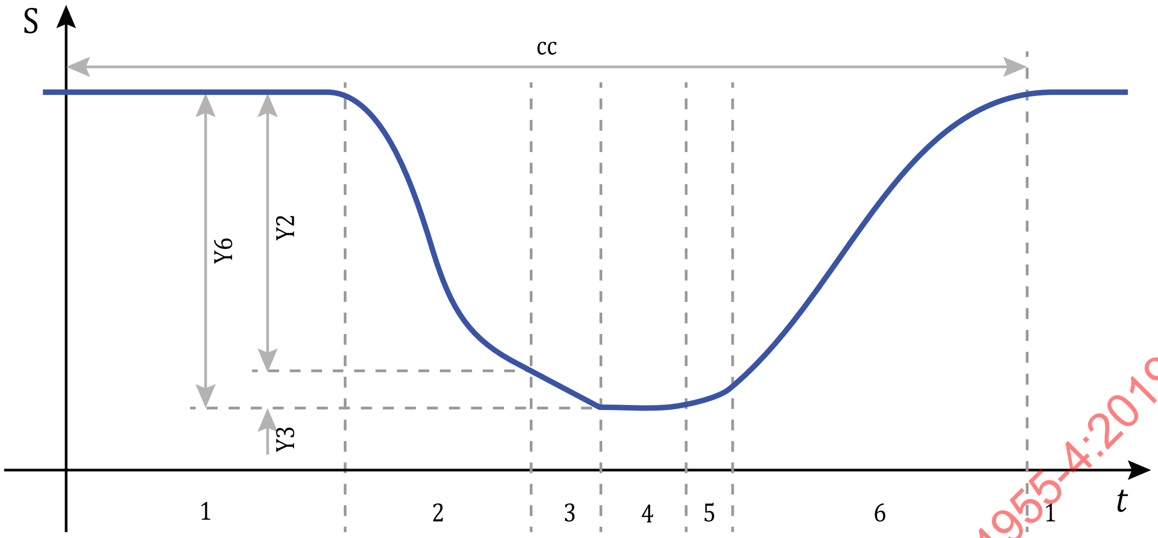
Operating state	Measuring period
1: OFF	5 min
2: MAIN SWITCH ON	5 min
3: AUXILLIARY DRIVES ON	10 min
4: MAIN DRIVES ON	10 min
5: READY TO RUN IN PRODUCTION MODE	10 min
6: PROCESSING: INTERMITTENT RUN	20 min and 100 cycles
7: TOOL CHANGE	1 complete tool change sequence

The measuring time in operating state PROCESSING shall be at least 20 min. If less than 100 cycles are performed during this time, the measuring shall continue until 100 complete bending cycles are performed.

In operating state PROCESSING, measurement shall be made on a cycling machine tool. Interruptions (e.g. by failure) leading to a total time of measurement interruption longer than 10 % of the scheduled measuring time requires a restart of the measurement. Total interruption time shorter or equal than 10 % of the scheduled measuring time shall prolong the measuring period.

5.3.5 Typical press brake cycle diagram

Figure 8 shows a typical press brake cycle diagram.



Key

S beam stroke

t time

1	machine tool activity 1: waiting for start:	Waiting for start signal while workpiece is loaded into die.
2	machine tool activity 2: beam close:	High speed descent (distance Y2).
3	machine tool activity 3: bending:	Bending (distance Y3).
4	machine tool activity 4: pressing:	Appliance of set-force and start of BDC dwell time.
5	machine tool activity 5: decompression:	The decompression is not adjustable by the user.
6	machine tool activity 6: return:	High speed ascent (distance Y6).

cc complete cycle

Y2 beam stroke between TDC and workpiece contact

Y3 bending distance

Y6 complete beam stroke

Measuring conditions:

— Pressurization operation by spacer, etc.;

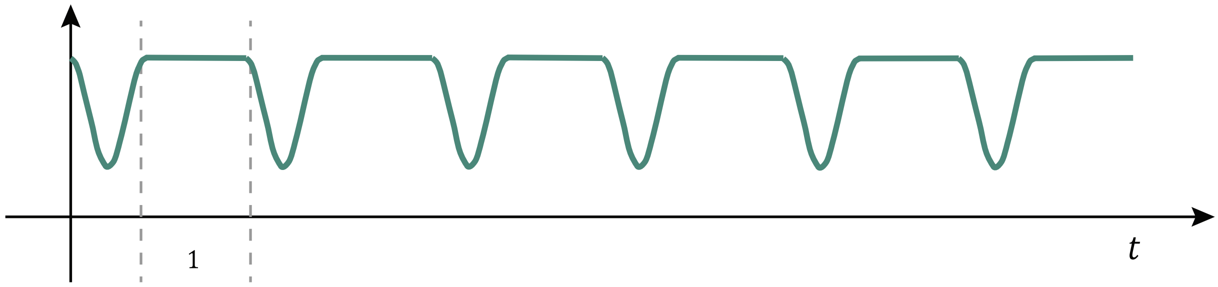
— 100 cycle operations;

— 20 min operation time.

Figure 8 — Typical press brake cycle diagram with machine tool activities

5.3.6 Reference and test cycle of hydraulic (servo)/mechanical (servo) press brake in operating-state PROCESSING

Figure 9 shows a typical test cycle of a hydraulic (servo)/mechanical (servo) press brake in intermittent operation.



Key

1 TDC dwell time

t time

Figure 9 — Typical cycles of hydraulic (servo)/mechanical (servo) press brake (intermittent operation)

Press brake shall be measured by the intermittent operation of the time period shown in the above-stated shift regime.

Set-values for test cycle are given in Table 6 (if adjustable by the user, values in % are related to nominal value):

Table 6 — Settings for test cycle of hydraulic (servo)/mechanical (servo) press brakes

Machine tool component	Parameter	Set-value
Beam	High speed descent speed (2)	100 %
	High speed descent stroke (Y2) (% of nominal stroke)	35 %
	Bending speed (3)	70 %
	Bending stroke (Y3)	10 mm
	Ascent speed	100 %
	Ascent stroke	Y6
	Force (4)	50 %
	BDC dwell time	0,5 s
	TDC dwell time	2 s
Backgauge etc.	Moving speed of all axis	100 %

NOTE The test cycle is done using a spacer without a bending plate in order to achieve reproducible conditions.

If the workpiece is manually fed to the press brake, the test cycle shall include the time required for feeding the workpiece (TDC dwell time).

If the press brake is equipped with automatic workpiece-feed-units, the test cycle shall include the operation of the automatic feed-unit (feeding workpiece). And an operating time of automatic feed-unit becomes the dwell time (waiting time), which is dependent on ability of the automatic feed-unit.

If an energy recovery/energy saving feature can be disabled by the user, the measurement shall be performed having the energy recovery/energy saving feature engaged as well as disengaged.

To allow repetitive measurement under reproducible conditions, the energy relevant process data shall be documented in the report.

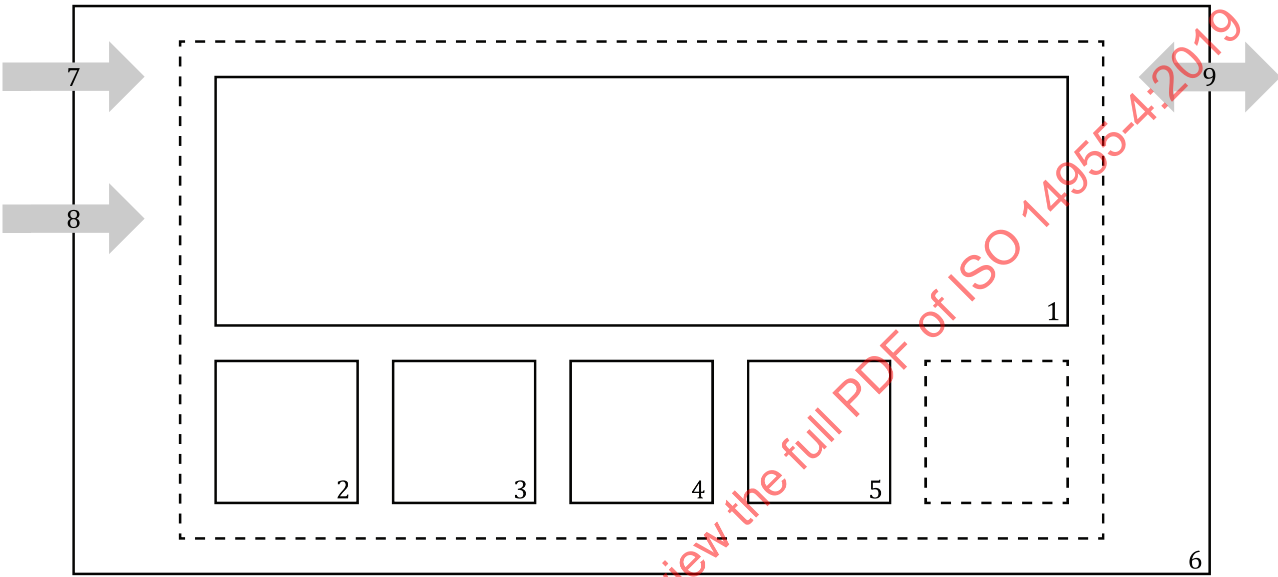
5.4 Energy supplied to pipe benders

5.4.1 General

An example for a pipe bender is given in Annex F.

5.4.2 System boundary

The energy flow at the system boundary during test-run test shall be as close as possible to the energy flow at the system boundary during production, see Figure 10.



Key

1 machine tool
2 machine tool component A
3 machine tool component B
4 machine tool component C
5 machine tool component D
6 system boundary
7 electrical energy
8 compressed air
9 heat exchange

Figure 10 — System boundary of pipe benders

5.4.3 Shift regime

As shift regimes are dependent on the equipment (e.g. NC unit, die layout and die equipment) and, therefore, can be different for each machine tool and machine tool user, a specific shift regime according to ISO 14955-2:2018, 5.2.2, may be set up for measurement. The shift regime and the clustered shift regime shall be reported.

5.4.4 Minimum measuring period

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

In a specific shift regime, the measuring periods for each operating state under stable conditions are at least as given in Table 7.

Table 7 — Minimum measuring periods in specific shift regime

Operating state	Measuring period
1: OFF	5 min
2: MAIN SWITCH ON	5 min
3: AUXILLIARY DRIVES ON	10 min
4: MAIN DRIVES ON	10 min
5: READY TO RUN IN PRODUCTION MODE	10 min
8: PROCESSING	5 cycles

In operating state PROCESSING, measurement shall be made on a cycling machine tool. Interruptions (e.g. by failure) leading to a total time of measurement interruption longer than 10 % of the scheduled measuring time requires a restart of the measurement. A total interruption time less than or equal to 10 % of the scheduled measuring time shall prolong the measuring period.

5.4.5 Test cycle

The minimum measuring periods in specific shift regime is 5 cycles (i.e. five tubes, with multiple bends on each tube), see Table 8 and Figure 11.

Table 8 — Settings in test cycle for pipe benders

Material/process	Parameter	Settings
Test material	— Carbon-steel pipe for machine tool structure, or, if different, the standard pipe material for the tested machine, e.g. copper — or other material agreed upon between manufacturer and user	SPCC[5], DC01[6], 1,033[7]
	Pipe diameter	100 %
	Pipe thickness	To get 90 % of the nominal bending torque
Bending process (5 bends for each tube)	(L) Feed length	200 mm
	(A) Bending angle	90°
	(R) Rotation between successive bends	90°
	Bending radius	2 * diameter

The adopted bending tools (e.g. mandrel, wiper dies) and the actual bending torque (measured by the machine drive) shall be reported.

If the machine tool can adopt different bending strategies (e.g. draw bending, compression bending), all technologies shall be tested and documented.

Figure 11 shows a test workpiece with 90° bend every 200 mm.

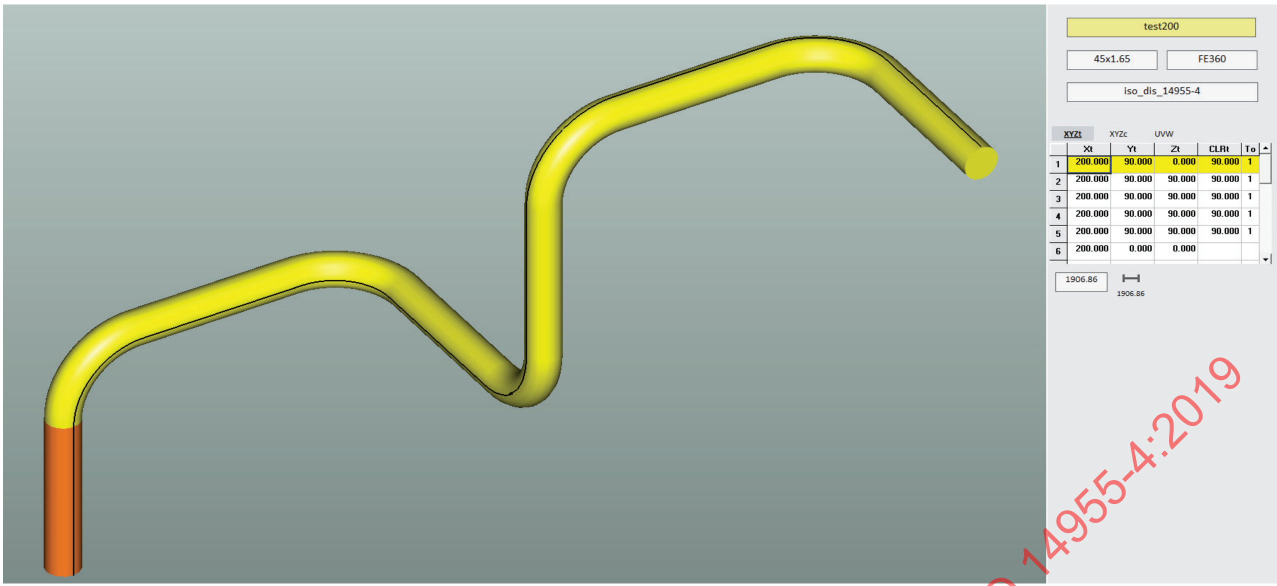


Figure 11 — Test workpiece with 90° bend every 200 mm

5.5 Energy supplied to turret punch presses

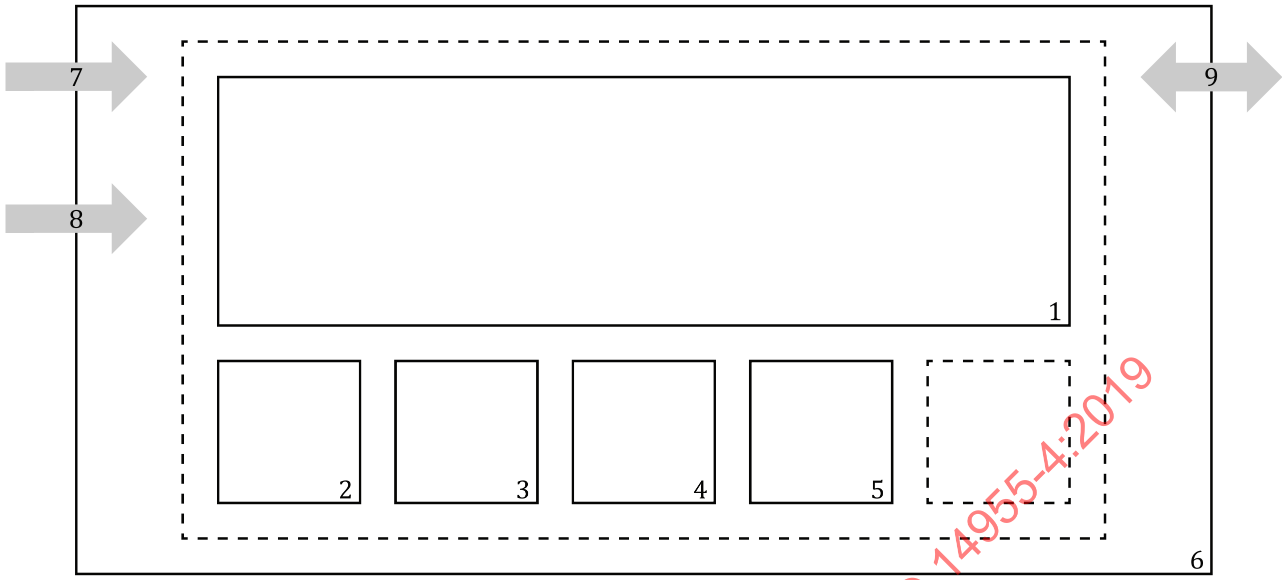
5.5.1 General

An example for a turret punch press is given in Annex D.

The type of turret punch press dealt in this standard is driven by electric means.

5.5.2 System boundary

The energy flow at the system boundary during test-run test shall be as close as possible to the energy flow at the system boundary during production, see Figure 12.



Key

1	machine tool	6	system boundary
2	machine tool component A, e.g. frame	7	electrical energy
3	machine tool component B, e.g. press drive	8	compressed air
4	machine tool component C, e.g. turret	9	heat exchange
5	machine tool component D, e.g. transfer table		

Figure 12 — System boundary of turret punch presses

5.5.3 Shift regime

As shift regimes are dependent on the equipment (e.g. NC unit, sheet loader and unloader) and therefore can be different for each machine tool and machine tool user, a specific shift regime according to ISO 14955-2:2018, 5.2.2, may be set up for measurement. The shift regime and the clustered shift regime shall be reported.

5.5.4 Minimum measuring period

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

In a specific shift regime, the measuring periods for each operating state under stable conditions shall be at least as given in Table 9.

Table 9 — Minimum measuring periods in specific shift regime

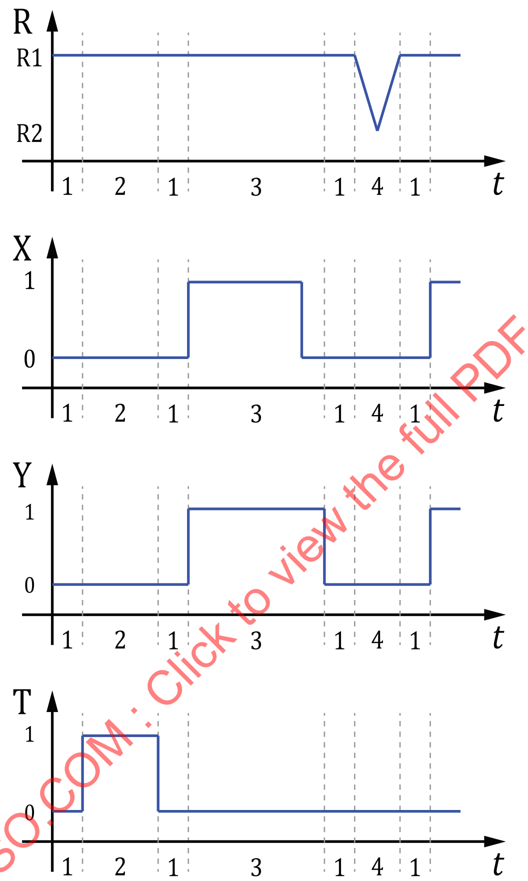
Operating state	Measuring period
1: OFF	5 min
2: MAIN SWITCH ON	5 min
3: AUXILLIARY DRIVES ON	10 min
4: READY TO RUN IN PRODUCTION MODE	10 min and 1 sheet
6: PROCESSING	10 min
7: TOOL CHANGE	1 complete tool change cycle

The measuring time in operating state PROCESSING shall be at least 10 min. If less than 1 sheet is processed during this time, the measuring shall continue until 1 sheet is processed completely.

In operating state PROCESSING, measurement shall be made on a cycling machine tool. Interruptions (e.g. by failure) leading to a total time of measurement interruption longer than 10 % of the scheduled measuring time requires a restart of the measurement. Total interruption time shorter or equal than 10 % of the scheduled measuring time shall prolong the measuring period.

5.5.5 Reference and test cycle for turret punch presses in operating state PROCESSING

Figure 13 shows a typical turret punch press cycle diagram.



Key

R ram

R1 ram upper end

R2 ram lower end

X X-axis active

Y Y-axis active

T T-axis active

t time

1 machine tool activity 1: STANDBY – waiting for the start signal of axes

2 machine tool activity 2: die positioning – T-axis is rotated for setting the die into the punch centre

3 machine tool activity 3: workpiece positioning – X-axis and Y-axis move for setting the workpiece to processing position

4 machine tool activity 4: punching – ram descends and processes punch holes, then moves to upper end

Figure 13 — Typical turret punch press cycle diagram with machine tool activities

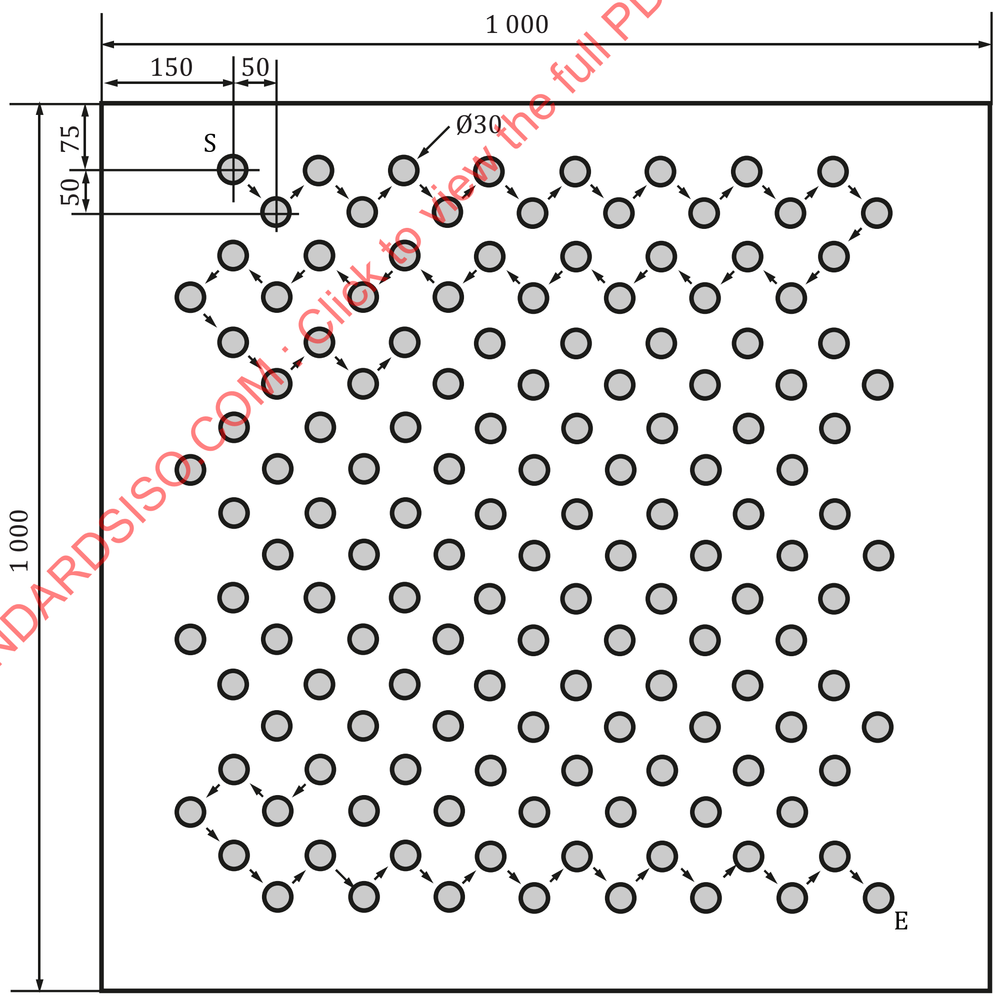
Axial feed rate and ram speed shall be set at maximum of machine tool specification.

Simultaneous positioning of X-axis and Y-axis, and ram descent and rise after completion of both axis positions, shall be performed.

The specification of a recommended test piece used during measurement is given in Table 10. If the specification is not met, set values and other relevant data shall be documented [see Clause 6 prescriptions d) and j)].

Table 10 — Recommended specification of test piece used in test cycle of turret punch presses

Property	Value
Test material	SPCC[5], DC01[6], 1,033[7]
Sheet thickness	1 mm or 2 mm
Sheet size	1 000 mm × 1 000 mm
Pattern	Pattern according to Figure 14
Cut shape	30 mm round
Number of processed holes	144
Pitch (X, Y staggered array)	50 mm



Key

S first cut (start of cycle)

E last cut (end of cycle)

Figure 14 — Processing pattern for turret punch presses

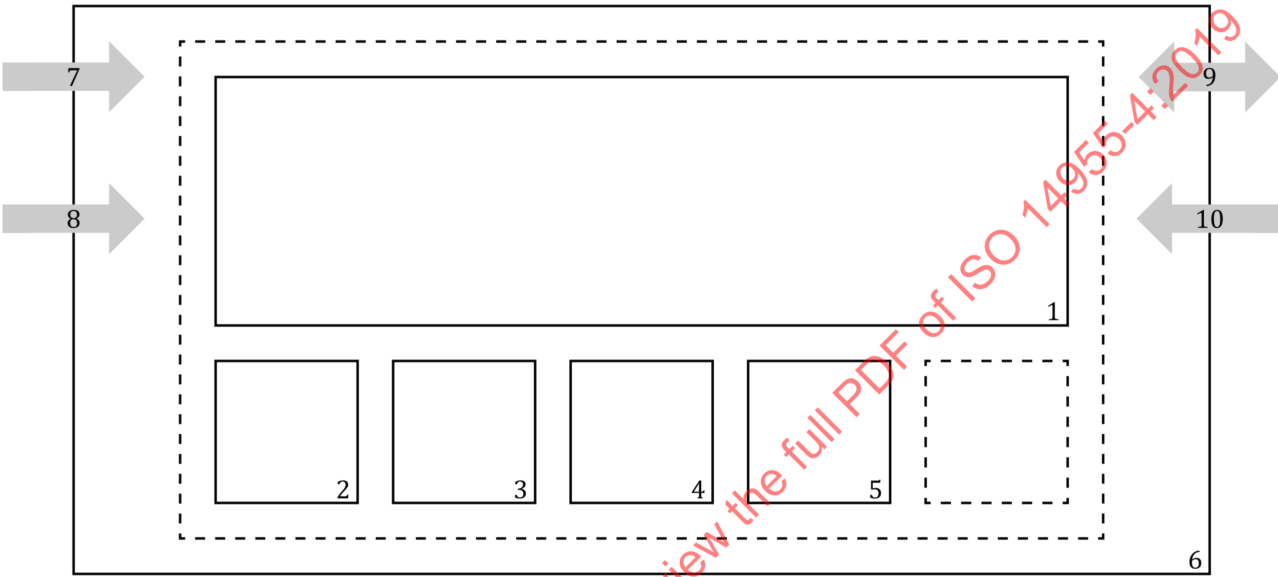
5.6 Energy supplied to laser processing machine tools

5.6.1 General

An example for a laser processing machine tool is given in Annex E.

5.6.2 System boundary

The energy flow at the system boundary during test-run test shall be as close as possible to the energy flow at the system boundary during production, see Figure 15.



Key

1	machine tool	6	system boundary
2	machine tool component A, e.g. frame	7	electrical energy
3	machine tool component B, e.g. oscillator	8	compressed air
4	machine tool component C, e.g. chiller	9	heat exchange
5	machine tool component	10	cutting gas

Figure 15 — System boundary of laser processing machine tools

5.6.3 Shift regime

As shift regimes are depending on the equipment (e.g. NC unit, sheet loader and unlader) and therefore can be different for each machine tool and machine tool user, a specific shift regime according to ISO 14955-2:2018, 5.2.2, can be set up for measurement. The shift regime and the clustered shift regime shall be reported.

5.6.4 Minimum measuring period

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

In a specific shift regime, the measuring periods for each operating state under stable conditions shall be at least as given in Table 11.

Table 11 — Minimum measuring periods in specific shift regime

Operating state	Measuring period
1: OFF	5 min
2: MAIN SWITCH ON	5 min
3: AUXILLIARY DRIVES ON (oscillator warm up)	15 min
4: MAIN DRIVES ON	10 min
5: READY TO RUN IN PRODUCTION MODE	10 min
6: PROCESSING	10 min and 5 test pieces

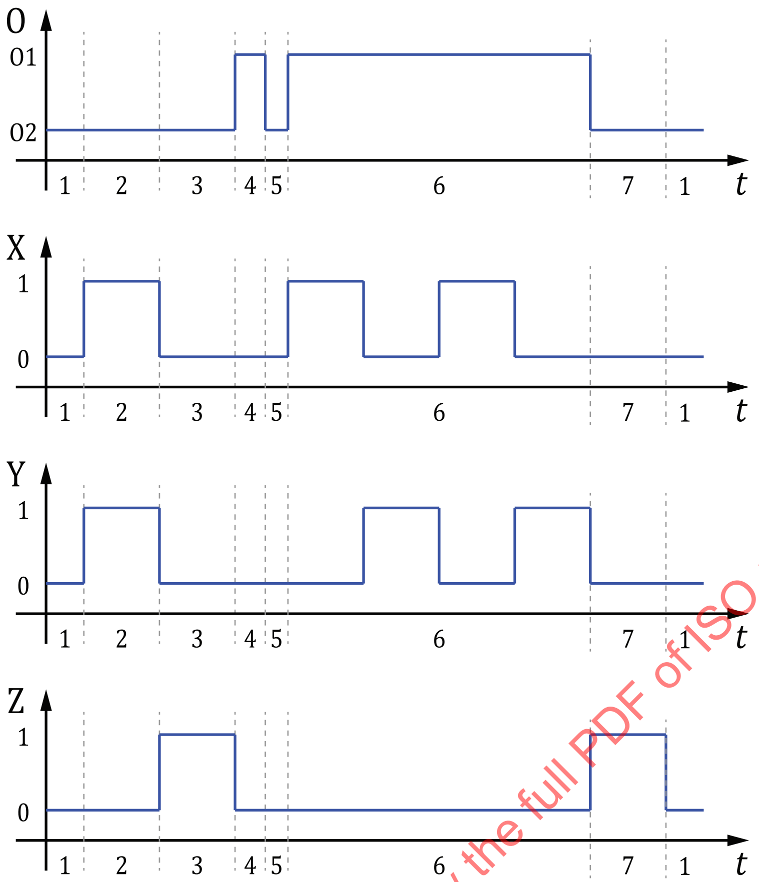
The measuring time in operating state PROCESSING shall be at least 10 min. If less than five test pieces are processed during this time, the measuring shall continue until five test pieces are processed completely.

The chiller repeats ON and OFF according to coolant fluid temperature for cooling of the oscillator. At least five or more cooling cycles of the chillers shall be measured for the chiller average power measurement. If less than that, processing shall be continued until reaching five or more cooling cycles.

In operating state PROCESSING, measurement shall be made on a processing machine tool. Interruptions (e.g. by failure) leading to a total time of measurement interruption longer than 10 % of the scheduled measuring time requires a restart of the measurement. A total interruption time less than or equal to 10 % of the scheduled measuring time shall prolong the measuring period.

5.6.5 Reference and test cycle for laser processing machine tools in operating state PROCESSING

Figure 16 shows a typical reference and test cycle for laser processing machine tools.



Key

O oscillator
O1 oscillator oscillating
O2 oscillator waiting
t time
X X-axis active
Y Y-axis active
Z Z-axis active
1 machine tool activity 1: STANDBY
2 machine tool activity 2: X-axis and Y-axis positioning – processing head is set horizontally to processing start position
3 machine tool activity 3: Z-axis descent – processing head descents to the position of processing above workpiece
4 machine tool activity 4: piercing – making a hole at the start position of cutting with laser beam
5 machine tool activity 5: shifting mode to cutting – shift the mode of oscillator and gas before cutting
6 machine tool activity 6: cutting – Laser beam moves in the programmed trace with X-axis and Y-axis
7 machine tool activity 7: Z-axis return – processing head moves up

Figure 16 — Typical laser processing machine tool cycle diagram with machine tool activities

Feed rates for X-, Y- and Z-axis and laser output power shall be set at maximum of machine tool specification.

The specification of a recommended test piece used during measurement is given in Table 12 and the set values for the test cycle in Table 13. If the specification is not met, set values and other relevant data shall be documented [see 6 d) and j)].

Table 12 — Recommended specification of test piece used in test cycle of laser processing machine tools

Material/process	Parameter	Settings
Test material	Type	SPCC[5], DC01[6], 1,033[7]
Sheet thickness ≤ 3,2 mm	Sheet thickness	≥30 % of maximum cutting thickness or 1,0 mm or 1,2 mm
	Pattern	Pattern (a)
	Cut shape	20 mm square
	Number of processed holes	80
	Perimeter cutting	880 mm × 530 mm
Sheet thickness > 3,2 mm	Sheet thickness	≥30 % of maximum cutting thickness
	Pattern	Pattern (b)
	Cut shape	30 mm round
	Number of processed holes	18
	Perimeter cutting	380 mm × 380 mm
Pitch (X, Y, staggered array)		50 mm

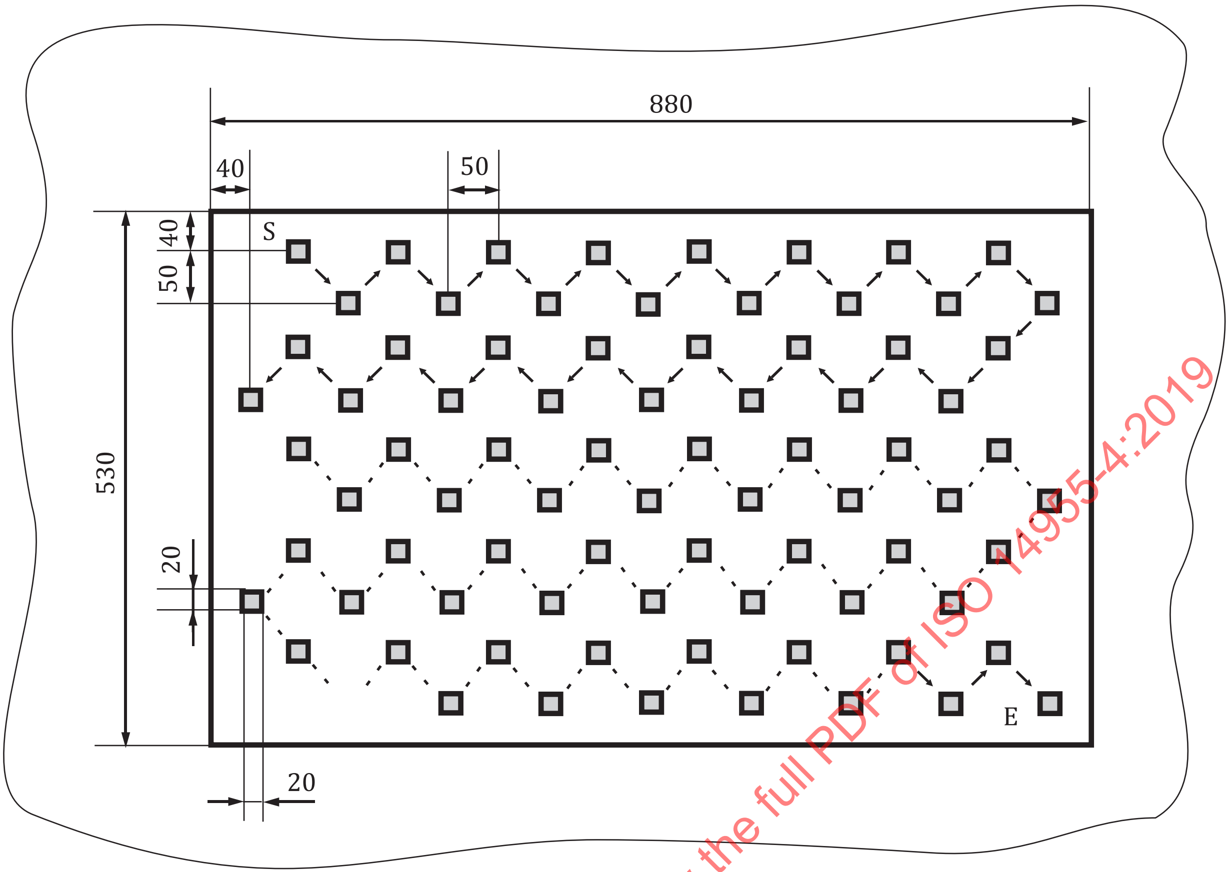
Table 13 — Set-values for test cycle of laser processing machine tools to be reported

Set-value			Unit
Oscillator	Piercing	Output	kW
		Duty	%
	Cutting	Output	kW
		Duty	%
Cutting speed			m/min
Tool path			
1 test piece processing time			s

The NC program should be saved for later repetition of the test procedure and the tool path should be documented.

NOTE Tool path for cutting the same shape, that is, three-dimensional (X, Y, Z) trajectory of the laser processing head, is possible in several ways. Therefore, the patterns of Figures 17 and 18 alone cannot determine the tool path due to effect of NC program and control specifications.

Figure 17 shows a processing pattern (a) for laser processing machine tools.



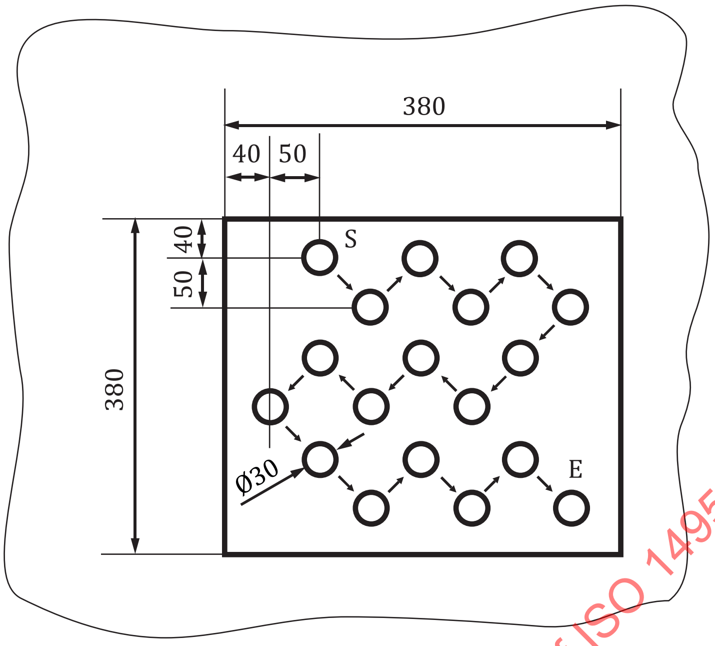
Key

S first cut (start of cycle)

E last cut before perimeter cutting

Figure 17 — Processing pattern (a)

Figure 18 shows a processing pattern (b) for laser processing machine tools.



Key

S first cut (start of cycle)

E last cut before perimeter cutting

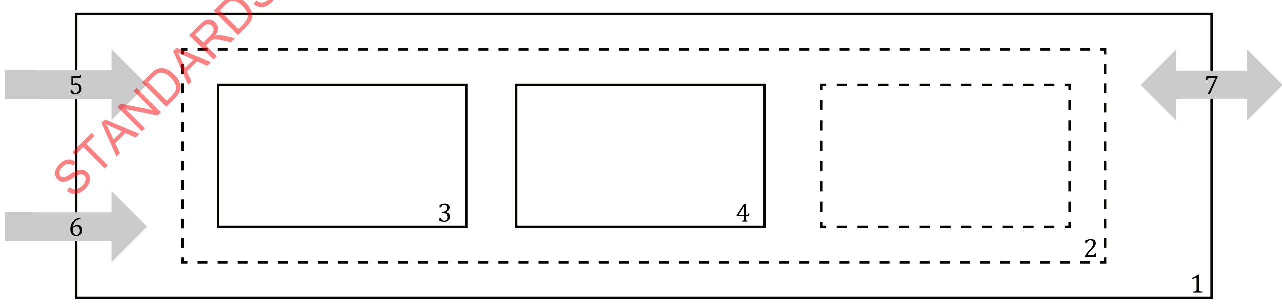
Figure 18 — Processing pattern (b)

5.7 Energy supplied to auxiliary devices

5.7.1 System boundary

To cover a broad selection of auxiliary devices, the system boundaries of these devices shall be defined according to the specific device and measurement shall be done either simultaneously or synchronized with the machine tool measurement. The system boundary for each auxiliary device used on the machine tool or being integral part of the machine tool shall be documented. See Figure 19.

NOTE Auxiliary devices being active in operating state processing are mostly automation systems for workpiece handling. Today, these automation systems are typically robots, gripper bar transfers, feeder systems or forging manipulators. The type of automation system provided is depending on the produced workpieces.



Key

1 system boundary

2 auxiliary device of a machine tool

3 axis A

4 axis B

5 electrical energy

6 compressed air

7 heat exchange

Figure 19 — System boundary of an auxiliary device of a machine tool

To avoid an excessive complexity of measurement, measurement at the system boundary is sufficient for auxiliary devices. The energy supplied shall be added to the energy supplied to the other machine tool components.

5.7.2 Shift regime

As auxiliary devices are linked to the machine tool, the shift regime of these devices corresponds to the shift regime of the machine tool.

5.7.3 Pneumatic energy and heat exchange measurement

Methods for measuring pneumatic energy and heat exchange shall be in accordance with ISO 14955-2:2018, Annex B.

6 Reporting

The measurement report shall contain the data and information shown as follows:

a) Technical data of the machine tool:

   1) manufacturer;

   2) machine tool type;

   3) serial number;

   4) year of construction;

   5) mechanical details (e.g. slide dimensions, max. die weight);

   6) rated electrical power, main drive(s) power, auxiliary drive(s) power;

   7) rated pneumatic pressure and flow; and

   8) type of operating fluid;

b) Technical data of auxiliary devices:

   1) rated electrical power; and

   2) rated pneumatic pressure and flow;

c) Environmental conditions during measurement;

d) Test piece specification (if test piece is processed during test run) or statement, that no test piece is processed during test run;

e) Shift regime and clustered shift regime;

f) System boundary of machine tool;

g) System boundary of auxiliary devices;

h) List of measuring points;

i) Specification of measurement devices (e.g. brand, measurement uncertainty);

j) Test cycle including all energy relevant settings in operation state processing;

k) Test cycle of machine tool including all energy relevant settings in operation state tool change;

l) Test cycle of auxiliary devices including all energy relevant settings in operation state processing;

m) Number of cycles run in continuous mode;

n) Measurement results related to the operating states and machine tool activities including all energies supplied at the system boundary of the machine tool;

o) Measurement results related to the operating states including all energies supplied at the system boundary of auxiliary device(s) (e.g. automation system, moving bolster);

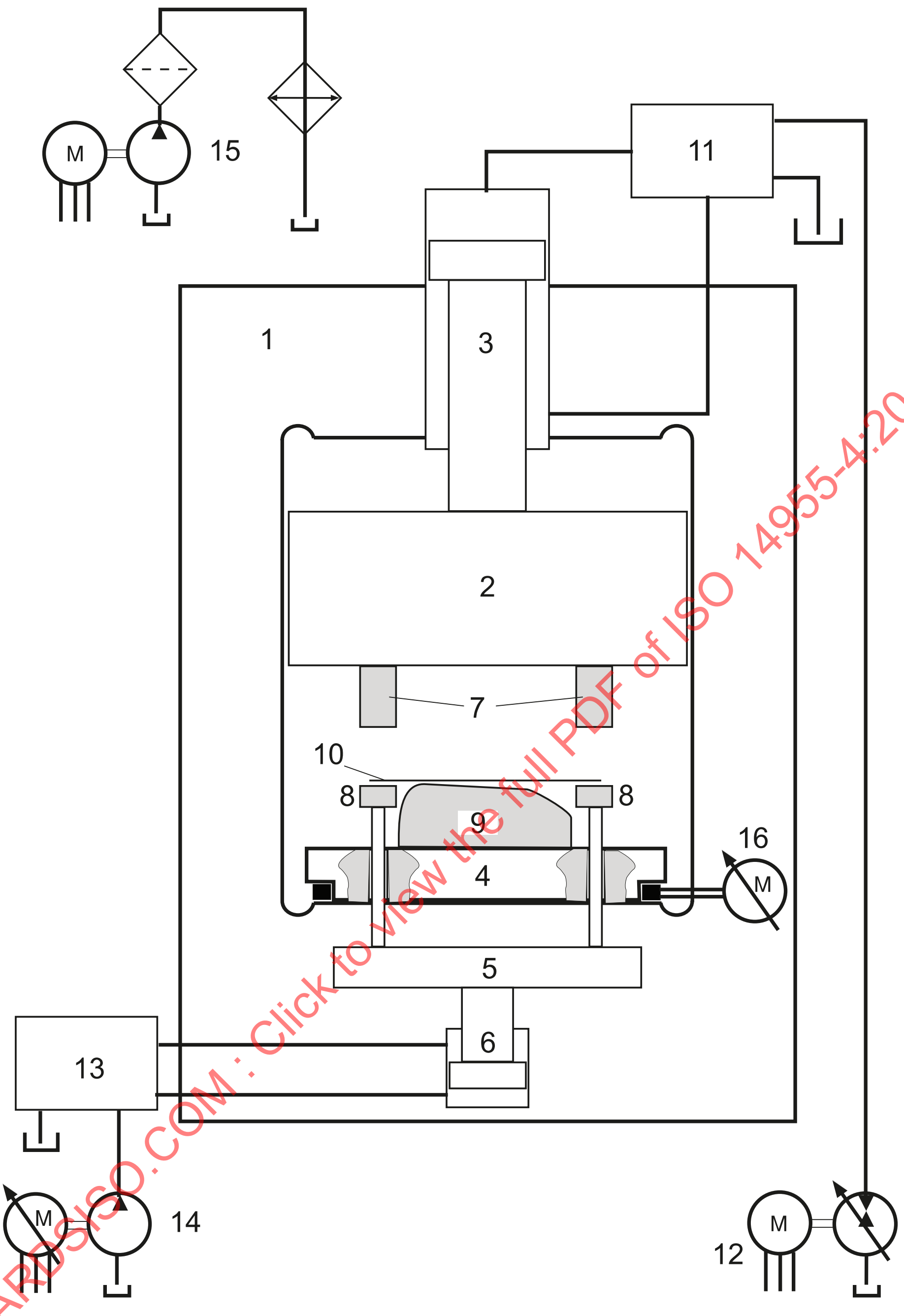
p) Measurement result in machine tool cycles per total energy supplied.

Annex A
(informative)

Hydraulic presses

A.1 Example of a downstroking hydraulic press (double action press)

Figure A.1 shows an example of a hydraulic double action press.



Key

1	frame
2	slide
3	main cylinder
4	moving bolster
5	die cushion
6	die cushion cylinder
7	upper die
8	drawing ring
9	lower die
10	workpiece (blank)
11	hydraulic manifold slide
12	main pump drive unit
13	hydraulic die cushion manifold
14	auxiliary pump drive(s)
15	cooling drive unit
16	moving bolster drive unit

Figure A.1 — Example of a hydraulic double action press

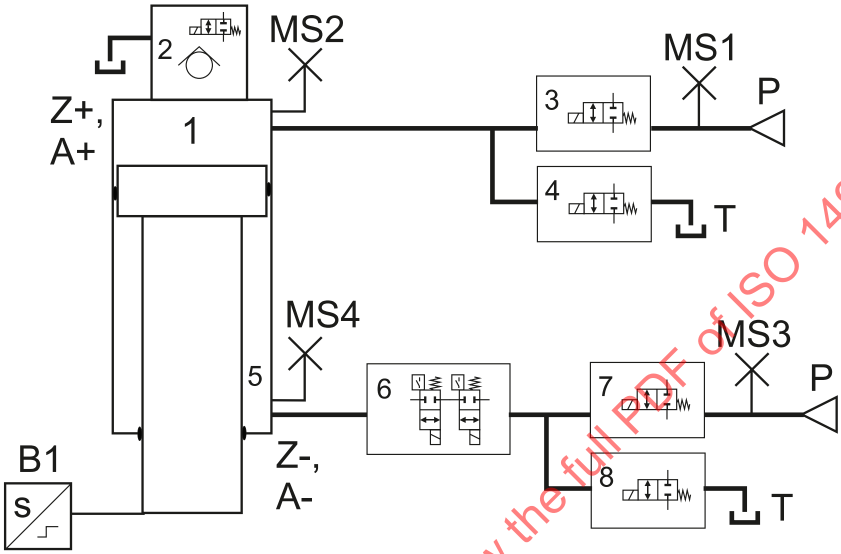
A.2 Power measurement

A.2.1 Power measurement at slide

A.2.1.1 Hydraulic presses

A.2.1.1.1 General

An example of slide hydraulic for a hydraulic press is given in Figure A.2.



Key

1 slide cylinder head side
2 prefill
3 main unit head side
4 decompression unit
5 main cylinder shaft side
6 press safety
7 slide return unit
8 slide down unit

Z+ slide cylinder port head side
Z− slide cylinder port shaft side
A+ slide cylinder area head side
A− slide cylinder area shaft side
P connection to pressure source
MSx pressure measuring points
B1 position sensor

Figure A.2 — Example of a slide hydraulic for a downstroking press

The flow can be calculated with Formulae (A.1) and (A.2):

$$Q = v * A \tag{A.1}$$

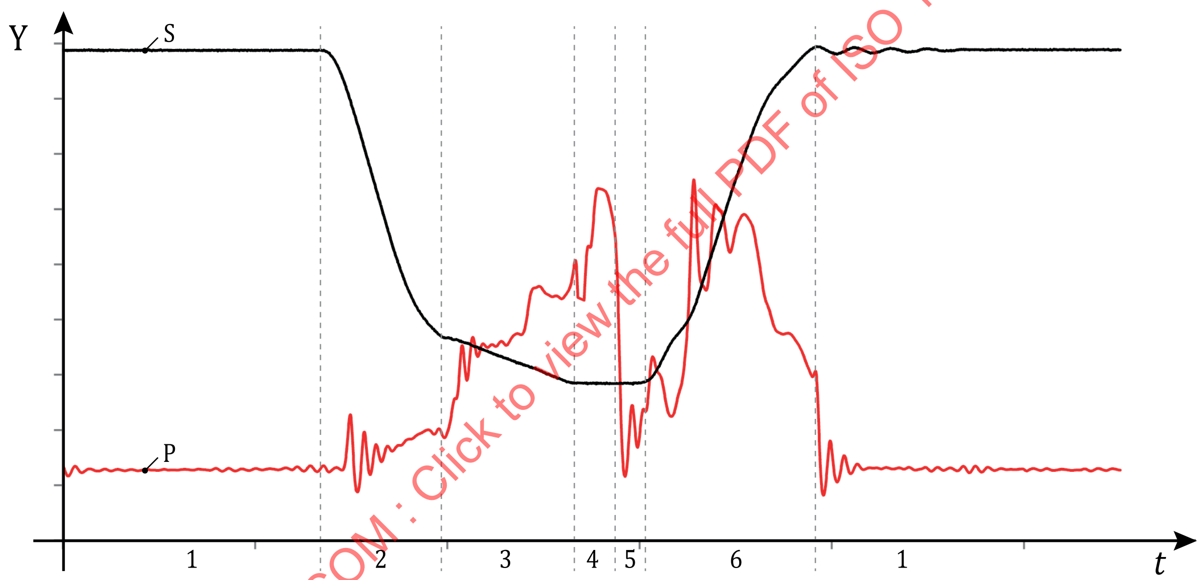
$$v = \frac{\Delta s}{\Delta t} \tag{A.2}$$

where

Q	is the flow to/out of the cylinder $\left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$;
A	is the cylinder area (A+, A−) [m^2];
v	is the slide speed $\left[\frac{\mathrm{m}}{\mathrm{s}}\right]$;
Δs	is the path travelled during measuring interval given by position sensor B1 [m];
Δt	is the measuring interval [s].

The following formulae are to calculate the power applied to the machine tool component and the efficiency factor related to the machine tool component in the press cycle. The power applied to overcome seal and guide friction is part of the power applied to the slide cylinder.

An example of typical slide power in a cycle of a hydraulic press is given in Figure A.3.



Key

S slide stroke

t time

1 machine tool activity 1: power during rest in TDC

2 machine tool activity 2: power during slide close

3 machine tool activity 3: power during forming

P actual power

Y stroke respectively power

4 machine tool activity 4: power during embossing

5 machine tool activity 5: power during decompression

6 machine tool activity 6: power during slide return

Figure A.3 — Example of slide power during a cycle of a hydraulic press

A.2.1.1.2 Power during rest in TDC (MT activity 1)

In this machine tool activity, no power is transferred to or from the slide. The measured power is the power required for idling and the energy efficiency factor is zero.

A.2.1.1.3 Power during slide descent (MT activity 2 to 4)

In this calculation, slide descent includes the power measurement at machine tool activities 2 (slide close), 3 (forming) and 4 (embossing). The given formulae are valid for all three machine tool activities.

Power applied to the slide is calculated with Formulae (A.3) to (A.5):

$$P_{SlTotalHeadDesc.} = p_{MS1} * A + * v_{Desc.} \quad (A.3)$$

$$P_{SlCylHeadDesc.} = p_{MS2} * A + * v_{Desc.} \quad (A.4)$$

$$P_{SlCylShaftDesc.} = p_{MS4} * A - * v_{Desc.} \quad (A.5)$$

where

$P_{SlTotalHeadDesc.}$	is the total power applied to the slide head side system [W];
$P_{SlCylHeadDesc.}$	is the total power applied to the slide cylinder head side [W];
$P_{SlCylShaftDesc.}$	is the total power applied to the slide cylinder shaft side [W];
p_{MSx}	is the pressure measured at the measuring point x [Pa];
$A+$	is the slide cylinder area head side [m^2];
$A-$	is the slide cylinder area shaft side [m^2];
$v_{Desc.}$	is the actual slide velocity during descent (Y2 in Table 2) $\left[\frac{m}{s}\right]$.

$P_{SlCylShaftDesc.}$ is the loss of power at the slide shaft side. If energy recovery is provided for the slide shaft side, the output power of the energy recovery system can be subtracted from $P_{SlCylShaftDesc.}$. The required power for displacing the die cushion during forming is generated by the slide and part of the measured power applied to the head side.

The total loss of power during descent is calculated with Formula (A.6):

$$P_{SlPwrLossDesc.} = P_{SlTotalHeadDesc.} + P_{SlCylShaftDesc.} + P_{SlShaftDescRecov.} + P_{CuTotalHeadDisp.} \quad (A.6)$$

where

$P_{SlPwrLossDesc.}$	is the total power loss during slide descent [W];
$P_{SlTotalHeadDesc.}$	is the total power applied to the slide head side system [W];
$P_{SlCylShaftDesc.}$	is the total power applied to the slide cylinder shaft side [W];
$P_{SlShaftDescRecov.}$	is the total power recovered from the slide shaft during descent [W];
$P_{CuTotalHeadDisp.}$	is the total power applied to the cushion cylinder head side during displacement, see also A.2.2 [W].

A.2.1.1.4 Power during decompression (MT activity 5)

The energy released during decompression was brought in the slide during embossing (MT activity 4). The recoverable average power is calculated with with Formula (A.7):

$$P_{\mathrm{SlCylDecomp.}} = \frac{\left(\left(p_{0\_\mathrm{MS2}}{}^{2} - p_{1\_\mathrm{MS2}}{}^{2}\right) * V + + \left(p_{0\_\mathrm{MS4}}{}^{2} - p_{1\_\mathrm{MS4}}{}^{2}\right) * V -\right) * \beta}{2 * t_{\mathrm{Decomp.}}} \quad \text{(A.7)}$$

where

$P_{\mathrm{SlCylDecomp.}}$	is the power generated by the slide during decompression [W];
p_{0_MS2}	is the pressure before decompression of slide cylinder head side [Pa];
p_{1_MS2}	is the pressure after decompression of slide cylinder head side [Pa];
p_{0_MS4}	is the pressure before decompression of slide cylinder shaft side [Pa];
p_{1_MS4}	is the pressure after decompression of slide cylinder shaft side [Pa];
$t_{\mathrm{Decomp.}}$	is the decompression time [s];
$V+$	is the oil volume at slide cylinder head side [m³];
$V-$	is the oil volume at slide cylinder shaft side [m³];
β	is the compressibility (e.g. mineral oil $\beta = 7 * 10^{-10} \left[\frac{1}{\mathrm{Pa}}\right]$).

The oil volume, *V*, should also include the oil volume in the pipes and manifolds that changes its pressure during decompression.

If energy recovery is provided for decompression, the integration of power measured at the output of the recovery system reflects the amount of energy recovered.

A.2.1.1.5 Power during slide return (MT activity 6)

The power applied to the slide is calculated with Formulae (A.8) to (A.11):

$$P_{\mathrm{SlTotalShaftRet.}} = p_{\mathrm{MS3}} * A - * v_{\mathrm{Return}} \quad \text{(A.8)}$$

$$P_{\mathrm{SlCylShaftRet.}} = p_{\mathrm{MS4}} * A - * v_{\mathrm{Return}} \quad \text{(A.9)}$$

$$P_{\mathrm{SlCylHeadRet.}} = p_{\mathrm{MS2}} * A + * v_{\mathrm{Return}} \quad \text{(A.10)}$$

$$P_{\mathrm{SlPwrLossRet.}} = P_{\mathrm{SlTotalHeadRet.}} + P_{\mathrm{SlTotalShaftRet.}} \quad \text{(A.11)}$$

where

$P_{\mathrm{SlTotalHeadRet.}}$	is the total power applied to the slide head side system [W];
$P_{\mathrm{SlTotalShaftRet.}}$	is the total power applied to the slide shaft side [W];
$P_{\mathrm{SlCylShaftRet.}}$	is the total power applied to the slide cylinder shaft side [W];

$P_{\text{SlCylHeadRet.}}$ is the total power applied to the slide cylinder head side [W];

$P_{\text{SlPwrLossRet.}}$ is the total power loss during return [W];

p_{MSx} is the pressure measured at the measuring point x [Pa];

$A+$ is the slide cylinder area head side [m^2];

$A-$ is the slide cylinder area shaft side [m^2];

v_{Return} is the actual slide return velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

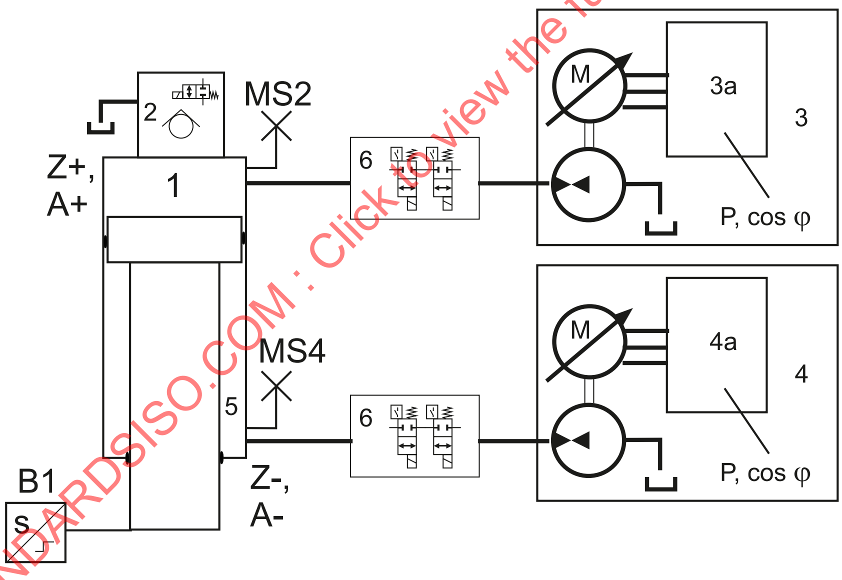
$P_{\text{SlCylHeadRet.}}$ is the loss of power at the slide head side. If energy recovery is provided for the slide head side, the output power of the recovery system can be subtracted from $P_{\text{SlCylHeadRet}}$.

The difference between $P_{\text{SlTotalShaftRet.}}$ and $P_{\text{SlCylShaftRet.}}$ is the loss of power at the slide shaft side manifold(s) during return.

A.2.1.2 Hydraulic servo presses

A.2.1.2.1 General

An example of slide hydraulic for a hydraulic servo press is given in Figure A.4.



Key

1	slide cylinder head side	Z+	slide cylinder port head side
2	prefill	Z−	slide cylinder port shaft side
3	drive unit head side	A+	slide cylinder area head side
3a	inverter system head side	A−A.7	slide cylinder area shaft side
4	drive unit shaft side	P	connection to pressure source
4a	inverter system shaft side	MSx	pressure measuring points
5	main cylinder shaft side	B1	position sensor
6	press safety	P, cosφ	values measured by inverter

Figure A.4 — Example of a slide servo drive hydraulic for a downstroking press

The flow can be calculated as given in Formulae (A.1) and (A.2).

The following formulae are to calculate the power applied to the machine tool component and the efficiency factor related to the machine tool component in the press cycle.

A.2.1.2.2 Power during rest in TDC (MT activity 1)

In this machine tool activity, no power is transferred to or from the slide. The measured power is the power required for idling and the energy efficiency factor is zero.

A.2.1.2.3 Power during slide descent (MT activity 2 to 4)

In this calculation, slide descent includes the power measurement at machine tool activities 2 (slide close), 3 (forming) and 4 (embossing). Formulae (A.12) and (A.13) are valid for all three machine tool activities.

Power applied to the slide is calculated as follows:

$$P_{\text{SlCylHeadDesc.}} = p_{\text{MS2}} * A+ * v \quad \text{(A.12)}$$

$$P_{\text{SlCylShaftDesc.}} = p_{\text{MS4}} * A- * v \quad \text{(A.13)}$$

where

$P_{\text{SlCylHeadDesc.}}$	is the total power applied to the slide cylinder head side;
$P_{\text{SlCylShaftDesc.}}$	is the total power applied to the slide cylinder shaft side [W];
p_{MSx}	is the pressure measured at the measuring point x [Pa];
$A+$	is the slide cylinder area head side [m²];
$A-$	is the slide cylinder area shaft side [m²];
v	is the actual slide velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

$P_{\text{SlCylShaftDesc.}}$ is the loss of power at the slide shaft side. If energy recovery is provided for the slide shaft side, the output power of the recovery system can be subtracted from $P_{\text{SlCylShaftDesc.}}$. The required power for displacing the die cushion during forming is generated by the slide and part of the measured power applied to the head side.

The total loss of power during descent is calculated with Formula (A.14):

$$P_{\text{SlPwrLossDesc.}} = P_{\text{SlTotalHeadDesc.}} + P_{\text{SlTotalShaftDesc.}} - P_{\text{CuTotalHeadDisp.}} \quad \text{(A.14)}$$

where

$P_{\text{SlPwrLossDesc.}}$	is the total electrical power loss during slide descent [W];
$P_{\text{SlTotalHeadDesc.}}$	is the total electrical power applied by the slide inverter system, head side [W];
$P_{\text{SlTotalShaftDesc.}}$	is the total electrical power applied by the slide inverter system, shaft side [W];
$P_{\text{CuTotalHeadDisp.}}$	is the total electrical power applied to the cushion inverter, head side during displacement [W].

NOTE During energy recovery, the value of $P_{\text{SlTotalShaftDesc.}}$ is supposed to be negative.

A.2.1.2.4 Power during decompression (MT activity 5)

The energy released during decompression was brought in the slide during embossing (MT activity 4). The recoverable average power is calculated with Formula (A.15):

$$P_{\text{SlCylDecomp.}} = \frac{\left(\left(p_{0\_\text{MS2}}{}^2 - p_{1\_\text{MS2}}{}^2\right) * V + + \left(p_{0\_\text{MS4}}{}^2 - p_{1\_\text{MS4}}{}^2\right) * V - \right) * \beta}{2 * t_{\text{Decomp.}}} \tag{A.15}$$

where

$P_{\text{SlCylDecomp.}}$ is the power generated by the slide during decompression [W];

p_{0_MS2} is the pressure before decompression of slide cylinder head side [Pa];

p_{1_MS2} is the pressure after decompression of slide cylinder head side [Pa];

p_{0_MS4} is the pressure before decompression of slide cylinder shaft side [Pa];

p_{1_MS4} is the pressure after decompression of slide cylinder shaft side [Pa];

$t_{\text{Decomp.}}$ is the decompression time [s];

$V+$ is the oil volume at slide cylinder head side [m^3];

$V-$ is the oil volume at slide cylinder shaft side [m^3];

β is the compressibility (e.g. mineral oil $\beta = 7 * 10^{-10} \left[\frac{1}{Pa}\right]$).

The oil volume, V, should also include the oil volume in the pipes and manifolds that changes its pressure during decompression.

If energy recovery is provided for decompression, the integration of power measured at the output of the recovery system reflects the amount of energy recovered.

A.2.1.2.5 Power during slide return (MT activity 6)

The power applied to the slide is calculated with Formulae (A.16) to (A.18):

$$P_{\text{SlCylShaftRet.}} = p_{\text{MS4}} * A - * v_{\text{Return}} \tag{A.16}$$

$$P_{\text{SlCylHeadRet.}} = p_{\text{MS2}} * A + * v_{\text{Return}} \tag{A.17}$$

$$P_{\text{SlPwrLossRet.}} = P_{\text{SlTotalHeadRet.}} + P_{\text{SlTotalShaftRet.}} \tag{A.18}$$

where

$P_{\text{SlCylShaftRet.}}$ is the total hydraulic power applied to the slide cylinder shaft side [W];

$P_{\text{SlCylHeadRet.}}$ is the total hydraulic power applied inverter system head side [W];

$P_{\text{SlPwrLossRet.}}$ is the total electrical power loss during return [W];

$P_{SlTotalHeadRet.}$ is the total electrical power applied inverter system head side [W];

$P_{SlTotalShaftRet.}$ is the total electrical power applied inverter system shaft side [W];

p_{MSx} is the pressure measured at the measuring point x [Pa];

$A+$ is the slide cylinder area head side [m^2];

$A-$ is the slide cylinder area shaft side [m^2];

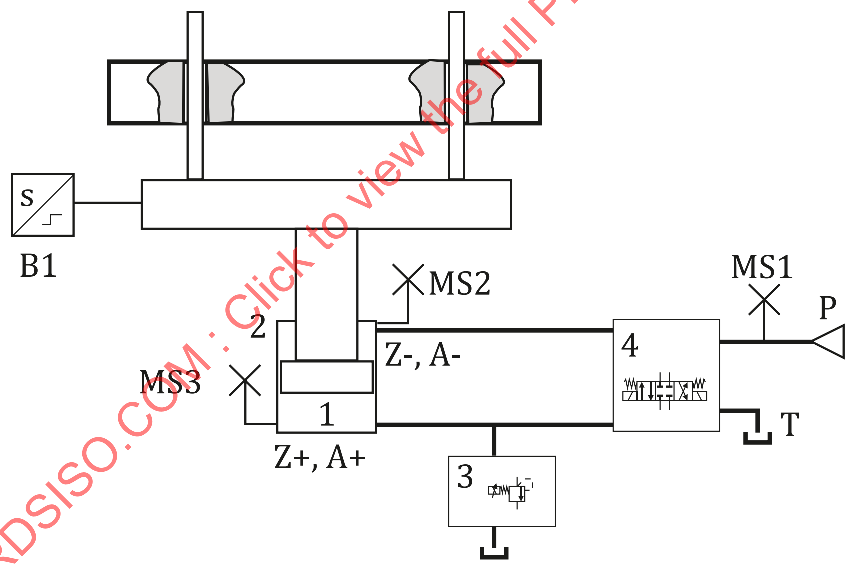
v_{Return} is the actual slide return velocity (Y6 in Table 2) $\left[\frac{m}{s}\right]$.

The difference between $P_{SlTotalShaftRet.}$ and $P_{SlCylShaftRet.}$ is the loss of power at the slide shaft side system during return. The difference between $P_{SlCylHeadRet.}$ and $P_{SlTotalHeadRet.}$ is the loss of power at the slide head side system during return.

A.2.2 Power measurement at die cushion

A.2.2.1 Die cushion without energy recovery

An example of a die cushion hydraulic without energy recovery is given in Figure A.5.



Key

1 die cushion cylinder head side
2 die cushion cylinder shaft side
3 pressure control unit
4 eject/retract unit

Z+ die cushion cylinder port head side
Z− die cushion cylinder port shaft side
A+ die cushion cylinder area head side
A− die cushion cylinder area shaft side
P connection to pressure source
MSx pressure measuring points
B1 position sensor

Figure A.5 — Example of a die cushion hydraulic without energy recovery

The flow can be calculated as given in Formulae (A.1) and (A.2).

Die cushion power can be measured during the complete press cycle and not only during the displacement of the die cushion. The power of a die cushion resting in its final position is zero due to the fact that the velocity is zero.

During forming (MT activity 3), the die cushion is displaced by the slide and generating its force.

The power loss is calculated with Formulae (A.19) to (A.21):

$$P_{\text{CuTotalHeadDisp.}} = p_{\text{MS3}} * A + * v \tag{A.19}$$

$$P_{\text{CuTotalShaftDisp.}} = p_{\text{MS1}} * A - * v \tag{A.20}$$

$$P_{\text{CuPowerLossDisp.}} = P_{\text{CuTotalHeadDisp.}} + P_{\text{CuTotalShaftDisp.}} \tag{A.21}$$

where

$P_{\text{CuTotalHeadDisp.}}$	is the total power applied to the head side during displacement [W];
$P_{\text{CuTotalShaftDisp.}}$	is the total power applied to the shaft side during displacement [W];
$P_{\text{CuPowerLossDisp.}}$	is the total power loss during displacement [W];
p_{MSx}	is the pressure measured at the measuring point x [Pa];
$A+$	is the die cushion cylinder area head side [m^2];
$A-$	is the die cushion cylinder area shaft side [m^2];
v	is the actual die cushion velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

During slide return (MT activity 6) the die cushion lifts the processed workpiece (MT activity 6a).

If no regenerative circuit is provided, the power applied to the die cushion is calculated with Formulae (A.22) and (A.23):

$$P_{\text{CuPwrLossLift.}} = p_{\text{MS1}} * A + * v + p_{\text{MS2}} * A - * v \tag{A.22}$$

If a regenerative circuit is provided (Z+ hydraulically connected to Z–), the power applied to the die cushion is calculated as follows:

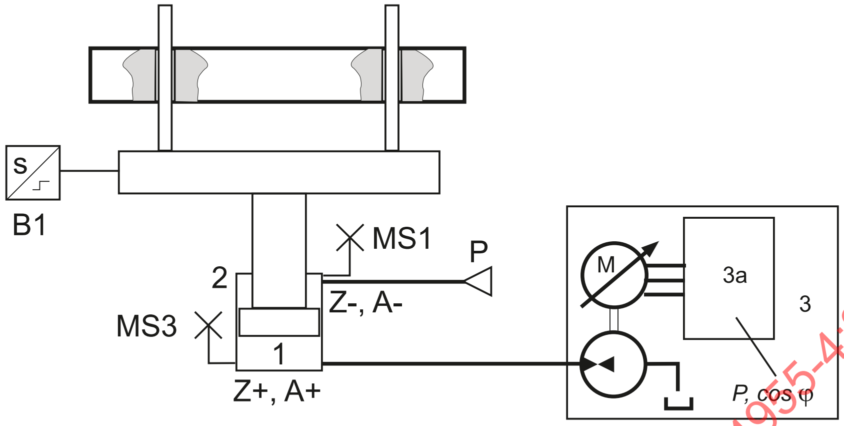
$$P_{\text{CuPwrLossLift.}} = p_{\text{MS1}} * (A + - v -) * v + (p_{\text{MS2}} - p_{\text{MS1}}) * A - * v \tag{A.23}$$

where

$P_{\text{CuPwrLossLift.}}$	is the total power lost during lifting of die cushion [W];
p_{MSx}	is the pressure measured at the measuring point x [Pa];
$A+$	is the die cushion cylinder area head side [m^2];
$A-$	is the die cushion cylinder area shaft side [m^2];
v	is the actual die cushion velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

A.2.2.2 Die cushion with energy recovery

An example of a die cushion hydraulic with energy recovery is given in Figure A.6.



Key

1	die cushion cylinder head side	Z+	die cushion cylinder port head side
2	die cushion cylinder shaft side	Z−	die cushion cylinder port shaft side
3	die cushion drive system	A+	die cushion cylinder area head side
3a	die cushion drive inverter unit	A−	die cushion cylinder area shaft side
		P	connection to pressure source
		MSx	pressure measuring points
		B1	position sensor
		P, cos φ	values measured by inverter

Figure A.6 — Example of a die cushion hydraulic with energy recovery

The flow can be calculated as given in Formulae (A.1) and (A.2).

Die cushion power can be measured during the complete press cycle and not only during the displacement of the die cushion. The power of a die cushion resting in its final position is zero due to the fact that the velocity is zero.

During forming (MT activity 3), the die cushion is displaced by the slide and generating its force.

The power loss is calculated with Formulae (A.24) to (A.26):

$$P_{\text{CuTotalHeadDisp.}} = p_{\text{MS3}} * A + * v \tag{A.24}$$

$$P_{\text{CuTotalShaftDisp.}} = p_{\text{MS1}} * A - * v \tag{A.25}$$

$$P_{\text{CuPowerLossDisp.}} = P_{\text{CuTotalHeadDisp.}} + P_{\text{CuTotalShaftDisp.}} - P_{\text{CuRecoveryDisp.}} \tag{A.26}$$

where

$P_{\text{CuTotalHeadDisp.}}$ is the power applied to the head side during displacement [W];

$P_{\text{CuTotalShaftDisp.}}$ is the power applied to the shaft side during displacement [W];

$P_{\text{CuPowerLossDisp.}}$ is the power recovered, measured at the inverter system during displacement [W];

$P_{CuRecoveryDisp.}$	is the power loss during displacement [W];
p_{MSx}	is the pressure measured at the measuring point x [Pa];
$A+$	is the die cushion cylinder area head side [m^2];
$A-$	is the die cushion cylinder area shaft side [m^2]
v	is the actual die cushion velocity $\left[\frac{m}{s}\right]$.

During slide return (MT activity 6) the die cushion lifts the processed workpiece (MT activity 6a). The power applied to the die cushion can be measured at the inverter system.

A.3 Formulae for energy calculation for a hydraulic press cycle (downstroking press)

A.3.1 General

The given formulae are examples valid for hydraulic presses as shown in A.1 and other presses with comparable functionality.

They are to calculate the energy required for changing the level of potential energy in the machine tool component (e.g. slide descent and return, charging and discharging of the oil spring in a hydraulic cylinder) and the efficiency factor for the machine tool activities according to the typical press diagram (see 5.2.5). The values can be used for $W_{MTActivity}$ in the energy calculation according to ISO 14955-2.

These examples do not include formulae for components of auxiliary devices (e.g. automation systems). Formulae for components with similar physical principles can be used to calculate the energy required.

A.3.2 Machine tool activity 1: Slide is waiting in TDC for start signal while die is loaded

Due to the fact that neither the slide nor the die cushion is moving, no energy transferred to or from the slide or die cushion. The efficiency factors of press components are zero.

A.3.3 Machine tool activity 2: Slide close

The slide descent is performed by gravity. The fluid flow out of the lower cylinder is controlling the slide movement.

The nascent potential energy is calculated with Formula (A.27):

$$W_{SlClose} = F_{MovingWeight} * s_{SlClose} \tag{A.27}$$

where

$W_{SlClose}$	is the nascent potential energy [Ws];
$F_{MovingWeight}$	is the force created by the weight of the moving parts [N];
$s_{SlClose}$	is the slide path between TDC and material contact [m].

The energy efficiency factor in this machine tool activity is calculated with Formula (A.28):

$$\eta_{SlClose} = \frac{W_{SlClose}}{W_{SysBoundMTa}} \tag{A.28}$$

where

$\eta_{SlClose}$	is the energy efficiency factor for slide close[1];
$W_{SlClose}$	is the nascent potential energy [Ws];
$W_{SysBoundMTa}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

NOTE For "slide close" on upstroking presses, see "slide return".

A.3.4 Machine tool activity 3: Forming

The workpiece is formed by the slide and held by the die cushion which is working as blankholder. The required slide force (mainly the addition die cushion force and force required for workpiece forming) is generated by fluid pressure.

The energy supplied is calculated with Formulae (A29) and (A.30):

$$W_{Forming} = F_{Forming} * s_{Forming} \tag{A.29}$$

$$F_{Forming} = F_{Workpiece} + F_{DieCushion} \tag{A.30}$$

where

$W_{Forming}$	is the energy supplied during forming [Ws];
$F_{Forming}$	is the average force of slide during forming [N];
$s_{Forming}$	is the slide path between material contact and BDC [m];
$F_{Workpiece}$	is the average force of the workpiece [N];
$F_{DieCushion}$	is the average force of the die cushion [N].

If no workpiece is used during test procedure the force of the workpiece is zero, $F_{Workpiece} = 0$.

The energy efficiency factor in this machine tool activity is calculated with Formula (A.31):

$$\eta_{Forming} = \frac{W_{Forming}}{W_{SysBoundMTa}} \tag{A.31}$$

where

$\eta_{Forming}$	is the energy efficiency factor for forming[1];
$W_{Forming}$	is the energy supplied during forming [Ws];
$W_{SysBoundMta}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

If no energy recovery during forming is provided (e.g. energy recovery at die cushion), the energy supplied during forming $W_{Forming}$ is converted into heat.

A.3.5 Machine tool activity 4: Embossing

During embossing the programmed slide force is applied for the BDC dwell time programmed in the die data. The slide stroke is close to zero, but elongation of press frame and compression of hydraulic spring is relevant for the energy supplied.

The energy supplied is calculated with Formula (A.32):

$$W_{\text{Embossing}} = F_{\text{Slide}} * \left(\frac{s_{\text{Elongation}} + s_{\text{Compression}}}{2} \right) \tag{A.32}$$

where

$W_{\text{Embossing}}$	is the energy supplied during embossing [Ws];
F_{Slide}	is the programmed value of slide force [N];
$s_{\text{Elongation}}$	is the frame elongation [m];
$s_{\text{Compression}}$	is the calculated path of compression (oil spring) [m].

The energy efficiency factor in this machine tool activity is calculated with Formula (A.33):

$$\eta_{\text{Embossing}} = \frac{W_{\text{Embossing}}}{W_{\text{SysBoundMTa}}} \tag{A.33}$$

where

$\eta_{\text{Embossing}}$	is the energy efficiency factor for embossing[1];
$W_{\text{Embossing}}$	is the energy supplied during embossing [Ws];
$W_{\text{SysBoundMta}}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

A.3.6 Machine tool activity 5: Decompression

In this phase the slide, die cushion(s) and press frame are decompressed. The nascent energy equals energy at the end of the embossing phase. Without means for regeneration, this energy is converted into heat.

During decompressing of spring-loaded dies in die cushions, the energy released from the die cushion can be recovered.

A.3.7 Machine tool activity 6: Slide return

The slide is returning to TDC driven by hydraulic fluid. A counterbalance system reduces the energy supplied.

The energy supplied is calculated with Formula (A.34):

$$W_{\text{SlideReturn}} = \left(F_{\text{MovingWeight}} - F_{\text{Counterbalance}} \right) * s_{\text{SlideReturn}} \tag{A.34}$$

where

$W_{SlideReturn}$ is the energy supplied during slide return [Ws];

$F_{MovingWeight}$ is the force created by the weight of the moving parts [N];

$F_{Counterbalance}$ is the average force created by the counterbalance system [N];

$s_{SlideReturn}$ is the slide path between TDC and BDC [m].

The energy efficiency factor in this machine tool activity is calculated with Formulae (A.35):

$$\eta_{SlideReturn} = \frac{W_{SlideReturn}}{W_{SysBoundMTa}} \quad (A.35)$$

where

$\eta_{SlideReturn}$ is the energy efficiency factor for slide return[1];

$W_{SlideReturn}$ is the energy supplied during slide return [Ws];

$W_{SysBoundMta}$ is the energy supplied at the system boundary for this machine tool activity [Ws].

NOTE For "Slide return" on upstroking presses, see "Slide close".

A.3.8 Machine tool activity 6a: Workpiece ejection

During slide return, the workpiece is ejected by die cushion(s).

The required energy for workpiece lifting (on all types of presses) is calculated with Formula (A.36):

$$W_{Ejection} = F_{MovingWeightDieCushion} * s_{Forming} \quad (A.36)$$

where

$W_{Ejection}$ is the energy supplied during ejection [Ws];

$F_{MovingWeightDieCushion}$ is the force created by the weight of the moving parts [N];

$s_{Forming}$ is the slide path between material contact and BDC [m].

A.4 Quantitative functional mapping for a hydraulic double action press

An example of functional mapping for a hydraulic double action press is given in Table A.1.

Table A.1 — Example for quantitative functional mapping

		Machine tool functions					
		Machine tool operation (machining, process, motion and control)	Process conditioning	Workpiece handling	Tool change	Recyclables and waste handling	Machine tool cooling/ lubrication
Machine tool components	Control components[a]	55 %	4 %	30 %	5 %	1 %	5 %
	Main pump drive(s)	80 %			20 %		
	Auxiliary pump drive(s)	80 %	5 %		15 %		
	Cooling pump drive(s)						100 %
	Slide	95 %			5 %		
	Die cushion	95 %			5 %		
	Automation system			97 %	3 %		
	Scrap conveyor					100 %	
	Moving bolster				100 %		
	Air compressor			90 %	3 %	7 %	
	PLC and CNC air conditioning						100 %

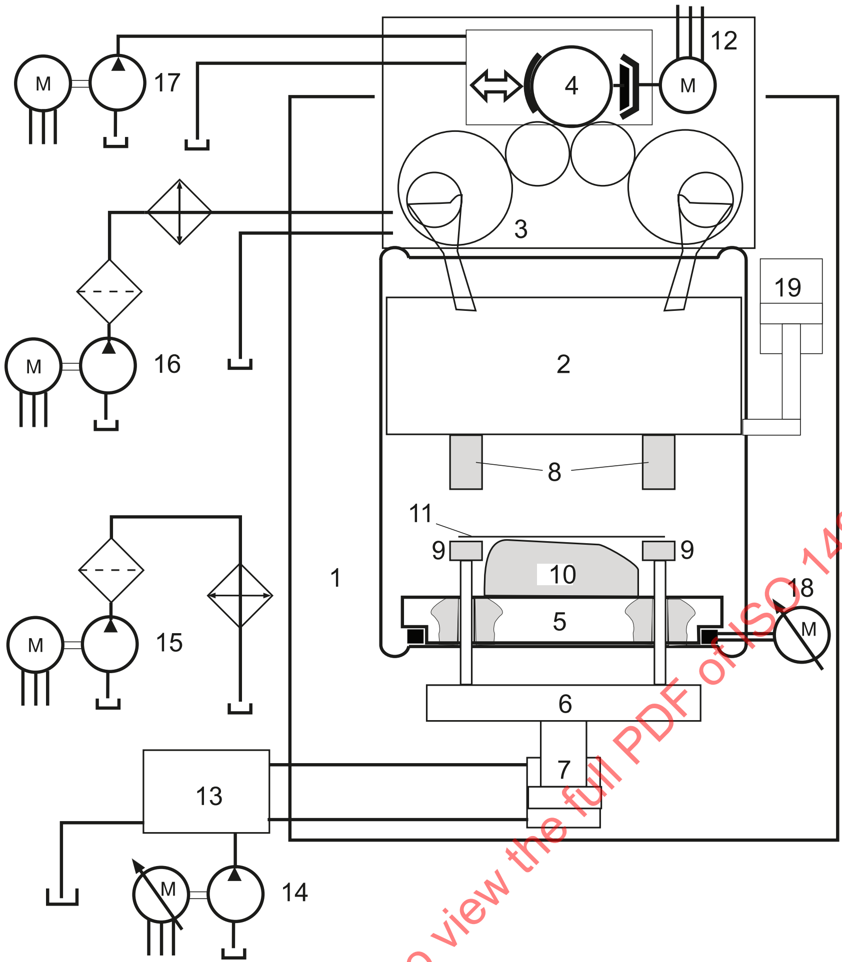
[a] Including PLC and CNC modules.

Annex B
(informative)

Mechanical presses

B.1 Example of a downstroking mechanical press (double action press)

Figure B.1 shows an example of a mechanical double action press.



Key

1	frame	11	workpiece (blank)
2	slide	12	main drive unit
3	eccentric or link drive	13	hydraulic die cushion manifold
4	clutch and brake	14	auxiliary pump drive(s)
5	moving bolster	15	cooling drive unit
6	die cushion	16	gearbox lubrication
7	die cushion cylinder	17	clutch and brake drive unit
8	upper die	18	moving bolster drive unit
9	drawing ring	19	counterbalance system
10	lower die		

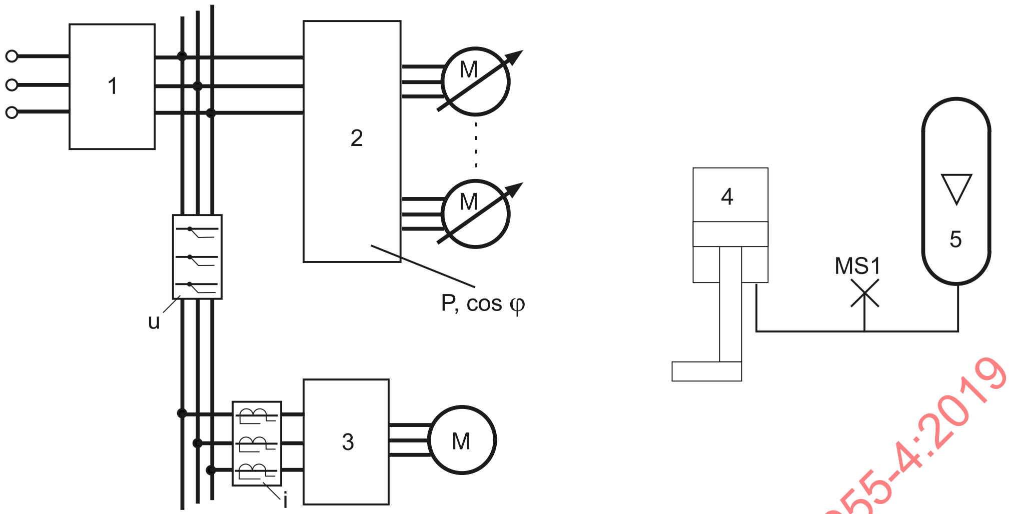
Figure B.1 — Example of a mechanical double action press

B.2 Power measurement

B.2.1 Power measurement at slide

B.2.1.1 General

An example of a drive unit and counterbalance system for a mechanical (servo) press is given in Figure B.2.



Key

1 main switch
2 inverter unit for main drive
3 control pressure drive unit, e.g. for clutch and brake
4 counterbalance cylinder
5 counterbalance accumulator system
MS1 pressure measuring point
u voltage measuring point
i current measuring point

Figure B.2 — Drive unit and counterbalance system for a mechanical (servo) press

The main drive unit may consist of one or more motors, the control pressure unit for clutch and brake may consist of one or more motor-pump combination with or without inverter.

As power is transferred from the main drive to the slide without any other than mechanical means, the power to or from the main drive(s) is the relevant power.

If power and power factor is measured by the inverter and the given values are the input power of the inverter, these values can be used.

The power required for operating the clutch and brake is mainly determined by:

— friction in the clutch while clutch is engaged;

— the power required for shifting;

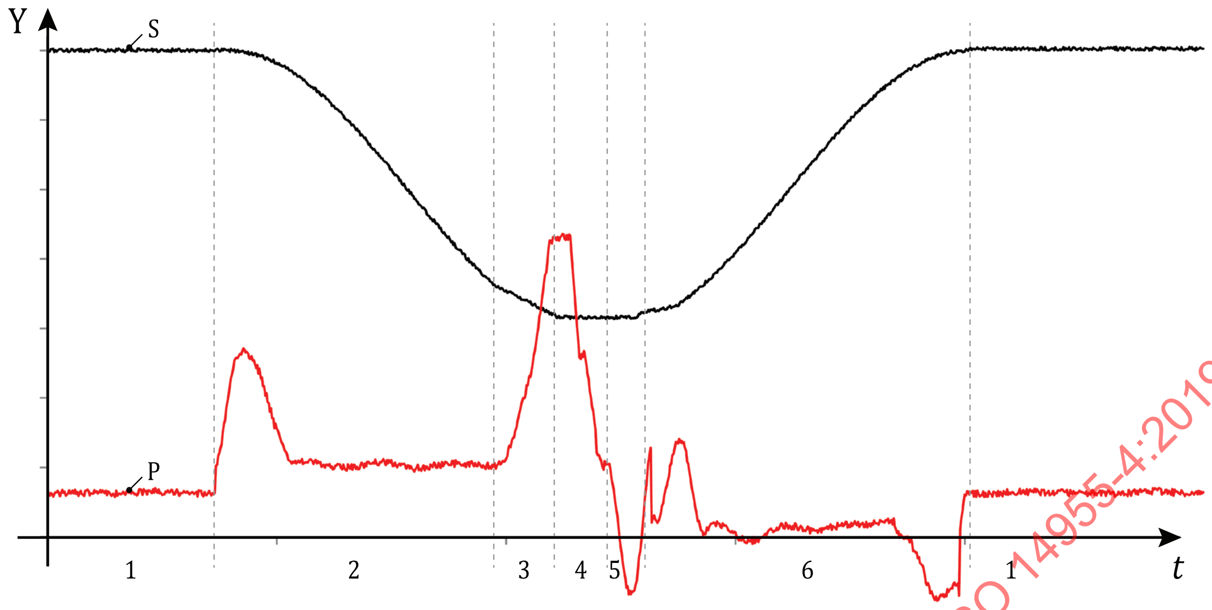
— the power required for generating the control pressure.

The power required for covering the friction in the clutch, the gearbox and the drive mechanism is part of the power applied to the main drive.

The power required for shifting the clutch and brake is based on power measurement of the control pressure unit.

The given formulae are to calculate the energy supplied to the machine tool excluding auxiliary devices (e.g. automation systems) and the efficiency factor related to the machine tool in the machine tool activities during the complete cycle.

An example of typical slide power in a cycle of a mechanical servo press is given in Figure B.3.



Key

S slide stroke

t time

1 machine tool activity 1: power during rest in TDC

2 machine tool activity 2: power during slide close

3 machine tool activity 3: power during forming

P actual power

Y stroke respectively power

4 machine tool activity 4: power during embossing

5 machine tool activity 5: power during decompression

6 machine tool activity 6: power during slide return

Figure B.3 — Example of slide power in a mechanical servo press cycle

B.2.1.2 Power during rest in TDC (MT activity 1)

In this machine tool activity, no power is transferred to or from the slide. The energy efficiency factor is zero.

B.2.1.3 Power during slide close (MT activity 2)

The power applied during slide close is to accelerate the slide and to overcome the friction in the press drive system and displace the counterbalance system. The measured power is the power applied to the main drive inverter unit.

The power applied to the slide is calculated with Formulae (B.1) and (B.2):

$$P_{\text{SlCntrBal.}} = p_{\text{MS1}} * A_{\text{CntrBal.}} * v_{\text{Closing}} \tag{B.1}$$

$$P_{\text{SlTotalClose}} = P_{\text{SlTotalInvClose}} - P_{\text{SlCntrBal.}} \tag{B.2}$$

where

$P_{\text{SlCntrBal.}}$ is the total power applied to the counterbalance system [W];

$P_{\text{SlTotalClose}}$ is the total electrical power applied to the slide during close [W];

$P_{\text{SlTotalInvClose}}$ is the total electrical power applied to the main drive inverter unit [W];

p_{MSx}	is the pressure measured at the measuring point x [Pa];
$A_{CntrBal.}$	is the counterbalance cylinder area [m^2];
$v_{Closing}$	is the actual slide closing velocity (Y2 in Table 4) $\left[\frac{m}{s}\right]$.

B.2.1.4 Power during forming and embossing (MT activity 3 and 4)

The power applied during slide forming and embossing is used to displace the die cushion and the counterbalance system and to overcome the friction in the press drive system (no workpiece is formed during the measurement).

The required power for displacing the die cushion is included in the measured power applied to the main drive inverter unit. To ensure correct calculation, the die cushion power $P_{CuTotalHeadDisp.}$ shall be subtracted from the slide power [see Formulae (B.3) and (B.4)].

$$P_{SlCntrBal.} = p_{MS1} * A_{CntrBal.} * v \quad (B.3)$$

$$P_{SlTotalForming} = P_{SlTotalInvClose} - P_{SlCntrBal.} - P_{CuTotalHeadDisp.} \quad (B.4)$$

where

$P_{SlCntrBal.}$	is the total electrical power applied to the counterbalance system [W];
$P_{SlTotalForming}$	is the total electrical power applied to the slide during forming [W];
$P_{SlTotalInvClose}$	is the total electrical power applied to the main drive inverter unit [W];
$P_{CuTotalHeadDisp.}$	is the total electrical power applied during die cushion displacement [W];
p_{MSx}	is the arithmetic average of the pressure of the counterbalance system [Pa];
$A_{CntrBal.}$	is the counterbalance cylinder area [m^2];
v	is the actual slide velocity $\left[\frac{m}{s}\right]$.

B.2.1.5 Power during decompression (MT activity 5)

The energy stored in the elongation of press frame and distortion of drive system is relieved during decompression. The power measured at the inverter system does not reflect the power transferred to an internal energy storage system (e.g. flywheel, powercaps, etc.); this energy is calculated by following the rules and formulae for the specific energy storage system.

B.2.1.6 Power during slide return (MT activity 6)

The power applied to the slide is calculated with Formulae (B.5) and (B.6):

$$P_{SlCntrBal.} = p_{MS1} * A_{CntrBal.} * v \quad (B.5)$$

$$P_{SlTotalRet.} = P_{SlTotalInvRet.} + P_{SlCntrBal.} \quad (B.6)$$

where

$P_{SlCntrBal.}$ is the total electrical power applied to the counterbalance system [W];

$P_{SlTotalRet.}$ is the total electrical power applied to the slide during slide close [W];

$P_{SlTotalInvRet}$ is the total electrical power applied to the main drive inverter unit [W];

p_{MS1} is the pressure measured at the measuring point x [Pa];

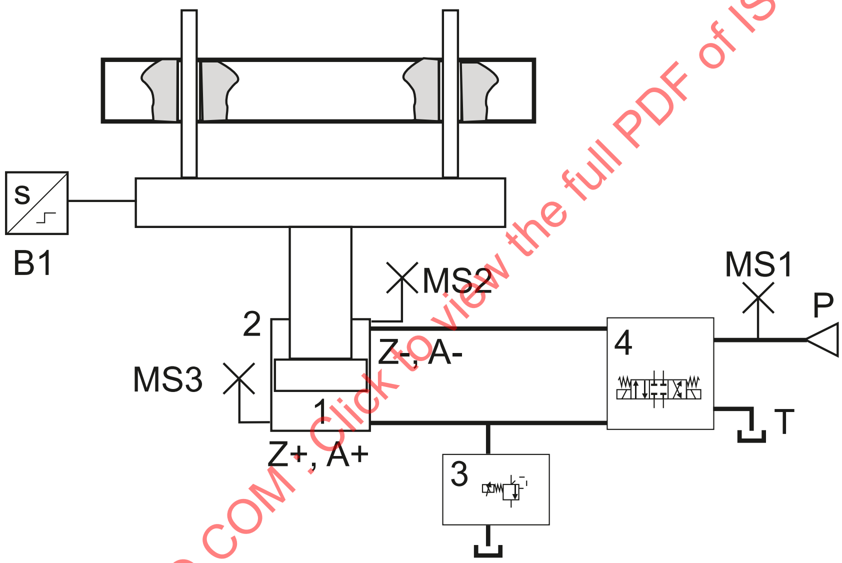
$A_{CntrBal.}$ is the counterbalance cylinder area [m²];

v is the actual slide velocity $\left[\frac{m}{s}\right]$.

B.2.2 Power measurement at die cushion

B.2.2.1 Die cushion without energy recovery

An example of a die cushion hydraulic without energy recovery is given in Figure B.4.



Key

1 die cushion cylinder head side
2 die cushion cylinder shaft side
3 pressure control unit
4 eject/retract unit

Z+ die cushion cylinder port head side
Z− die cushion cylinder port shaft side
A+ die cushion cylinder area head side
A− die cushion cylinder area shaft side
P connection to pressure source
MSx pressure measuring points
B1 position sensor

Figure B.4 — Example of a die cushion hydraulic without energy recovery

The flow can be calculated with Formulae (B.7) and (B.8):

$$Q = v * A \tag{B.7}$$

$$v = \frac{\Delta s}{\Delta t} \tag{B.8}$$

where

Q	is the flow to/out of the cylinder $\left[\frac{m^3}{s}\right]$;
A	is the cylinder area ($A+$, $A-$) [m^2];
v	is the die cushion velocity $\left[\frac{m}{s}\right]$;
Δs	is the path travelled during measuring interval given by position sensor B1 [m];
Δt	is the measuring interval [s].

Die cushion power can be measured during the complete press cycle and not only during the displacement of the die cushion. The power of a die cushion resting in its final position is zero due to the fact that the velocity is zero.

During forming (MT activity 3), the die cushion is displaced by the slide and generating its force.

The power loss is calculated with Formulae (B.9) to (B.11):

$$P_{\text{CuTotalHeadDisp.}} = p_{\text{MS3}} * A+ * v \tag{B.9}$$

$$P_{\text{CuTotalShaftDisp.}} = p_{\text{MS1}} * A- * v \tag{B.10}$$

$$P_{\text{CuPowerLossDisp.}} = P_{\text{CuTotalHeadDisp.}} + P_{\text{CuTotalShaftDisp.}} \tag{B.11}$$

where

$P_{\text{CuTotalHeadDisp.}}$	is the total power applied to the head side during displacement [W];
$P_{\text{CuTotalShaftDisp.}}$	is the total power applied to the shaft side during displacement [W];
$P_{\text{CuPowerLossDisp.}}$	is the total power loss during displacement [W];
$p_{\text{MS}x}$	is the pressure measured at the measuring point x [Pa];
$A+$	is the die cushion cylinder area head side [m^2];
$A-$	is the die cushion cylinder area shaft side [m^2];
v	is the actual die cushion velocity $\left[\frac{m}{s}\right]$.

During slide return (MT activity 6) the die cushion lifts the processed workpiece (MT activity 6a).

If no regenerative circuit is provided, the power applied to the die cushion is calculated with Formula (B.12):

$$P_{\text{CuPwrLossLift.}} = p_{\text{MS1}} * A + * v + p_{\text{MS2}} * A - * v \tag{B.12}$$

If a regenerative circuit is provided (Z+ hydraulically connected to Z–), the power applied to the die cushion is calculated with Formula (B.13):

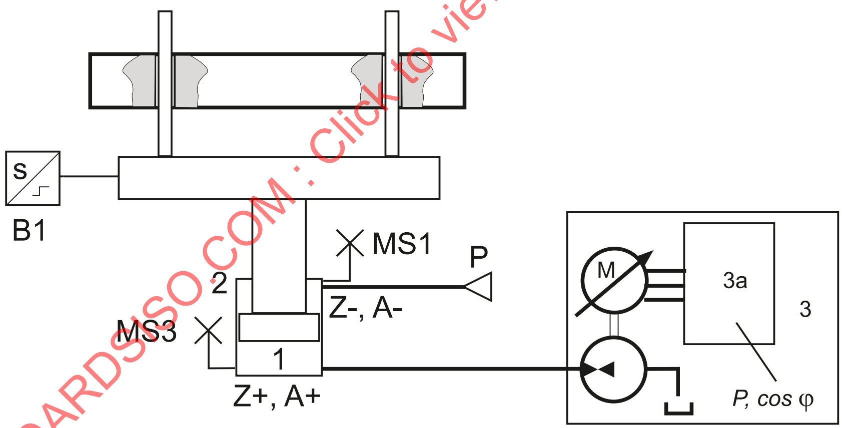
$$P_{\text{CuPwrLossLift.}} = p_{\text{MS1}} (A + - A -) * v + (p_{\text{MS2}} - p_{\text{MS1}}) * A - * v \tag{B.13}$$

where

$P_{\text{CuPwrLossLift.}}$	is the total electrical power lost during lifting of die cushion [W];
$p_{\text{MS}x}$	is the pressure measured at the measuring point x [Pa];
$A+$	is the die cushion cylinder area head side [m²];
$A-$	is the die cushion cylinder area shaft side [m²];
v	is the actual die cushion velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

B.2.2.2 Die cushion with energy recovery

An example of a die cushion hydraulic with energy recovery is given in Figure B.5.



Key

1	die cushion cylinder head side	Z+	die cushion cylinder port head side
2	die cushion cylinder shaft side	Z–	die cushion cylinder port shaft side
3	die cushion drive system	A+	die cushion cylinder area head side
3a	die cushion drive inverter unit	A–	die cushion cylinder area shaft side
		P	connection to pressure source
		MSx	pressure measuring points
		B1	position sensor
		P, cosφ	values measured by inverter

Figure B.5 — Example of a die cushion hydraulic with energy recovery

The flow can be calculated as given in Formulae (B.7) and (B.8).

Die cushion power can be measured during the complete press cycle and not only during the displacement of the die cushion. The power of a die cushion resting in its final position is zero due to the fact that the velocity is zero.

During forming (MT activity 3), the die cushion is displaced by the slide and generating its force.

The power loss is calculated with Formulae (B.14) to (B.16):

$$P_{\text{CuTotalHeadDisp.}} = p_{\text{MS3}} * A + * v \tag{B.14}$$

$$P_{\text{CuTotalShaftDisp.}} = p_{\text{MS1}} * A - * v \tag{B.15}$$

$$P_{\text{CuPowerLossDisp.}} = P_{\text{CuTotalHeadDisp.}} + P_{\text{CuTotalShaftDisp.}} - P_{\text{CuRecoveryDisp.}} \tag{B.16}$$

where

$P_{\text{CuTotalHeadDisp.}}$	is the total electrical power applied to the head side during displacement [W];
$P_{\text{CuTotalShaftDisp.}}$	is the total electrical power applied to the shaft side during displacement [W];
$P_{\text{CuPowerLossDisp.}}$	is the total electrical power recovered, measured at the inverter system during displacement [W];
$P_{\text{CuRecoveryDisp.}}$	is the total electrical power loss during displacement [W];
$p_{\text{MS}x}$	is the pressure measured at the measuring point x [Pa];
$A+$	is the die cushion cylinder area head side [m^2];
$A-$	is the die cushion cylinder area shaft side [m^2];
v	is the actual die cushion velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

During slide return (MT activity 6) the die cushion lifts the processed workpiece (MT activity 6a). The power applied to the die cushion can be measured at the inverter system.

B.3 Formulae for energy calculation for a mechanical press cycle (downstroking press)

B.3.1 General

The given formulae are examples valid for a mechanical press as shown in B.1 and other presses with comparable functionality.

They are to calculate the energy required for changing the level of potential energy in the machine tool component (e.g. slide descent and return, charging and discharging of the oil spring in a hydraulic cylinder) and the efficiency factor for the machine tool activities according to the typical press diagram (see 5.2.5). The values can be used for $W_{\text{MTActivity}}$ in the energy calculation according to ISO 14955-2.

These examples do not include formulae for components of auxiliary devices (e.g. automation systems). Formulae for components with similar physical principles can be used to calculate the energy required.

B.3.2 Machine tool activity 1: Slide is waiting in TDC for start signal while die is loaded

Due to the fact that neither the slide nor the die cushion is moving, no energy transferred to or from the slide or die cushion. The efficiency factors of press components are zero.

B.3.3 Machine tool activity 2: Slide close

The slide descents by a main drive system overcoming the friction in the drive system. Mechanical drive characteristic, driven by motor or flywheel, determine the slide movement. If a counterbalance system is provided, the main drive system shall overcome the counterbalance force additionally.

The energy brought to the slide is stored in the counterbalance system and is calculated with Formula (B.17):

$$W_{\text{SlideClose}} = \left(F_{\text{MovingWeight}} - F_{\text{Counterbalance}}\right) * s_{\text{SlideClose}} \qquad \text{(B.17)}$$

where

$W_{\text{SlideClose}}$	is the energy required for slide close [Ws];
$F_{\text{MovingWeight}}$	is the force created by the weight of the moving parts [N];
$F_{\text{Counterbalance}}$	is the average force created by the counterbalance system [N];
$s_{\text{SlideClose}}$	is the slide path between TDC and material contact [m].

The energy efficiency factor in this machine tool activity is calculated with Formula (B.18):

$$\eta_{\text{SlideClose}} = \frac{W_{\text{SlideClose}}}{W_{\text{SysBoundMTa}}} \qquad \text{(B.18)}$$

where

$\eta_{\text{SlideClose}}$	is the energy efficiency factor for slide close[1];
$W_{\text{SlideClose}}$	is the nascent potential energy [Ws];
$W_{\text{SysBoundMTa}}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

NOTE For "Slide close" on upstroking presses, see "Slide return".

B.3.4 Machine tool activity 3: Forming

The workpiece is formed by the slide while the die cushion creates a counter force to work as a blankholder. The required slide force (mainly the addition of die cushion force and force required for workpiece forming) is generated by flywheel or servo motor torque.

The energy supplied is calculated with Formulae (B.19) and (B.20):

$$W_{\text{Forming}} = F_{\text{Forming}} * s_{\text{Forming}} \qquad \text{(B.19)}$$

$$F_{\text{Forming}} = F_{\text{Workpiece}} + F_{\text{DieCushion}} \qquad \text{(B.20)}$$

where

$W_{Forming}$ is the energy supplied during forming [Ns];

$F_{Forming}$ is the average force of slide during forming [N];

$s_{Forming}$ is the slide path between material contact and BDC [m];

$F_{Workpiece}$ is the average force of the workpiece [N];

$F_{DieCushion}$ is the average force of the die cushion [N].

If no workpiece is used during test procedure the force of the workpiece is zero, $F_{Workpiece} = 0$.

The energy efficiency factor in this machine tool activity is calculated with Formula (B.21):

$$\eta_{Forming} = \frac{W_{Forming}}{W_{SysBoundMTa}} \quad (B.21)$$

where

$\eta_{Forming}$ is the energy efficiency factor for forming[1];

$W_{Forming}$ is the energy supplied during forming [Ws];

$W_{SysBoundMTa}$ is the energy supplied at the system boundary for this machine tool activity [Ws].

If no energy recovery during forming is provided (e.g. energy recovery at die cushion), the energy supplied during forming $W_{Forming}$ is converted into heat.

B.3.5 Machine tool activity 4: Embossing

During embossing, the (programmed) slide force is applied to the press which leads to the maximum elongation of the press frame and a distortion of the drive mechanism in the cycle.

The energy supplied is calculated with Formula (B.22):

$$W_{Embossing} = F_{Slide} * s_{Elongation} \quad (B.22)$$

where

$W_{Embossing}$ is the energy supplied during embossing [Ws];

F_{Slide} is the average force of slide [N];

$s_{Elongation}$ is the elongation of the frame and distortion of drive unit [m].

The energy efficiency factor in this machine tool activity is calculated with Formula (B.23):

$$\eta_{Embossing} = \frac{W_{Embossing}}{W_{SysBoundMTa}} \quad (B.23)$$

where

$\eta_{Embossing}$ is the energy efficiency factor for embossing[1];

$W_{Embossing}$ is the energy supplied during embossing [Ws];

$W_{SysBoundMTa}$ is the energy supplied at the system boundary for this machine tool activity [Ws].

B.3.6 Machine tool activity 5: Decompression

In this phase the stress in slide drive mechanism, die cushion and press frame is relieved. The nascent energy is the energy stored in the system at the end of the embossing phase. On mechanical presses with flywheel, the energy is transferred into the flywheel; on mechanical servo presses, the energy is transferred into the provided energy storage system (e.g. powercaps or electrically driven flywheel).

During decompressing of spring-loaded dies in die cushions, the energy released from the die cushion can be transferred into the slide energy storage system.

The nascent energy is calculated with Formula (B.24):

$$W_{\text{SlideDecomp.}} = W_{\text{SlideInvDecomp.}} + \Delta W_{\text{EnergyStorage}} \tag{B.24}$$

where

$W_{\text{SlideDecomp.}}$	is the energy transferred to the energy storage system [Ws];
$W_{\text{SlideInvDecomp.}}$	is the energy by integration of power over time [Ws];
$\Delta W_{\text{EnergyStorage}}$	is the energy transferred to the energy storage system [Ws].

B.3.7 Machine tool activity 6: Slide return

If a counterbalance system is provided, the slide is returning to TDC driven by counterbalance system. In other cases, the energy is supplied by the main drive system.

The nascent energy is calculated with Formulae (B.25) and (B.26):

$$W_{\text{SlideReturn}} = \left(F_{\text{Counterbalance}} - F_{\text{MovingWeight}}\right) * s_{\text{SlideReturn}} \tag{B.25}$$

where

$W_{\text{SlideReturn}}$	is the energy supplied during slide return [Ws];
$F_{\text{MovingWeight}}$	is the force created by the weight of the moving parts [N];
$F_{\text{Counterbalance}}$	is the average force created by the counterbalance system [N];
$s_{\text{SlideReturn}}$	is the slide path between TDC and BDC [m].

$$\eta_{\text{SlideReturn}} = \frac{W_{\text{SlideReturn}}}{W_{\text{SysBoundMTa}}} \tag{B.26}$$

where

$\eta_{\text{SlideReturn}}$	is the energy efficiency factor for slide return[1];
$W_{\text{SlideReturn}}$	is the energy supplied during slide return [Ws];
$W_{\text{SysBoundMTa}}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

NOTE For "Slide return" on upstroking presses, see "Slide descent".

B.3.8 Machine tool activity 6a: Workpiece ejection

During slide return, the workpiece is ejected by die cushion(s).

The required energy for workpiece lifting (on all types of presses) is calculated with Formula (B.27):

$$W_{\text{Ejection}} = F_{\text{MovingWeightDieCushion}} * s_{\text{Forming}} \tag{B.27}$$

where

$W_{Ejection}$	is the energy supplied during ejection [Ws];
$F_{MovingWeightDieCushion}$	is the force created by the weight of the moving parts [N];
$s_{Forming}$	is the slide path between material contact and BDC [m].

B.4 Quantitative functional mapping for a mechanical double action press

An example of functional mapping for a mechanical double action press is given in Table B.1

Table B.1 — Example for quantitative functional mapping

		Machine tool functions					
		Machine tool operation (machining, process, motion and control)	Process conditioning	Workpiece handling	Tool change	Recyclables and waste handling	Machine tool cooling/ lubrication
Machine tool components	Control components[a]	55 %	4 %	30 %	5 %	1 %	5 %
	Auxiliary pump drive(s)	80 %	5 %	5 %	10 %		
	Cooling pump drive(s)						100 %
	Gear box lubrication						100 %
	Slide (main dirve unit)	95 %			5 %		
	Die cushion	95 %			5 %		
	Automation system			97 %	3 %		
	Scrap conveyor					100 %	
	Moving bolster				100 %		
	Air compressor	5 %		85 %	3 %	7 %	
	Counterbalance system	95 %			5 %		
	PLC and CNC air conditioning						100 %

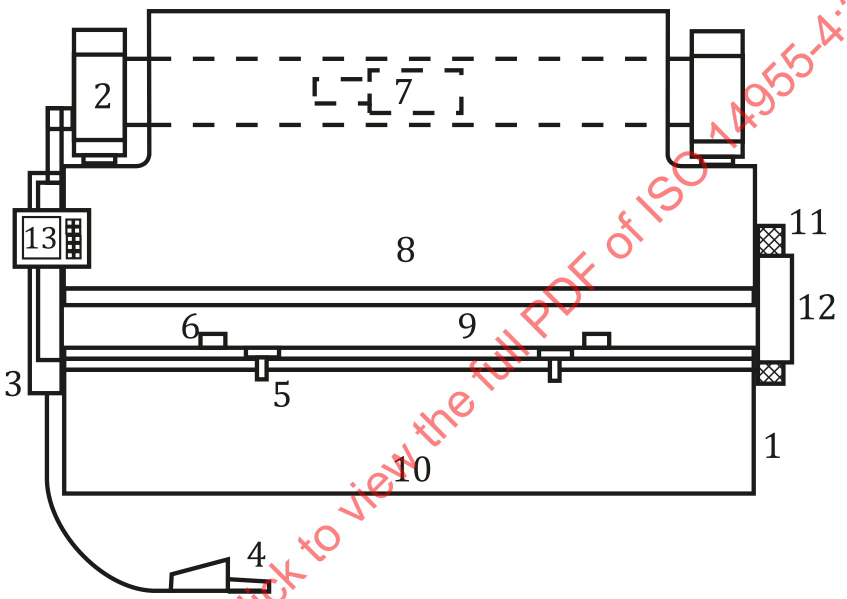
[a] Including PLC and CNC modules.

Annex C
(informative)

Hydraulic press brakes

C.1 Example of a hydraulic press brake

Figure C.1 shows an example of a down-stroking hydraulic press brake.



Key

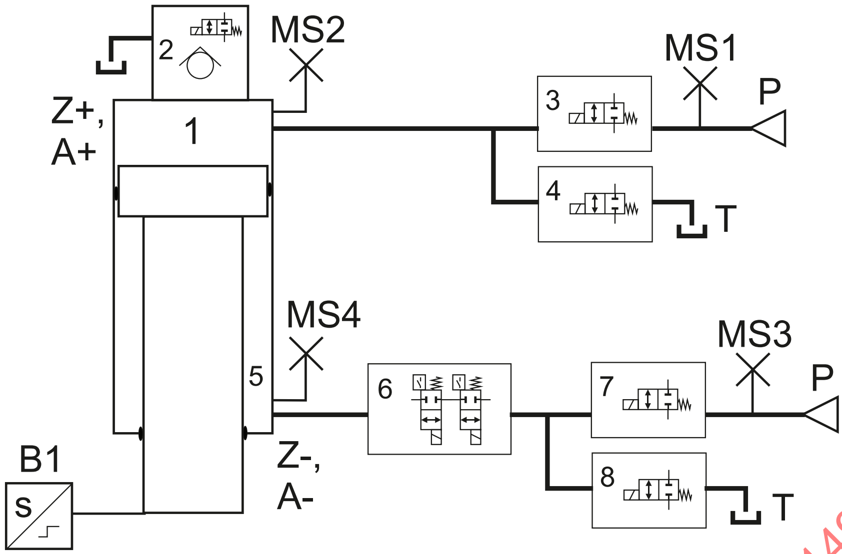
1	frame	8	beam
2	press cylinder	9	tools
3	electrical switch gear cabinet	10	bed
4	foot pedal	11	side safeguard
5	workpiece support	12	light curtain
6	backgauge	13	control panel
7	hydraulic system		

Figure C.1 — Example of a downstroking hydraulic press brake

C.2 Power measurement at a hydraulic press brake

C.2.1 General

An example of a press brake hydraulic with energy recovery is given in Figure C.2.



Key

1	beam cylinder head side	Z+	beam cylinder port head side
2	prefill	Z−	beam cylinder port shaft side
3	main unit head side	A+	beam cylinder area head side
4	decompression unit	A−	beam cylinder area shaft side
5	beam cylinder shaft side	P	connection to pressure source
6	press break safety	MSx	pressure measuring points
7	beam return unit	B1	position sensor
8	beam down unit		

Figure C.2 — Example of a beam hydraulic for a downstroking press brake

The flow can be calculated with Formulae (C.1) and (C.2):

$$Q = v * A \tag{C.1}$$

$$v = \frac{\Delta s}{\Delta t} \tag{C.2}$$

where

Q is the flow to/out of the cylinder $\left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$;

A is the cylinder area (A+, A−) [m^2];

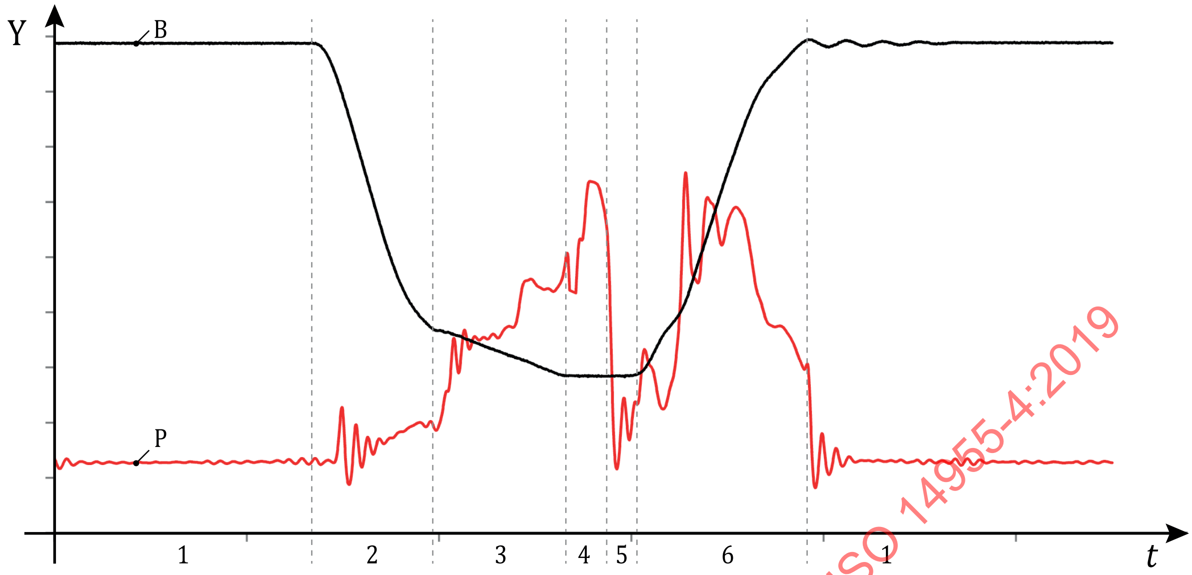
v is the beam velocity $\left[\frac{\mathrm{m}}{\mathrm{s}}\right]$;

Δs is the path travelled during measuring interval given by position sensor B1 [m];

Δt is the measuring interval [s].

The following formulae are to calculate the power applied to the machine tool component and the efficiency factor related to the machine tool component in the press cycle. Power applied to overcome seal and guide friction is part of the power applied to the beam cylinder.

An example of typical beam power in a cycle of a hydraulic press brake is given in Figure C.3.



Key

B beam stroke

t time

1 machine tool activity 1: power during rest in TDC

2 machine tool activity 2: power during beam close

3 machine tool activity 3: power during bending

P actual power

Y stroke respectively power

4 machine tool activity 4: power during pressing

5 machine tool activity 5: power during decompression

6 machine tool activity 6: power during beam return

Figure C.3 — Example of beam power during a cycle of a hydraulic press brake

C.2.2 Power during rest in TDC (MT activity 1)

In this machine tool activity, no power is transferred to or from the beam. The measured power is the power required for idling and the energy efficiency factor is zero.

C.2.3 Power during slide descent (MT activity 2 to 4)

In this calculation, beam descent includes the power measurement at machine tool activities 2 (beam close), 3 (bending) and 4 (pressing). The given formulae are valid for all three machine tool activities.

Power applied to the beam is calculated with Formulae (C.3) and (C.5):

$$P_{\text{SlTotalHeadDesc.}} = p_{\text{MS1}} * A + * v \tag{C.3}$$

$$P_{\text{SlCylHeadDesc.}} = p_{\text{MS2}} * A + * v \tag{C.4}$$

$$P_{\text{SlCylShaftDesc.}} = p_{\text{MS4}} * A - * v \tag{C.5}$$

where

$P_{SlTotalHeadDesc.}$ is the total electrical power applied to the beam head side system [W];

$P_{SlCylHeadDesc.}$ is the total electrical power applied to the beam cylinder head side [W];

$P_{SlCylShaftDesc.}$ is the total electrical power applied to the beam cylinder shaft side [W];

p_{MSx} is the pressure measured at the measuring point x [Pa];

$A+$ is the beam cylinder area head side [m^2];

$A-$ is the beam cylinder area shaft side [m^2];

v is the actual beam velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

$P_{SlCylShaftDesc.}$ is the loss of power at the beam shaft side. If energy recovery is provided for the beam shaft side, e.g. recovery to the grid, by accumulator, the output power of the energy recovery system can be subtracted from $P_{SlCylShaftDesc.}$

NOTE During energy recovery, the value of $P_{SlCylShaftDesc.}$ is supposed to be negative.

The total loss of power during descent is calculated with Formula (C.6):

$$P_{SlPwrLossDesc.} = P_{SlTotalHeadDesc.} + P_{SlCylShaftDesc.} - P_{SlShaftDescRecov.} \quad \text{(C.6)}$$

where

$P_{SlPwrLossDesc.}$ is the total electrical power loss during beam descent [W];

$P_{SlTotalHeadDesc.}$ is the total electrical power applied to the beam head side system [W];

$P_{SlCylShaftDesc.}$ is the total electrical power applied to the beam cylinder shaft side [W];

$P_{SlShaftDescRecov.}$ is the total electrical power recovered from the beam shaft during descent [W].

C.2.4 Power during decompression (MT activity 5)

The energy released during decompression was brought in the beam during pressing (MT activity 4). The recoverable average power is calculated with Formula (C.7):

$$P_{SlCylDecomp.} = \frac{\left(\left(p_{0\_MS2}{}^2 - p_{1\_MS2}{}^2\right)*V+ + \left(p_{0\_MS4}{}^2 - p_{1\_MS4}{}^2\right)*V-\right)*\beta}{2*t_{Decomp.}} \quad \text{(C.7)}$$

where

$P_{SlCylDecomp.}$ is the power generated by the beam during decompression [W];

p_{0_MS2} is the pressure before decompression of beam cylinder head side [Pa];

p_{1_MS2} is the pressure after decompression of beam cylinder head side [Pa];

p_{0_MS4} is the pressure before decompression of beam cylinder shaft side [Pa];

p_{1_MS4} is the pressure after decompression of beam cylinder shaft side [Pa];

$t_{Decomp.}$ is the decompression time [s];

$V+$	is the oil volume at beam cylinder head side [m^3];
$V-$	is the oil volume at beam cylinder shaft side [m^3];
β	is the compressibility (e.g. mineral oil $\beta = 7 * 10^{-10}\left[\frac{1}{Pa}\right]$).

The oil volume, V, should also include the oil volume in the pipes and manifolds that changes its pressure during decompression.

If energy recovery is provided for decompression, the integration of power measured at the output of the recovery system reflects the amount of energy recovered.

C.2.5 Power during beam return (MT activity 6)

Power applied to the beam is calculated with Formulae (C.8) and (C.11):

$$P_{\text{SlTotalShaftRet.}} = p_{\text{MS3}} * A- * v \quad \text{(C.8)}$$

$$P_{\text{SlCylShaftRet.}} = p_{\text{MS4}} * A- * v \quad \text{(C.9)}$$

$$P_{\text{SlCylHeadRet.}} = p_{\text{MS2}} * A+ * v \quad \text{(C.10)}$$

$$P_{\text{SlPwrLossRet.}} = P_{\text{SlTotalHeadRet.}} + P_{\text{SlTotalShaftRet.}} \quad \text{(C.11)}$$

where

$P_{\text{SlTotalShaftRet.}}$	is the total electrical power applied to the beam shaft side [W];
$P_{\text{SlCylShaftRet.}}$	is the total electrical power applied to the beam cylinder shaft side [W];
$P_{\text{SlCylHeadRet.}}$	is total electrical power applied to the beam cylinder head side [W];
$P_{\text{SlPwrLossRet.}}$	is the total electrical power loss during return [W];
$P_{\text{SlTotalHeadRet.}}$	is the total electrical power applied to the beam head side [W];
$p_{\text{MS}x}$	is the pressure measured at the measuring point x [Pa];
$A+$	is the beam cylinder area head side [m^2];
$A-$	is the beam cylinder area shaft side [m^2];
v	is the actual beam velocity $\left[\frac{\text{m}}{\text{s}}\right]$.

$P_{\text{SlCylHeadRet.}}$ is the loss of power at the beam head side. If energy recovery is provided for the beam head side, the output power of the recovery system can be subtracted from $P_{\text{SlCylHeadRet.}}$.

The difference between $P_{\text{SlTotalShaftRet.}}$ and $P_{\text{SlCylShaftRet.}}$ is the loss of power at the beam shaft side manifold(s) during return.

C.3 Formulae for energy calculation for a hydraulic press brake cycle (downstroking press)

C.3.1 General

The given formulae are examples valid for a hydraulic press brake as shown in C.1 and other press brakes with comparable functionality.

They are to calculate the energy required for changing the level of potential energy in the machine tool component (e.g. beam descent and return, charging and discharging of the oil spring in a hydraulic cylinder) and the efficiency factor for the machine tool activities according to the typical press brake diagram (see 5.3.5). The values can be used for $W_{\text{MTActivity}}$ in the energy calculation according to ISO 14955-2.

These examples do not include formulae for components of auxiliary devices (e.g. automation systems). Formulae for components with similar physical principles can be used to calculate the energy required.

C.3.2 Machine tool activity 1: Beam is waiting in TDC for start signal while die is loaded

Due to the fact that the beam is not moving, no energy is transferred to or from the beam. The efficiency factor of press brake components are zero.

C.3.3 Machine tool activity 2: Beam close

The beam descents by gravity. The fluid flow out of the lower cylinder is controlling the beam movement.

The initial energy stored in the beam mass is calculated with Formula (C.12):

$$W_{\text{SlClose}} = F_{\text{MovingWeight}} * s_{\text{SlClose}} \tag{C.12}$$

where

W_{SlClose}	is the initial energy stored in the beam mass [Ws];
$F_{\text{MovingWeight}}$	is the force created by the weight of the moving parts [N];
s_{SlClose}	is the beam path between TDC and material contact [m];

The energy efficiency factor in this machine tool activity is calculated with Formula (C.13):

$$\eta_{\text{SlClose}} = \frac{W_{\text{SlClose}}}{W_{\text{SysBoundMTa}}} \tag{C.13}$$

where

η_{SlClose}	is the energy efficiency factor for beam close[1];
W_{SlClose}	is the initial energy stored in the beam mass [Ws];
$W_{\text{SysBoundMTa}}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

NOTE For "Beam close" on upstroking press brakes, see "Beam return".

C.3.4 Machine tool activity 3: Bending

The workpiece is held by the operator or the work support and formed by the beam equipped with tools. The required beam force (in relevant of workpiece thickness, tensile strength, length and v-width of tools) is generated by fluid pressure.

The energy supplied is calculated with Formulae (C.14) and (C.15):

$$W_{Bending} = F_{Bending} * s_{Bending} \tag{C.14}$$

where

$W_{Bending}$	is the energy supplied during bending [Ws];
$F_{Bending}$	is the average force of beam during bending [N];
$s_{Bending}$	is the beam path between material contact and BDC [m].

The energy efficiency factor in this machine tool activity is calculated as follows:

$$\eta_{Bending} = \frac{W_{Bending}}{W_{SysBoundMTa}} \tag{C.15}$$

where

$\eta_{Bending}$	is the energy efficiency factor for bending[1];
$W_{Bending}$	is the energy supplied during bending [Ws];
$W_{SysBoundMta}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

C.3.5 Machine tool activity 4: Pressing

During pressing, the beam force is generated by elongation of the press brake frame by beam positioning and applied for the programmed processing time. Elongation of press brake frame and compression of hydraulic spring are relevant for the energy supplied.

The energy supplied is calculated with Formulae (C.16) and (C.17):

$$W_{Pressing} = F_{Sl} * \left(s_{Elongation} + \frac{s_{Compression}}{2} \right) \tag{C.16}$$

where

$W_{Pressing}$	is the energy supplied during pressing [Ws];
F_{Sl}	is the average force of beam [N];
$s_{Elongation}$	is the frame elongation [m];
$s_{Compression}$	is the calculated path of compression (oil spring) [m].

The energy efficiency factor in this machine tool activity is calculated as follows:

$$\eta_{Pressing} = \frac{W_{Pressing}}{W_{SysBoundMTa}} \tag{C.17}$$

where

$\eta_{Pressing}$	is the energy efficiency factor for pressing[1];
$W_{Pressing}$	is the energy supplied during pressing [Ws];
$W_{SysBoundMta}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

C.3.6 Machine tool activity 5: Decompression

The initial energy stored in the cylinder head is equal to the energy at the end of the bending phase. Without means of regeneration, generated energy on the cylinder head is converted into heat by the decompression unit.

C.3.7 Machine tool activity 6: Beam return

The beam is returning to TDC driven by hydraulic fluid.

The energy supplied is calculated with Formulae (C.18) and (C.19):

$$W_{\mathrm{SlRet.}} = F_{\mathrm{MovingWeight}} * s_{\mathrm{SlRet.}} \tag{C.18}$$

where

$W_{\mathrm{SlRet.}}$	is the energy supplied during beam return [Ws];
$F_{\mathrm{MovingWeight}}$	is the force created by the weight of the moving parts [N];
$s_{\mathrm{SlRet.}}$	is the beam path between TDC and BDC [m].

The energy efficiency factor in this machine tool activity is calculated as follows:

$$\eta_{\mathrm{SlRet.}} = \frac{W_{\mathrm{SlRet.}}}{W_{\mathrm{SysBoundMTa}}} \tag{C.19}$$

where

$\eta_{\mathrm{SlRet.}}$	is the energy efficiency factor for beam return[1];
$W_{\mathrm{SlRet.}}$	is the energy supplied during beam return [Ws];
$W_{\mathrm{SysBoundMta}}$	is the energy supplied at the system boundary for this machine tool activity [Ws].

NOTE For "Beam return" on upstroking press brakes, see "Beam close".

C.4 Quantitative functional mapping for hydraulic press brakes

An example of functional mapping for a hydraulic press brake is given in Table C.1.

Table C.1 — Example for quantitative functional mapping

		Machine tool functions					
		Machine tool operation (machining, process, motion and control)	Process conditioning	Workpiece handling	Tool change	Recyclables and waste handling	Machine tool cooling/ lubrication
Machine tool components	Control components[a]	95 %					5 %
	Hydraulic unit beam drive	95 %					5 %
	Crowning unit	95 %					5 %
	Backgauge	95 %					5 %
	Tool clamping unit				100 %		

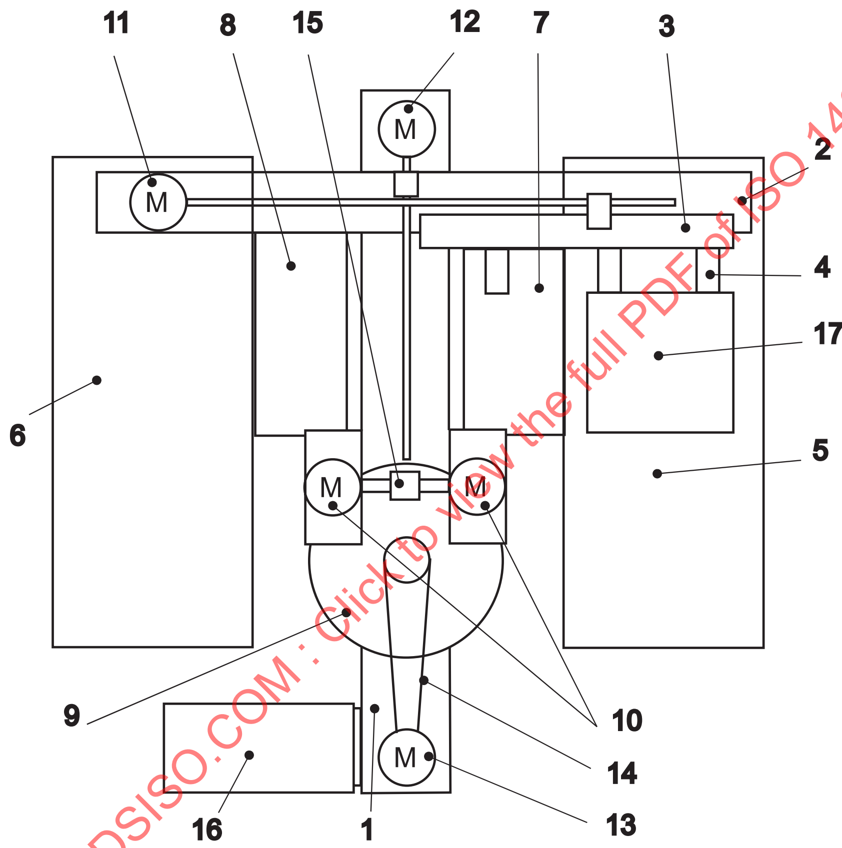
[a] Including PLC and CNC modules.

Annex D
(informative)

Turret punch presses

D.1 Example of a servo punching press

Figure D.1 shows an example of a servo punching press (AC servo direct twin drive punching press).



Key

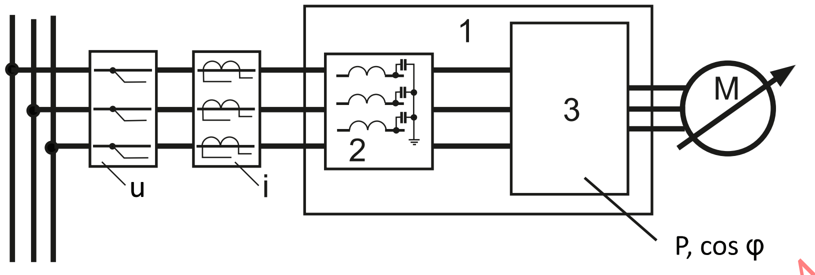
1	frame	10	ram drive motor
2	slide	11	X-axis motor
3	carriage	12	Y-axis motor
4	clamp	13	T-axis motor
5	fixed table F	14	chain
6	fixed table R	15	striker and ram
7	moving table F	16	NC-console
8	moving table R	17	workpiece
9	turret		

Figure D.1 — Example of AC servo direct twin drive punching press

D.2 Power measurement at a turret punch press

D.2.1 General

An example of a typical drive unit for a servo punching press is given in Figure D.2.



Key

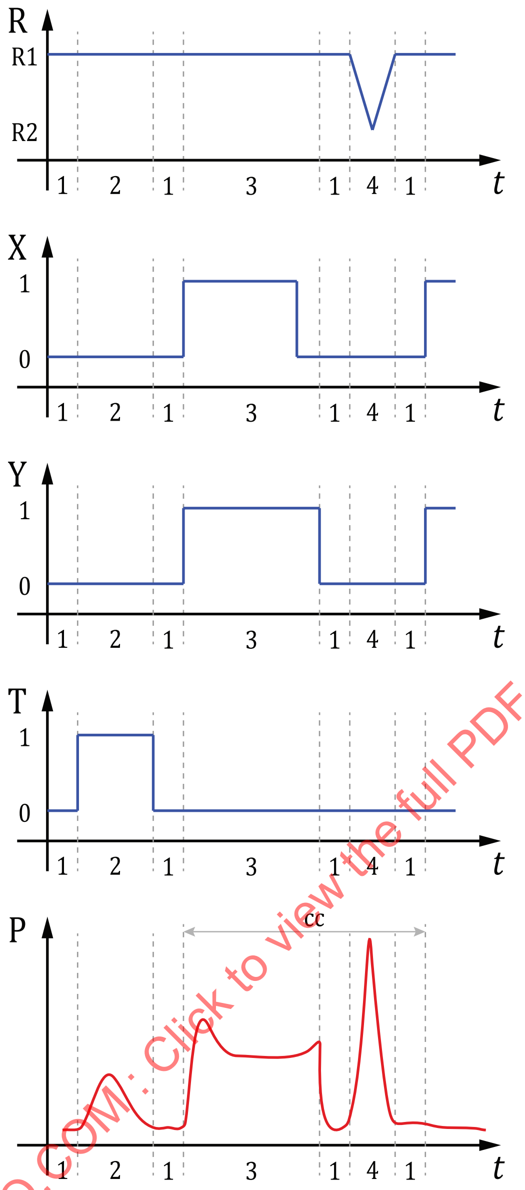
1	inverter system	u	voltage measuring point
2	line filter and line reactor	i	current measuring point
3	inverter (with power measurement feature)	*P*, cos*φ*	values measured by inverter

Figure D.2 — Example of a drive unit for a servo punching press

The power of motors driving components through mechanical transmissions, such as ram, X-axis, Y-axis and T-axis, is usually relevant.

If the inverter provides a measure of the input power and phase angle, those values may be used.

An example of typical power in a cycle of a turret punch press is given in Figure D.3.



Key

R ram
R1 ram upper end
R2 ram lower end
X X-axis active
Y Y-axis active
T T-axis active
t time
P actual power
cc complete punching cycle
1 machine tool activity 1: STANDBY – waiting for the start signal of axes
2 machine tool activity 2: die positioning – T-axis is rotated for setting the die into the punch centre
3 machine tool activity 3: workpiece positioning – X-axis and Y-axis move for setting the workpiece to processing position
4 machine tool activity 4: punching – ram descends and processes punch holes, then moves to upper end

Figure D.3 — Example of power in a servo punching press

D.2.2 Power for standby (MT activity 1)

In this activity, the macine is waiting for a start signal. No axis is transmitting power. Measured power is idling power and the energy efficiency factor is zero.

D.2.3 Power for die positioning (MT activity 2)

In this activity, for setting the die into the punch center, T-axis is rotated. This operation will act only the first time, if there is no alteration in the die. The measured power is the power applied to the T-axis motor.

D.2.4 Power for workpiece positioning (MT activity 3)

Clamp (4) grasping workpiece (17) moves to the processing position with X-axis motor and Y-axis motor through carriage (3), which is in the state of acceleration, uniform movement and deceleration. The measured power is the power applied to the X-axis motor and Y-axis motor (the numbers in brackets refer to Figure D.1).

D.2.5 Power for punching (MT activity 4)

Descending ram-axis by drive motor (10), and processing punch holes into workpiece (17) through the die. And, the ram which moves down to the lower end, and then moves up to the upper end in order to prepare for the next work movement. The measured power is the power applied to the ram drive motor (the numbers in brackets refer to Figure D.1).

D.3 Formulae for energy calculation for a servo punching press

D.3.1 General

The calculation formula obtained in this clause conforms to the servo punching press as shown in D.2, and punch presses with the same elements (e.g. number of ram drive motor, X- and Y-axis driven by rack and pinion or ball screw).

D.3.2 Machine tool activity 1: Standby

X-axis, Y-axis and ram are in the state which waits for start signal without movement, and no power transmission to X-axis, Y-axis and ram. Each energy efficiency factor is zero.

D.3.3 Machine tool activity 2: Die positioning

The state where the die on the turret is rotated with T-axis motor and positioned to specified position (angle) in advance.

The energy required to set T-axis in position as specified in advance is calculated with Formulae (D.1) and (D.2):

$$W_T = T_{TAcc.} * \Theta_{TAcc.} + T_{TFriction} * \Theta_T + T_{TDec.} * \Theta_{TDec.} \quad \text{(D.1)}$$

$$\Theta_T = \Theta_{TAcc.} + \Theta_{TUni.} + \Theta_{TDec.} \quad \text{(D.2)}$$

where

W_T is the energy required for T-axis positioning rotation [Ws];

$T_{TAcc.}$ is the torque required for T-axis acceleration [Nm];

$\Theta_{TAcc.}$ is the rotation angle which moved at the time of T-axis acceleration[1];

$T_{TFriction}$ is the friction torque when moving the T-axis rotating part at uniform velocity, depending on the weight of the machine components linked to the T-axis, e.g. turret (9) and die [Nm];

Θ_T is the rotation angle which requires T-axis positioning[1];

$T_{TDec.}$ is the torque required for T-axis deceleration [Nm];

$\Theta_{TDec.}$ is the rotation angle which moved at the time of T-axis deceleration[1];

$\Theta_{TUni.}$ is the rotation angle which moved at the time of T-axis uniform velocity[1].

The energy efficiency factor in this machine tool activity is calculated with Formula (D.3):

$$\eta_T = \frac{W_T}{W_{SysBoundMTa}} \quad \text{(D.3)}$$

where

η_T is the energy efficiency factor at the time of die positioning[1];

W_T is the energy required for T-axis positioning rotation [Ws];

$W_{SysBoundMta}$ is the energy supplied at the system boundary for this machine tool activity [Ws].

If a regenerative drive is adopted, deceleration energy of T-axis can be partially recovered.

D.3.4 Machine tool activity 3: Workpiece positioning

The state where the workpiece is positioned to specified position in advance with X-axis motor and Y-axis motor.

The energy required to set X-axis in position as specified in advance with Formulae (D.4) to (D.7):

$$W_X = W_{XAcc.} + W_{XUni.} + W_{XDec.} \quad \text{(D.4)}$$

$$W_{XAcc.} = \left(F_{XAcc.} + F_{XFriction}\right) * s_{XAcc.} \quad \text{(D.5)}$$

$$W_{XUni.} = F_{XFriction} * s_{XUni.} \quad \text{(D.6)}$$

$$W_{XDec.} = \left(F_{XDec.} - F_{XFriction}\right) * s_{XDec.} \quad \text{(D.7)}$$

where

W_X is the energy required for X-axis positioning [Ws];

$W_{XAcc.}$ is the energy required for X-axis acceleration [Ws];

$F_{XAcc.}$ is the force required for X-axis acceleration [N];

$F_{XFriction}$ is the friction force when moving the X-axis, depending on the weight of the machine components linked to the X-axis, e.g. carriage (3), clamp (4), workpiece (17) (numbers in brackets see Figure D.1) [N];

$s_{XAcc.}$ is the distance covered by the X-axis during acceleration [m];

$W_{XUni.}$ is the energy required for X-axis uniform movement [Ws];

$s_{XUni.}$ is the distance which moved at the time of X-axis uniform movement [m];

$W_{XDec.}$ is the energy required for X-axis deceleration [Ws];

$F_{XDec.}$ is the force required for X-axis deceleration [N];

$s_{XDec.}$ is the distance which moved at the time of X-axis deceleration [m].

The energy required to set Y-axis in position as specified in advance with Formulae (D.8) to (D.11):

$$W_Y = W_{YAcc.} + W_{YUni.} + W_{YDec.} \tag{D.8}$$

$$W_{YAcc.} = (F_{YAcc.} + F_{YWeight}) * s_{YAcc.} \tag{D.9}$$

$$W_{YUni.} = F_{YWeight} * s_{YUni.} \tag{D.10}$$

$$W_{YDec.} = (F_{YDec.} - F_{YWeight}) * s_{YDec.} \tag{D.11}$$

where

W_Y is the energy required for Y-axis positioning [Ws];

$W_{YAcc.}$ is the energy required for Y-axis acceleration [Ws];

$F_{YAcc.}$ is the force required for Y-axis acceleration [N];

$F_{YWeight}$ is the friction force when moving the Y-axis, depending on the weight of the machine components linked to the Y-axis, e.g. weight linked to the X-Axis, X-axis drive unit, slide (2), moving table F (7), moving table R (8) (numbers in brackets see Figure D.1) [N];

$s_{YAcc.}$ is the distance covered by the Y-axis during acceleration [m];

W_{YUni} is the energy required for Y-axis uniform movement [Ws];

s_{YUni} is the distance which moved at the time of Y-axis uniform movement [m];

$W_{YDec.}$ is the energy required for Y-axis deceleration [Ws];

$F_{YDec.}$ is the force required for Y-axis deceleration [N];

$s_{YDec.}$ is the distance which moved at the time of Y-axis deceleration [m].

The energy efficiency factor in this machine tool activity is calculated with Formula (D.12):

$$\eta_{XY} = \frac{W_X + W_Y}{W_{SysBoundMTa}} \tag{D.12}$$

where

η_{XY} is the energy efficiency factor at the time of workpiece positioning[1];

W_X is the energy required for X-axis positioning [Ws];

W_Y is the energy required for Y-axis positioning [Ws];

$W_{SysBoundMTa}$ is the energy supplied at the system boundary for this machine tool activity [Ws].

In the case that each motor has a regeneration system, deceleration energy of the X-axis and Y-axis can be recovered.

D.3.5 Machine tool activity 4: Punching

The striker driven by the ram moves down and performs punching, and then moves up to upper end.

The energy required for punching is calculated with Formula (D.13):

$$W_{\text{Punching}} = F_{\text{Punching}} * s_{\text{Punching}} \quad \text{(D.13)}$$

where

W_{Punching} is the energy required for punching [Ns];

F_{Punching} is the force required for punching [N];

s_{Punching} is the length which punching power generates (shear length) [m];

NOTE Shear length varies with the clearance of punch and die, material and tool shape.

The energy efficiency factor for punching is calculated with Formula (D.14):

$$\eta_{\text{Punching}} = \frac{W_{\text{Punching}}}{W_{\text{SysBoundMTa}}} \quad \text{(D.14)}$$

where

η_{Punching} is the energy efficiency factor at the time of punching[1];

W_{Punching} is the energy required for punching [Ws];

$W_{\text{SysBoundMTa}}$ is the energy supplied at the system boundary for this machine tool activity [Ws].

In case the ram drive motor has regeneration system, deceleration energy of the ram at the time of down and up can be recovered.

D.4 Quantitative functional mapping for a servo punching press

An example of functional mapping for a servo punching press is given in Table D.1.

Table D.1 — Example for quantitative functional mapping

		Machine tool functions					
		Machine tool operation (machining, process, motion and control)	Process conditioning	Workpiece handling	Tool change	Recyclables and waste handling	Machine tool cooling/ lubrication
Machine tool components	Control components[a]	85 %		5 %	5 %		5 %
	Ram drive motor	100 %					
	X-axis motor	100 %					
	Y-axis motor	100 %					
	T-axis motor	90 %			10 %		
	Cooling fan for ram drive motor						100 %

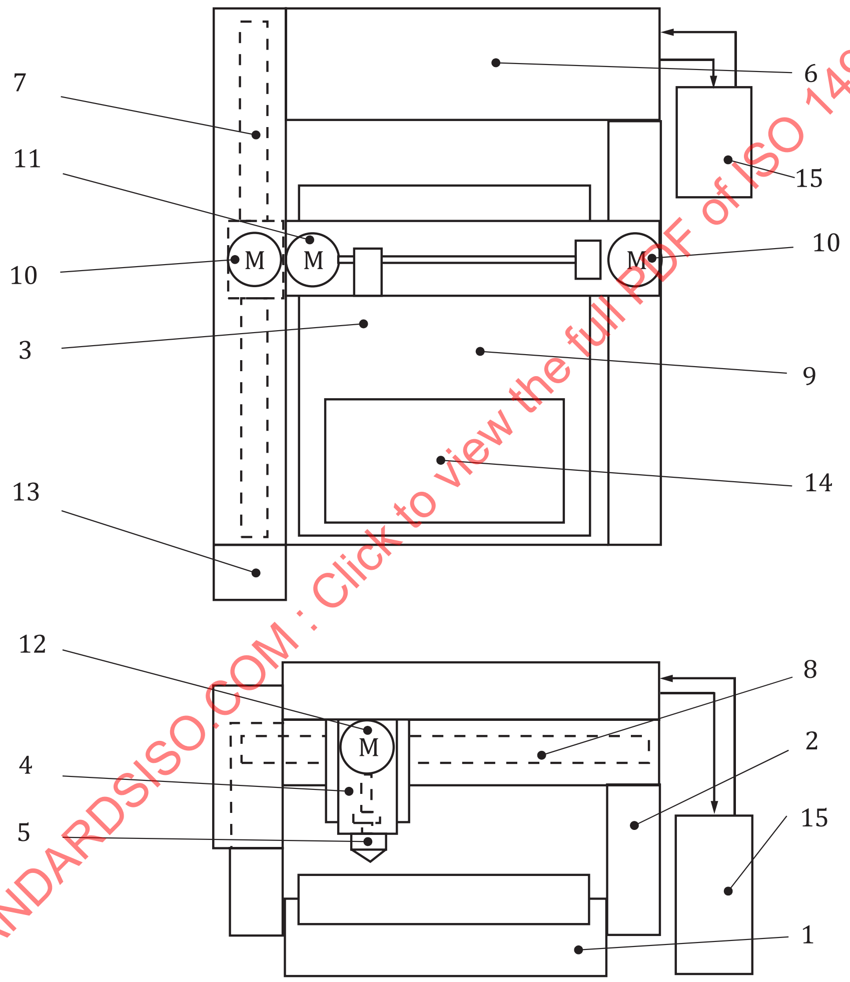
a Including PLC and CNC modules.

Annex E
(informative)

Laser processing machine tools

E.1 Example of a laser processing machine tool

Figure E.1 shows an example of a laser processing machine tool (flying optics laser processing machine tool).



Key

1 frame
2 X carriage
3 Y carriage
4 Z-axis
5 processing head
6 oscillator
7 X optical path
8 Y optical path
9 pallet
10 X-axis motor
11 Y-axis motor
12 Z-axis motor
13 NC-console
14 workpiece
15 chiller unit

Figure E.1 — Example of a flying optics laser processing machine tool

