INTERNATIONAL STANDARD

ISO 15616-1

First edition
2003-03-01

Acceptance tests for CO_2-laser beam machines for high quality welding and cutting —

Part 1: General principles, acceptance conditions

Essais de réception des machines de soudage et de coupage de qualité par faisceau laser CO_2 —

Partie 1: Principes généraux et conditions de réception

Reference number
ISO 15616-1:2003(E)

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Published in Switzerland

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 15616 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15616-1 was prepared by the European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 10, *Unification of requirements in the fielsd of metal welding*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this document, read "...this European Standard..." to mean "...this International Standard...".

ISO 15616 consists of the following parts, under the general title *Acceptance tests for* CO_2*-laser beam machines for high quality welding and cutting*:

— *Part 1: General principles, acceptance conditions*

— *Part 2: Measurement of static and dynamic accuracy*

— *Part 3: Calibration of instruments for measurement of gas flow and pressure*

Contents

Foreword

This document (EN ISO 15616-1:2003) has been prepared by Technical Committee CEN/TC 121, "Welding", the secretariat of which is held by DS, in collaboration with ISO/TC 44 "Welding and allied processes".

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2003, and conflicting national standards shall be withdrawn at the latest by September 2003.

This European Standard "*Acceptance test for CO_2 – laser beam machines for high quality welding and cutting*" consists of the following Parts:

— *Part 1: General principles, acceptance conditions.*

— *Part 2: Measurement of static and dynamic accuracy.*

— *Part 3: Calibration of instruments for measurement of gas flow and pressure.*

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This Part of this European Standard is applicable to CO_2-laser beam machines for welding and cutting in two operating directions (2D).

The main purpose of this standard is to provide requirements for acceptance testing of CO_2-laser beam machines prior to or during installation at the user's premises. The acceptance tests are used to document the ability of CO_2-laser beam machines to produce welded joints and cuts of consistent quality.

This standard is intended to be used for preparation of the technical specification for CO_2-laser beam machines for high quality welding and cutting in two operating directions (2D). This standard specifies basic requirements. Additional tests and requirements may be specified in the technical specification for the CO_2-laser beam machine.

NOTE 1 The technical specification for the CO_2-laser beam machine usually forms a part of the contract and it is agreed by the parties concerned (the manufacturer of the CO_2-laser beam machine and the customer/user).

NOTE 2 The requirements may be too stringent for non-high quality cutting.

However, the standard may also be used for testing as part of maintenance, as appropriate.

If modifications are made to a CO_2-laser beam machine (rebuilding, repairs, modifications to the operating conditions etc.) that may have an effect on the acceptance testing, repeat test may be necessary covering the machine parameters affected by such modifications.

If a CO_2-laser beam machine that has already been accepted is dismantled (e.g. in order to change its location) such tests may involve verification according to the requirements in 6.4 as a minimum.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 60204-1, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements (IEC 60204-1:1997).*

EN ISO 11145:2001, *Optics and optical instruments — Lasers and laser-related equipment — Vocabulary and symbols (ISO 11145:2001).*

EN ISO 11146:1999, *Lasers and laser-related equipment — Test methods for laser beam parameters — Beam widths, divergence angle and beam propagation factor (ISO 11146:1999).*

EN ISO 11554, *Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam power, energy and temporal characteristics (ISO 11554:1998).*

EN ISO 11670, *Lasers and laser related equipment — Test methods for laser beam parameters — Beam positional stability (ISO 11670:1999).*

EN ISO 15616-2, *Acceptance tests for CO_2-laser beam machines for high quality welding and cutting — Part 2: Measurement of static and dynamic accuracy (ISO 15616-2:2003).*

EN ISO 15616-3, *Acceptance tests for CO_2-laser beam machines for high quality welding and cutting — Part 3: Calibration of instruments for measurement of gas flow and pressure (ISO 15616-3:2003).*

ISO 230-2, *Test code for machine tools — Part 2: Determination of accuracy and repeatability of positioning numerically controlled axes.*

International Vocabulary of Basic and General Terms in Metrology.

3 Terms, definitions and symbols

For the purposes of this Part of this European Standard, the terms and definitions given in EN ISO 11145:2001, EN ISO 11146:1999 and in the International Vocabulary of Basic and General Terms in Metrology apply.

The symbols listed in Table 1 are used in this standard.

Table 1 — Explanation of symbols

Symbol	Unit	Term
	—	effective f-number, see EN ISO 11145
D	mm	work piece diameter
$d_{(s)}$	mm	laser beam diameter at the distance s, see EN ISO 11145
$d_{o,u}$	mm	laser beam waist diameter, see EN ISO 11145
d_{opt}	mm	laser beam diameter on the focusing optic, see EN ISO 11145
E_u	W/cm^2	average power density, see EN ISO 11145
f	mm	focal length, see EN ISO 11146
f_a	mm	error in rounding-off
f_o	mm	error in overshooting
K	—	beam propagation factor, see EN ISO 11145. M_2 is an alternative term, frequently used instead of K
m_N	kg	working load
n	min^{-1}	rotational speed
P_L	W	laser beam power output of the cw laser
P_P	W	laser beam power at the point-of-use
r	mm	error in reversibility
t	mm	error in circularity
U'_v	mV	speed signal
U''_v	mV	speed signal

Table 1 *(continued)*

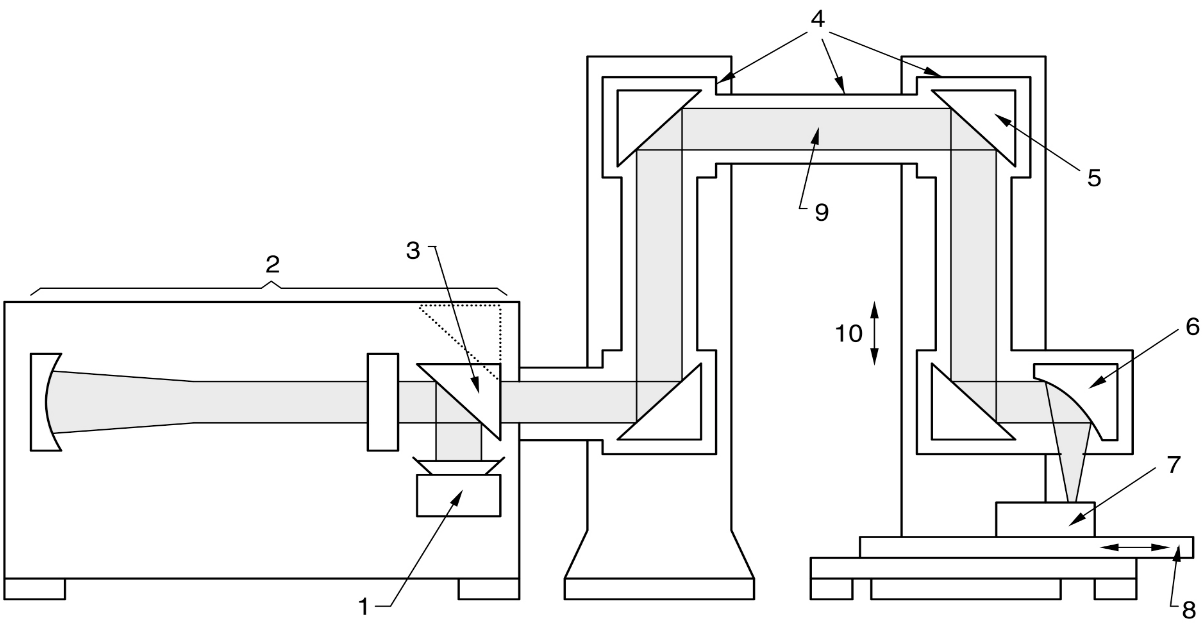
Symbol	Unit	Term
$\Delta U'_{v}$	mV	deviation of speed signal
$\Delta U'_{v\ max}$	mV	maximum deviation of speed signal
v	m/min	linear speed
v_{s}	m/min	average velocity in trajectory
v_{max}	m/min	maximum velocity in trajectory
v_{min}	m/min	minimum velocity in trajectory
v_{prog}	m/min	programmed velocity in trajectory

4 Acceptance test conditions

4.1 Setting up the CO_2-laser beam machine

The CO_2-laser beam machine shall be erected and installed in such a way that the processing operation is not disturbed by environmental factors, e.g. vibrations, large temperature variations, contaminated atmosphere. The conditions specified by the laser system manufacturer have to be fulfilled during erection and installation.

A schematic view of a typical CO_2-laser beam machine is shown in Figure 1.



Key

1	absorber
2	laser
3	shutter
4	beam guiding system
5	bending optics
6	focusing head
7	work piece
8	working table
9	laser beam
10	movement in z direction

Figure 1 — Schematic view of CO_2-laser beam machine

4.2 Power supply

The power source for the CO_2-laser beam machine shall be an electrical main system with voltage fluctuations not exceeding ± 10 %, see EN 60204-1.

4.3 Health, safety and environment

4.3.1 Health and safety

This standard does not cover inspection of safety devices and other safety aspects.

NOTE Current health and safety regulations, accident prevention rules, as well as generally accepted technical specifications should be applied and adhered to, respectively.

4.3.2 Environment

Exhaust systems removing hazardous gaseous and particulate emission from the laser beam source or the processing operation process shall be designed and installed according to the requirements of the local environmental regulations.

4.4 Cooling system

The cooling system shall meet the laser equipment manufacturer's specifications with respect to the operation temperature (compared to atmospheric dew point), temperature stability, control of high and low temperatures, operation pressure, flow rate and quality of the cooling medium. The laser equipment shall be fitted with a safety cut out system in the event of any anomaly occurring in the cooling system.

4.5 Gas supply and gas supply system

The purity and properties, e.g. dew point, of the laser gases, the purging gas of the beam guiding system, working gases (plasma control, cutting and shielding gases), other gases (for the aerodynamic window, beam shutter) and the gas supply system shall meet the specifications of the CO_2-laser beam machine manufacturer and the standards.

4.6 Operation instructions

All instructions in the technical specification for the CO_2-laser beam machine for the operation, safety, service and maintenance of the CO_2-laser beam machine shall be followed.

5 Acceptance test principles

5.1 Range of system settings

The range of system settings (minimum and maximum values) shall be specified in the technical specification for the CO_2-laser beam machine. The parameters shall include (as appropriate):

— laser beam power;

— focal length;

— laser beam path and motion system (processing speed; processing length, motion direction);

— revolutions per minute (rotary fixture);

— working load;

— working gases (type, gas flow rate or gas pressure);

— type of working gas device (axial, lateral, nozzle, tube, diameter, angle, nozzle/plate distance etc.);

— working mode of laser.

5.2 Limit deviations

The limit deviations stated in Table 2 shall be applied for acceptance testing unless otherwise agreed. The limits are applied to each of the set points.

Table 2 — Limit deviations

Specification	Limit deviations
maximum laser beam power	+ 5 % to – 2 %
minimum laser beam power	+ 10 % to – 3 %
medium term stability	± 5 %
long term stability	± 2 %
repeatability	± 2 %
laser beam power losses	... [a]
pulsed or modulated laser beam power	± 5 %
laser beam diameter (enclosed laser beam)	... [a]
free-running laser beam diameter	± 15 % to ± 5 %
beam positional stability	... [a]
beam propagation factor	Measured $K \geq$ specified value
laser beam waist diameter (focused laser beam)	± 0,1 mm
laser beam waist position (focused laser beam)	... [a]
welding-/cutting speed	
short term stability, speed: v_{max}	± 2 %
short term stability, speed: 0,1 v_{max}	± 5 %
repeatability	± 1 %
working gas	
gas flow rate	± 10 %
gas pressure	± 10 %

[a] No limits, however measured values shall be recorded on the test certificate.

5.3 Precision required

The technical specification for the CO_2-laser beam machine shall refer to an appropriate level of precision as specified in Table 3 unless otherwise agreed. The limits are applied to each of the set points.

The intended use of the levels is:

A: Special high precision processing;

B: High quality processing;

C: Normal processing;

D: Large installations with movable laser beam sources for heavy industry application.

Table 3 — Levels of precision

Levels of precision	A	B	C	D
mean reversal value, in mm, see ISO 230-2	0,02	0,04	0,06	0,1
repeatability of positioning, in mm				
unidirectional	0,01	0,01	0,02	0,2
bi-directional	0,02	0,04	0,06	0,4
accuracy of positioning in mm/m	0,05	0,1	0,2	0,4

5.4 Acceptance report

The results of all tests shall be documented by test reports. The outcome of the entire acceptance testing shall be documented by an acceptance report referring to all test results.

The test program and the specifications of additional tests (if any) shall be described in the acceptance report separately.

6 Acceptance test

6.1 General

The standards for testing stated in Table 4 shall be used for acceptance testing unless otherwise specified in the in the technical specification for the CO_2-laser beam machine.

When the laser is switched on, the time delay specified by the manufacturer for stabilisation of the output shall be respected before any measurement.

Table 4 — Standards for testing

Sub-clause	Property	Test standard
6.2.1	Laser beam power	EN ISO 11554
6.2.2	Medium and long term power stability	EN ISO 11554
6.2.3	Repeatability	EN ISO 11554
6.2.4	Laser beam power losses	No standard
6.2.5	Pulsed and modulated laser beam power	EN IS0 11554
6.2.6	Laser beam diameter (enclosed laser beam)	EN ISO 11146
6.2.7	Free-running laser beam properties	EN ISO 11146 or procedure specified in 6.2.7
6.2.8	Beam positional stability	EN ISO 11670
6.3.1	Beam propagation factor	EN ISO 11146
6.3.2	Laser beam waist position and diameter (focused laser beam)	EN ISO 11146 or procedure specified in 6.3.2
6.4.2	Manipulation system precision	EN ISO 15616-2
6.4.3	Positioning accuracy	ISO 230-2
6.4.4	Trajectory exactness	EN ISO 15616-2
6.5.2	Short-term speed stability	No standard
6.5.3	Repeatability	No standard
6.6.2	Testing of instruments for gas flow and gas pressure	EN ISO 15616-3

6.2 General properties

6.2.1 Laser beam power

The laser beam power at maximum and minimum set point (manufacturer’s specification) shall be measured at the laser beam output of the resonator.

6.2.2 Medium and long term power stability

Medium and long term power stability are measured by determination of the maximum and minimum laser beam power within the specified period. Medium and long term power stability shall be measured at the maximum rated power.

Maximum and minimum values are compared to (max. + min.)/2. Limit deviations in medium and long term power stability are given in Table 2.

6.2.3 Repeatability

Measurements of the laser beam power shall be repeated after a total shut-down of the laser or the CO_2-laser beam machine for at least 2 h. Measurements are carried out applying the same parameters being used in 6.2.1.

The accompanying limits are listed in Table 2.

6.2.4 Laser beam power losses

The laser beam power shall be measured at the laser beam output and right before the focusing optics position as well, operating the laser at maximum power set point, respectively. Losses are calculated from the drop in power from the laser beam output to the focusing optics position.

6.2.5 Pulsed and modulated laser beam power

The average power level shall be measured during pulsed or modulated operation 15 min after laser switch-on and again 30 min after the first measurement.

The parameters to be used during measurements are:

— typical pulse repetition rates, e.g. 100 Hz and 1000 Hz

— pulse-duty factor: 50 %

— amplitude: 100 %

The permissible deviations are listed in table 2.

The technical specification for the CO_2-laser beam machine may specify additional testing procedures during pulsed or modulated operation.

6.2.6 Laser beam diameter (enclosed laser beam)

The laser beam diameter shall be measured right before the focusing optic's position at a minimum, medium and maximum length of the laser beam path, at the rated power.

The laser beam diameter shall comply with the range specified by the manufacturer for the particular CO_2-laser beam machine.

NOTE It is essential to maintain purge gas quality while measuring laser beam diameters.

6.2.7 Free-running laser beam properties

Characteristics describing the laser beam propagation are the laser beam waist diameter, the position of the laser beam waist and the laser beam divergence. The divergence is the angle being caused by the enlargement of the laser beam diameter in the far-field, the divergence is described in mrad. The laser beam waist diameter is the smallest laser beam width in the laser beam propagation. See also EN ISO 11145.

The diameter of the free-running laser beam shall be measured at the mid position of the laser beam path in accordance with 6.2.6. The diameter of the free-running laser beam shall comply with the range specified by the manufacturer for the particular laser source.

NOTE Further measurements can be necessary in case the performance of the laser source has to be tested independently of the function of the assembled CO_2-laser beam machine.

Suitable methods for measuring diameter of the free-running laser beam are specified in EN ISO 11146.

Values are identified in two characteristic orientations, perpendicular to each other, if the laser beam is not of radial symmetry.

A less accurate estimate of laser beam dimensions may be obtained by ‘burn-in ’s’, e.g. on acrylics or on fine-grain brick. The size of the ‘resulting burn patterns' is dependent on the material and the radiation time period, which may cause deviations of 10 % to 30 %. The method usually leads to emission of considerable amounts of fumes and gases, which have to be eliminated as required.

6.2.8 Beam positional stability

The beam positional stability is the spatial stability of the laser beam axis in relation to the mechanical axis pointing from the output of the laser resonator towards the focusing optics. Measurements are carried out at rated laser beam power.

The beam positional stability shall be measured in accordance with EN ISO 11670, except that only the long term stability shall be tested, using a minimum of 10 observations.

The measured deviation shall comply with the limit deviation specified by the manufacturer for the particular CO_2-laser beam machine.

6.3 Examination of the focused laser beam

6.3.1 Beam propagation factor

The beam propagation factor K shall be measured and calculated in accordance with EN ISO 11146, at maximum rated power.

6.3.2 Laser beam waist position and diameter (focused laser beam)

The laser beam waist position and diameter shall be measured. For CO_2-laser beam machines with movable optics, the laser beam waist position and diameter shall be measured at the minimum and maximum length of the optical path.

The laser beam waist position and diameter shall be within the values specified by the manufacturer for the focusing optics of the particular CO_2-laser beam machine.

The laser beam waist position and diameter shall be measured preferably at the maximum rated laser power.

The position of the laser beam waist caused by the focusing optics should be measured and calculated using a beam diagnostic device in accordance with EN ISO 11146. If not feasible an alternative procedure may be used for determination of the laser beam waist position.

The following procedure may be used for welding machines:

The laser beam is guided across an inclined steel plate. The position of the capping run and the width of the Heat Affected Zone (HAZ) at the reverse side are examined afterwards. In the latter case the steel plate has to be fixed and clamped in an inclined position (recommended angle of inclination: 3° [f/100 mm]), so that the nominal laser beam waist position would be expected on top of the middle of the plate. Plate thickness should be about 75 % of the specified penetration depth. Parameter settings (laser beam power and welding speed) should lead to a clearly visible HAZ at the reverse side of the weld with an optimized laser beam waist position in order to obtain a full penetration. The welding process shall be made in both directions. The result shall be used to calculate an average value which may be used to indicate a suitable laser beam waist position.

6.4 Manipulation system precision, positioning accuracy and trajectory exactness

6.4.1 Examination procedure

Examination shall be carried out in accordance with EN ISO 15616-2.

6.4.2 Manipulation system precision

The precision of the moving working table or the rotary fixture shall be measured unloaded and at maximum working load. The precision of moving laser beam axis shall be measured if moving laser beams are used.

6.4.3 Positioning accuracy

The positioning accuracy and repeatability shall be measured in accordance with ISO 230-2.

The moving working table or the rotary fixture shall be tested in the unloaded condition. The positioning accuracy of moving laser beam axis shall be measured if this is used. The precision of the laser systems is classified in Table 3.

6.4.4 Trajectory exactness

The dynamic behaviour of the manipulation system shall be examined on three representative test contours. The dynamic behaviour of the manipulation system is defined by the trajectory exactness.

The technical specification for the CO_2-laser beam machine shall refer to an appropriate level of precision as specified in Table 5 unless otherwise agreed.

Table 5 — Trajectory exactness

Levels	A	B	C	D
maximum value within four measurements				
Square: error in rounding-off f_a and error in overshooting f_o in mm	0,1	0,2	0,5	1,0
Circle: error in circularity t in mm	0,05	0,1	0,25	0,5
45° bevel: error in reversibility r in mm	0,05	0,1	0,25	0,5

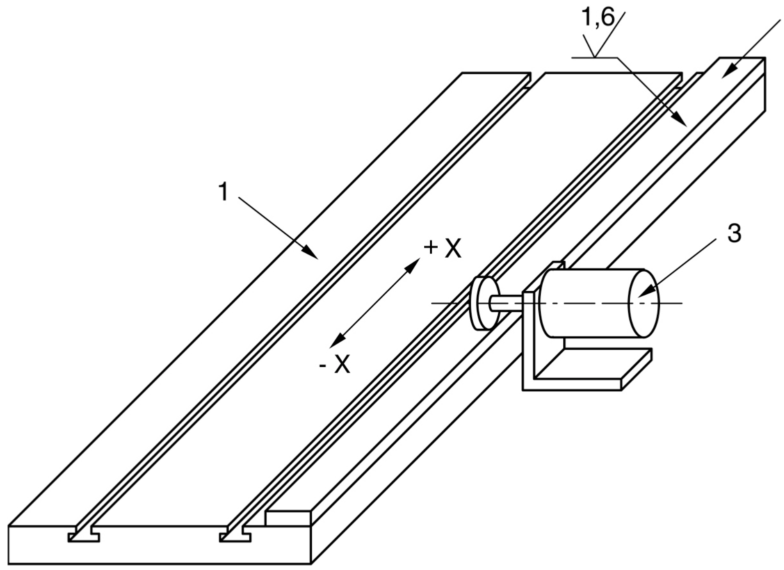
6.5 Welding and cutting speed

6.5.1 Measurement procedure

The speed shall be measured at the moving working table, the rotary fixture or the moving laser beam axis directly by use of an external measuring device (e.g. digital incremental).

To take account of all interferences affecting the welding speed, the measurement shall be made directly on the work piece or on the device positioning the work piece or on a movable focussing head, if appropriate. Suit working table transducers, with a linear response, may be used to transmit the translational or rotational movement, e.g. rotary transducers, via a hard rubber friction wheel (see Figures 2 and 3). Sufficient length of movement should be utilized to negate affects of acceleration and/or deceleration.

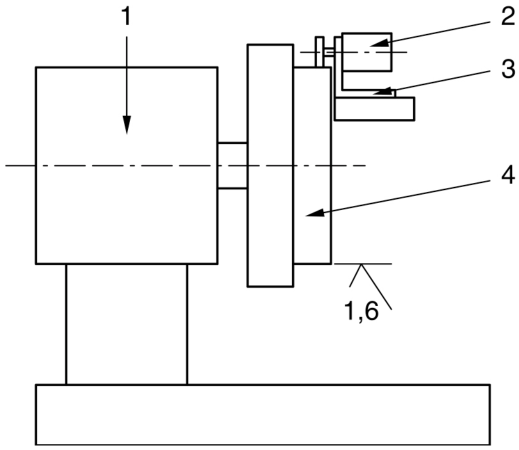
Build-in encoders or resolvers may also be used, if directly connected to the moving parts.



Key

1 working table
2 contact strip
3 rotary transducer fixed to non-moving part

Figure 2 — Example of arrangement for measuring the speed of translational movements



Key

1 rotating device
2 rotary transducer
3 flexible metal angle fixed to non-moving part
4 contact ring

Figure 3 — Example of arrangement for measuring the speed of rotational movements

A special support may be used to effect a mechanical contact between the transducer and the device positioning the work piece. For greater accuracy of measurement, this is to fulfil the following requirements:

a) it shall keep the transducer firmly in place with minimum vibration, e.g. on the working table supporting structure. In some cases, multi-axial support of the transducer can be necessary;

b) it shall allow for a certain yield in the contact between friction wheel and contact surface, e.g. by means of a resilient metal angle (see Figure 2). Any slip occurring is at once evident in the measurement and can be compensated for by slightly increasing the pressure application.

Rotary transducers may also be used for speed measurements. Relevant information can be obtained from the manufacturer of the transducer.

In the case of rotational movements, measurements shall be made at the maximum and minimum number of revolutions corresponding to the maximum and minimum rotational speed of the device and shall be calculated as follows:

$$n_{\text{max}} = \frac{v_{\text{smax}}}{\pi \cdot D_{\text{min}}}$$

$$n_{\text{min}} = \frac{v_{\text{smin}}}{\pi \cdot D_{\text{max}}}$$

6.5.2 Short-term speed stability

The speed shall be measured in all relevant directions applying the parameters:

$v_{\text{prog,max}}$ with m_{Nmax} and $m_{\text{N}} = 0$

0,1 $v_{\text{prog,max}}$ with m_{Nmax} and $m_{\text{N}} = 0$

The positive and negative deviations of the speed signal, $\Delta U'_{\text{v}}$, from its mean value, U'_{v}, shall be measured using an oscilloscope.

The maximum short-term constancy shall be calculated, as a percentage, from the maximum deviation, $\Delta U'_{\text{v max}}$, as follows:

$$\frac{\Delta U'_{\text{v max}}}{U'_{\text{v}}} \cdot 100$$

6.5.3 Repeatability

The motion devices shall be set on v_{prog} applying half of the load and shall be switched on and off 5 times without changes. The speed values shall be measured. The procedure shall be repeated applying 0,1 v_{prog}.

The devices positioning shall be switched on and the speed signal, U''_{v}, obtained shall be measured. The positioning devices shall subsequently be switched off and on and the corresponding speed signal, U''_{v}, measured. The repeatability limits shall be calculated, as a percentage, from the maximum deviation, $\Delta U''_{\text{v max}}$, from the initial value of U''_{v} as follows:

$$\frac{\Delta U''_{\text{v max}}}{U''_{\text{v}}} \cdot 100$$

6.5.4 Evaluation

The measured values of short term speed stability and repeatability shall be assessed by comparing them with the limit deviations specified in Table 2.

6.6 Working gas: testing and instrumentation

6.6.1 Testing procedure

The testing shall be in accordance with EN ISO 15616-3.

6.6.2 Testing of instruments for gas flow and gas pressure

The maximum and minimum working gas flow rates and stability of the gas supply shall be specified for the application being used:

— laser welding gas flow, in l/min;

— laser cutting gas pressure, in MPa.

The accompanying limits are listed in Table 2.

Bibliography

EN 60825-1, *Safety of laser products — Part 1: Equipment classification, requirements and user's guide (IEC 60825-1:1993).*

EN 60825-2, *Safety of laser products — Part 2: Safety of optical fibre communication systems (IEC 60825-2:2000).*

EN 60825-4, *Safety of laser products — Part 4: Laser guards (IEC 60825-4:1997).*

ISO 11553, *Safety of machinery — Laser processing machines — Safety requirements.*

ISO 13694, *Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam power [energy] density distribution.*

ICS 25.160.30
Price based on 13 pages