
**Lasers and laser-related equipment —
Laser materials-processing machines —
Performance specifications and
benchmarks for cutting of metals**

*Lasers et équipements associés aux lasers — Machines à laser pour travail
des matériaux — Spécifications de performances et bancs d'essai de
découpage de métaux*



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X.400 c=ch; a=400net; p=iso; o=isocs; s=central

Printed 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.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances, a technical committee may propose the publication of a Technical Report of one of the following types:

- Type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- Type 2, when the subject is still under technical development or where, for any other reason, there is the future, but not immediate, possibility of an agreement on an International Standard;
- Type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of Types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of Type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 11552, which is a Technical Report of Type 2, has been prepared by Technical Committee ISO/TC 172, *Optics and optical Instruments*, Subcommittee SC 9 *Electro-optical systems*, in collaboration with the European Committee for Standardization CEN/TC123 *Lasers and laser related equipment*.

This document is being issued in the Technical Report (Type 2) series of publications (according to subclause G.3.2.2 of part 1 of the ISO/IEC Directives) as a "prospective standard for provisional application" in the field of laser materials processing, because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the ISO Central Secretariat.

A review of this Technical Report (Type 2) will be carried out not later than three years after its publication, with the options of extension for another three years; conversion into an International Standard; or withdrawal.

Annexes A, B, C and D of this Technical Report are for information only.

Introduction

The objective of this Technical Report is to:

- a) increase user awareness of the design and operational parameters which affect the performance of laser cutting machines;
- b) provide a means by which changes in laser performance over a period of time may be detected and the effectiveness of rectification procedures assessed;
- c) provide a quality assurance tool for use in conjunction with ISO 9000.

Because of the enormous variety of materials cut by lasers, and the wide variation of quality requirements to meet the needs of end users, this Technical Report does not lay down specific tests and quality levels. Instead, guidelines are provided to enable the user to define suitable tests. This Technical Report leaves the design of test pieces to the user. However, an informative Annex (Annex C) describes suitable one-, two- and three-dimensional test pieces. Evaluation procedures are based on ISO 9013.

By following these guidelines, it should be possible to provide a single sheet Quality Assurance record card for routine workshop use on production runs. A sample card is illustrated in Annex B.

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Lasers and laser-related equipment — Laser materials-processing machines — Performance specifications and benchmarks for cutting of metals

1 Scope

This Technical Report provides a comprehensive set of measurements, measurement techniques, tools and common terminology to characterize the performance attributes of laser cutting machines applied to the cutting of metals.

The measurement techniques and tools can also be used for recording the characteristics of laser cutting machines and/or tracking the performance of the laser cutting machine over a period of time.

This Technical Report is applicable to both general-purpose and dedicated laser machines.

This report contains no absolute performance criteria nor requirements. This report is therefore not applicable to competitive comparison between one manufacturer's laser machines and another's.

2 Normative references

The following standards contain provisions which, through reference in the text, constitute provisions of this Technical Report. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of the IEC and ISO maintain registers of currently valid International Standards.

ISO 9013:1992	<i>Welding and allied processes — Quality classification and dimensional tolerances of thermally cut (oxygen/fuel gas flame) surfaces.</i>
ISO 11145:1994	<i>Optics and optical instruments — Lasers and laser-related equipment — Vocabulary and symbols.</i>
ISO 11146:—1)	<i>Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam parameters: Beam widths, divergence angle and beam propagation factor.</i>

3 Definitions

For the purposes of this Technical Report, the definitions given in ISO 11145 and ISO 11146 and the following definitions apply.

3.1 drag

angular deviation, behind the direction of cut, of striations visible on the cut surface from the direction of incidence of the laser beam

1) To be published.

3.2**dross**

unwanted solidified material, including resolidified metal droplets at the beam exit surface of the cut

3.3**full cut**

cut performed over the whole length of the specimen

3.4**heat-affected-zone width**

maximum distance, measured normal to the cut edge, between the cut and points where changes in characteristics by the heat of cutting can be noted

NOTE The heat-affected-zone width is expressed in millimetres or micrometres.

3.5**interrupted cut**

cut performed along only a part of the length of the specimen

3.6**kerf width**

width of the cut as measured between sound metal on either side of the point of entry of the laser beam into the workpiece.

NOTE The kerf width is expressed in millimetres.

3.7**oxidation level**

maximum thickness of resolidified oxidized metal at the cut edge

NOTE The oxidation level is expressed in micrometres.

3.8**profile**

locus of a cut, measured in one, two or three dimensions, as viewed along the laser beam direction

NOTE Profile accuracy is a measure of the deviation between the desired and the attained profiles and includes systematic and random variations.

3.9**recast level**

maximum thickness of resolidified metal forming a uniform surface or film at the cut edge, measured normal to the cut surface

NOTE The recast level is expressed in micrometres.

4 Machine and process parameters**4.1 General**

The performance of laser cutting is dependent upon a large number of parameters. This Technical Report provides a framework and consistent language for these parameters, such that measurements of cutting performance are comparative, both between systems and/or on the same system over time. Obviously, parameters are different for various types or brands of laser devices.

Many of the parameters (such as cavity geometry or gas flow) used to characterize a given device or system are fixed, by design or by factory setting. These are termed "system-invariable" in this Technical Report. Other parameters, such as electrical current adjustment or optical characteristics, can be set for a given function by an operator. These parameters are referred to as "variable" or "controllable" parameters. Within these major groupings or parameter types, there are those which must be held consistent from test to test, those which should be measured each test (including those which might be measured, but held proprietary by the use of code or other

means), and those which, though they might be varied or not, make no difference to the consistency of result for this Technical Report. Table 1 provides a category to each type of parameter applicable to establishing a "benchmark" test protocol for laser cutting (see Annex A):

Table 1 — Categorization of system parameters

Category	Description
0	Parameters which cannot be varied (system-invariable)
1	Parameters to be kept constant at a known value at each test
2	Parameters to be logged at each test
3	Parameters which are unknown or proprietary (confidential) but will be kept constant at each test as far as possible
4	Parameters which are not controllable within the scope of this Technical Report
5	Parameters which are not pertinent to achieving benchmark results in this case

Annex A contains a listing of laser system parameters applicable to benchmark controlled testing. Each parameter is listed with its possible acceptable categories (see Table 1). For example: "Maximum pulse repetition rate (Hz)" may be classed as a "system invariable", a "parameter to be logged at each test" or it may be irrelevant to the test (e.g. the laser will only operate continuous wave).

Although some 150 parameters are listed in Annex A, it is not envisaged that each of these be evaluated individually. The list should, however, be reviewed, and the classification and/or value adopted for each parameter noted, whenever a new test is being established.

The format in Annex B provides but one example of the type of checklist which may be constructed to use this Technical Report. Checklists need not reproduce Annex B, but shall be constructed as appropriate to laser style, use etc. Each user of this Technical Report shall provide his own protocol and checklist which gives the individual operator guidance on which parameters are required to be adjusted, held constant, and/or tabulated for each respective test. The user may perform this by resolving those parameters from the listing of Annex A which are appropriate to his laser system or installation.

First, items in category 4 or 5 may be eliminated from the list. Secondly, items in category 0 or 1 should be identified and listed; test check sheets need refer only to a code number allocated to a particular combination of categories 0 and 1. Each check sheet should then contain a list of codes for category 3 parameters, and a list of logged values for category 2 parameters. The sheet should also contain a code to identify the combination of parameters classed as 0 or 1, unless this combination is invariable. There should be a series title to identify the overall test (see 4.2 below and Annex B).

4.2 Specification of benchmark test

4.2.1 General

A benchmark test specification stipulates for each parameter allocated to category 0, 1, 2 or 3: either

- a) a value, if the parameter is allocated to 0, 1 or 2, or
- b) an identifier code, if the parameter is allocated to category 3.

Parameters allocated to category 4 or 5 need not be recorded.

4.2.2 Benchmark test for one-dimensional cutting

4.2.2.1 Specification of sample

The samples shall be specified by the user, provided they are of uniform thickness, at least 100 mm long, and meet the requirements of 4.2.2.2.

4.2.2.2 Cutting specification

One full cut and one interrupted cut shall be carried out. The interrupted cut shall be $55 \text{ mm} \pm 5 \text{ mm}$ long. The cuts shall be performed at a distance of at least ten times the material thickness from the edge of the sample.

4.2.3 Benchmark test for two-dimensional cutting

4.2.3.1 Specification of sample

Samples may be designed by the user to suit local requirements. Suitable test samples are defined in Annex C, in which case samples should be of uniform thickness, flat, and of the dimensions shown. Figure C.1 shows an example of a test cut. The size of the test sample can be increased, if required, but the dimensions should remain generally in the proportions indicated.

For repeating patterns, the radii of circles and the base dimension of tooth patterns should be in approximate geometrical progression.

4.2.3.2 Cutting specification for materials up to 20 mm thick

Figure C.2 shows a suggested cut for thicker materials. The size of the test sample may be increased if required, but the dimensions should remain generally in the proportions indicated.

Figure C.3 shows an alternative test cut incorporating smaller detail. The size of the test sample is adjusted in proportion to the material thickness.

4.2.3.3 Test locations

Three samples should be cut in three different locations to test consistency over the machine's specified cutting area.

4.2.4 Benchmark test for three-dimensional cutting

4.2.4.1 Specification of sample

Two samples are specified:

- a) a curved sample with a radius of curvature not greater than 1 m. If samples are tubular sections, then tests shall be carried out with different orientations of the tube axis. Details of material, thickness and radius of curvature shall be determined by the user;
- b) a hollow cube or spaceframe with five flat faces. Material and thickness shall be determined by the user.

4.2.4.2 Cutting specification and test positions

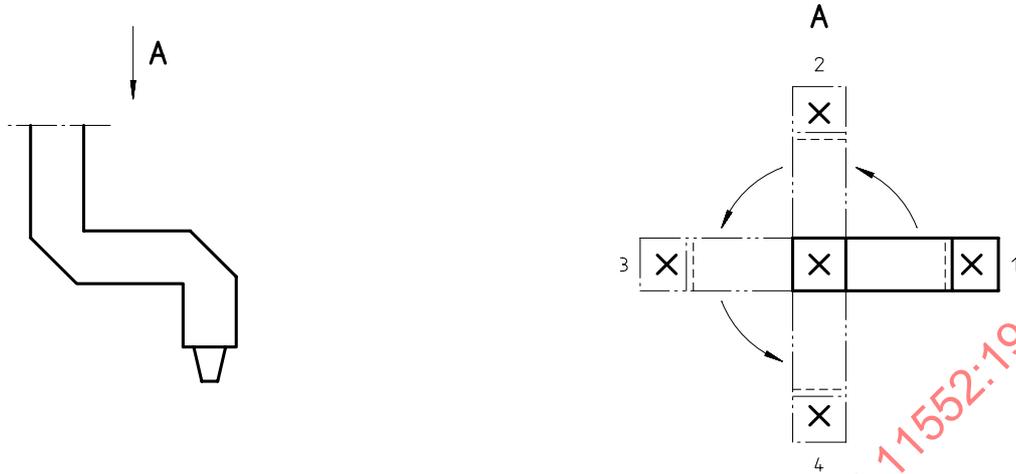
4.2.4.2.1 Curved sample

The cut should be performed in at least three places chosen to test consistency over the full cutting area.

4.2.4.2.2 Hollow cube

- a) Four cuts shall be performed on the top face of the cube, one for each position of the off-set wrist shown in Figure 1.
- b) Two cuts shall be performed on each of the four vertical faces of the cube, one for each of the positions shown in Figure 2.

Dimensions in millimetres



a) Side view of off-set wrist

b) Top view showing the four positions, gun pointing downwards.

Figure 1 — The four positions of the offset wrist to be employed when cutting the cube top face

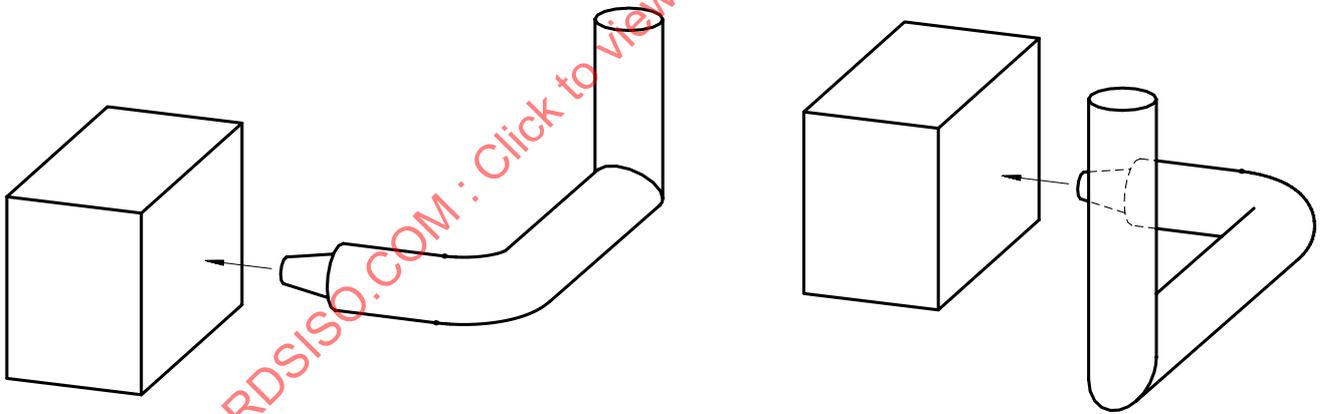


Figure 2 — The two positions of the offset wrist for cuts on the vertical faces

5 Evaluation

5.1 General

The evaluation of cut quality is a critical component of this Technical Report. As far as possible this document has adopted the cut evaluation procedure from ISO 9013. Evaluation may be carried out by the user without recourse to a test house. The following characteristics are considered:

- a) Quantitative evaluations
 - squareness or inclination, u (in millimetres);
 - roughness, R_z (in micrometres).

b) Qualitative evaluations

- drag;
- top edge rounding;
- profile accuracy;
- kerf width;
- dross;
- heat-affected-zone width;
- oxidation level;
- recast level;
- cracking;
- colouration.

5.2 Quantitative evaluation — Classification

The performance of the machine for squareness and roughness of cut is assigned a quality class as shown in Table 2.

Table 2 — Classification for squareness and roughness of cut

Class	Description
0	Stringent
I	Intermediate
II	Moderate
N	Not classified

These classes are assigned by comparing the measurements with the class zones shown in Figure 3. At present, laser cutting of metals is not normally possible beyond 40 mm thickness. Values given in Figure 3 beyond 40 mm thickness are reference values only.

Quantitative evaluation of drag and top edge roundness can be implemented by the user if desired. No further guidelines are provided in this Technical Report.

5.3 Measurements

5.3.1 Squareness or inclination, u

The squareness or inclination, u , which is defined as the greatest perpendicular distance, expressed in millimetres, between the actual surface and the intended surface (see Figure 4), should be measured.

Allowable values of u for any given quality class of cut are a function of the thickness of the material cut.

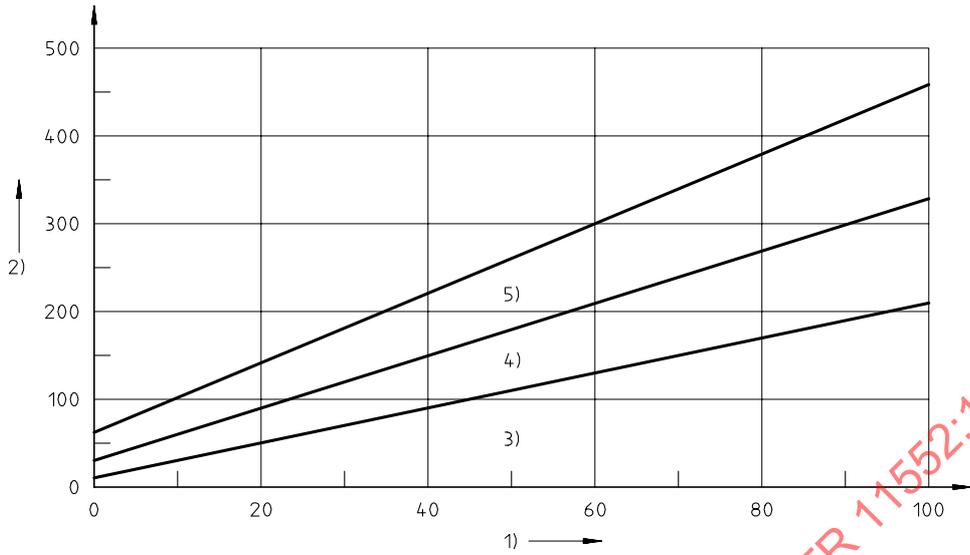
NOTE This definition is used to align with ISO 9013.

5.3.2 Roughness, R_z

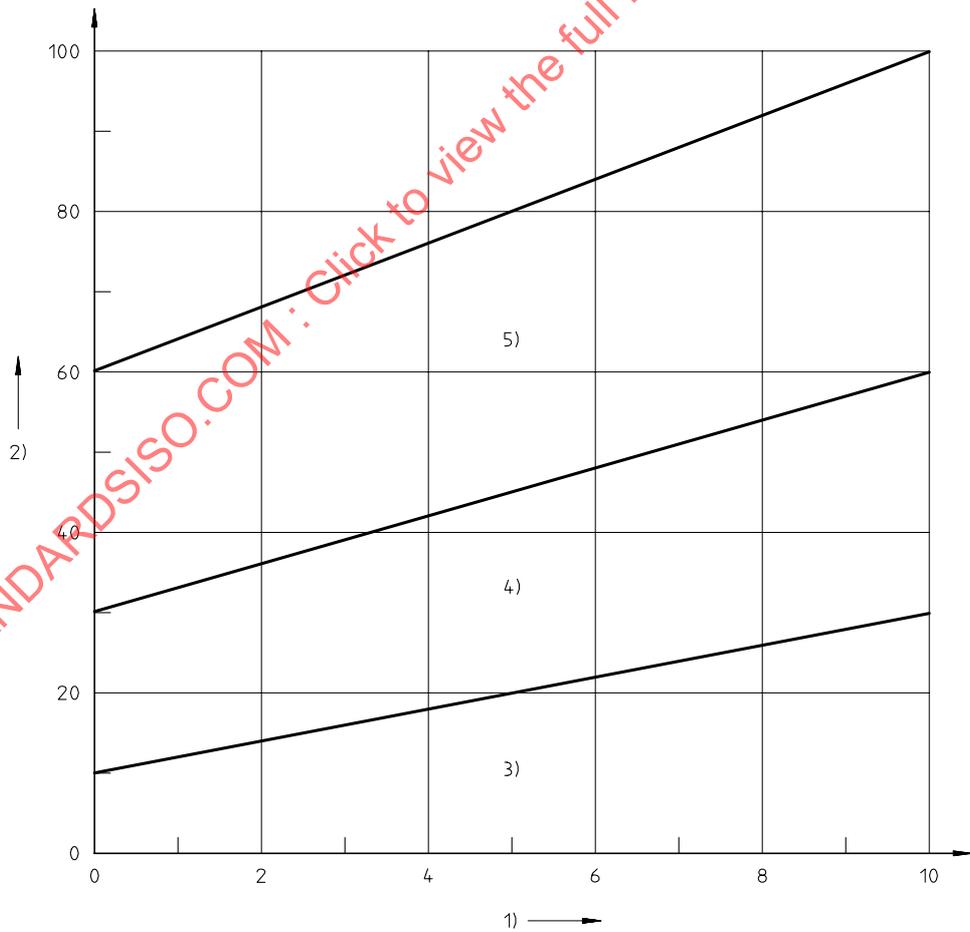
Each roughness measurement is carried out over a 15-mm length of cut. Peak and trough heights are determined along a line of the cut and the results examined in 3-mm steps. The distance between the highest peak and the lowest valley is chosen for each 3-mm section to yield roughness values z_1 to z_5 . R_z , the roughness, is the average of the values obtained for z . Hence $R_z = (z_1 + z_2 + \dots + z_5)/5$.

Allowable values of R_z for any given quality class of cut are a function of the thickness of the material cut.

NOTE This definition is used to align with ISO 9013. Other definitions are taken from ISO 468 and ISO 4287-1.

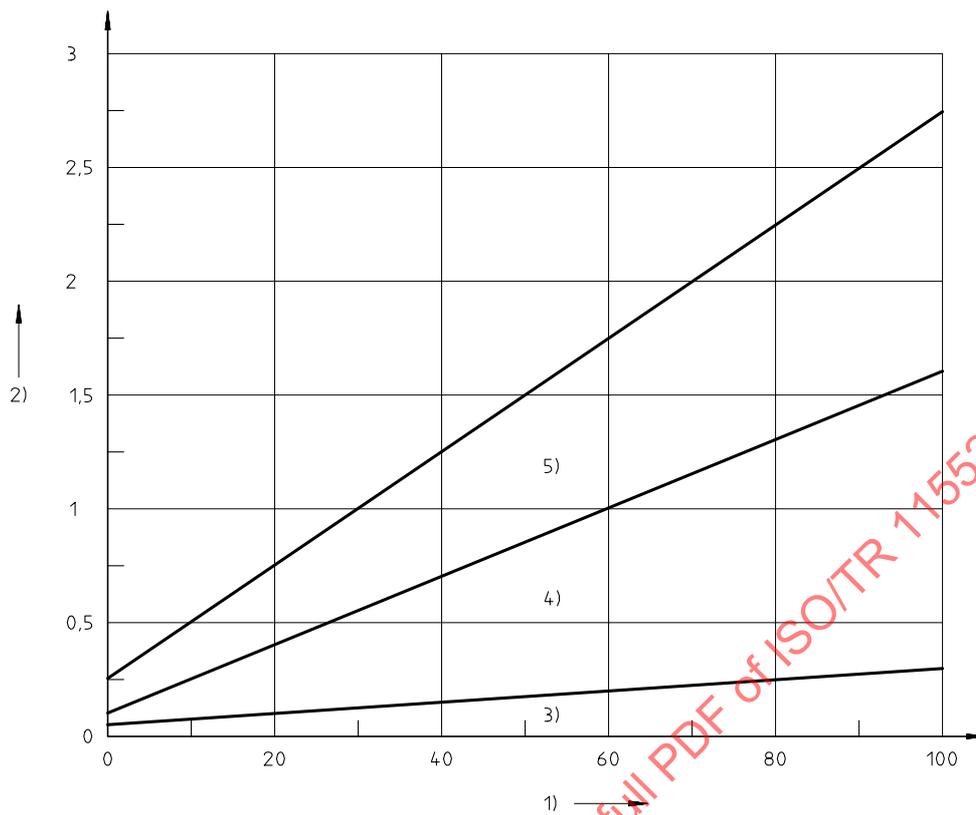


a) Roughness Q, 0 mm to 100 mm



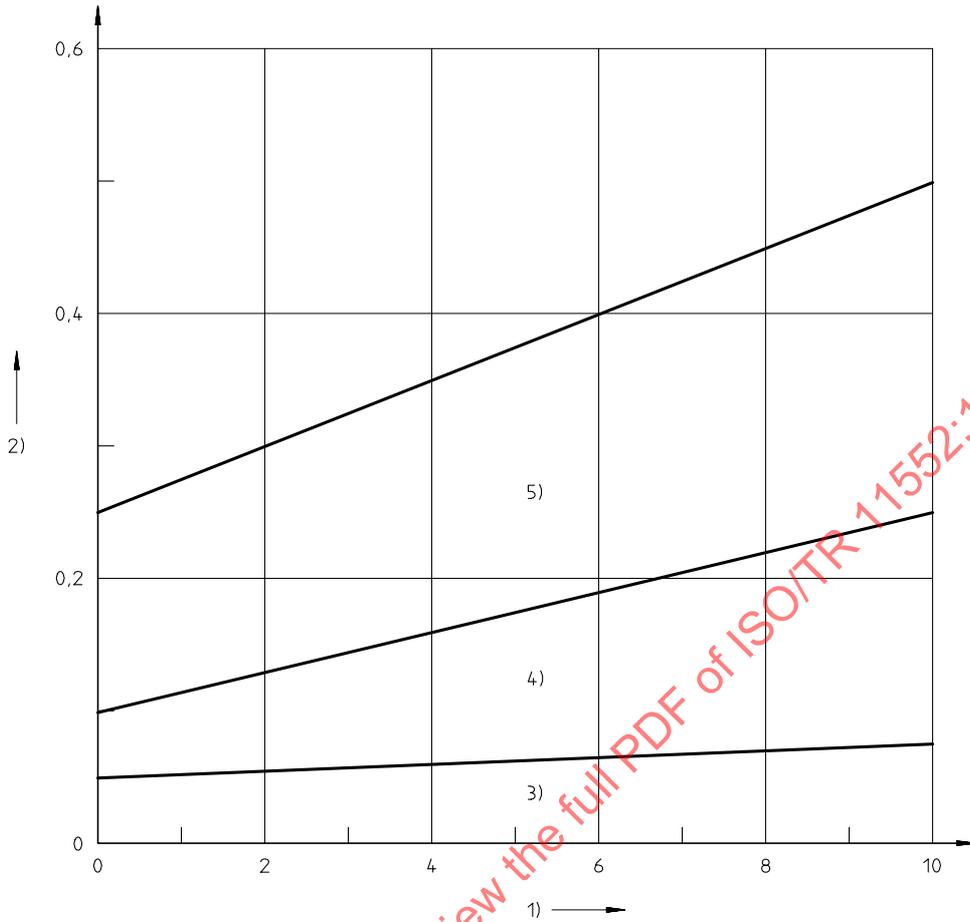
b) Roughness Q, 0 mm to 10 mm

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c) Squareness u , 0 mm to 100 mm

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d) Squareness u , 0 mm to 10 mm

Key

- | | |
|------------------------------------|-------------|
| 1) Thickness, mm | 4) Class I |
| 2) Roughness R_a , μm | 5) Class II |
| 3) Class 0 | |

Figure 3 — Laser cut quality

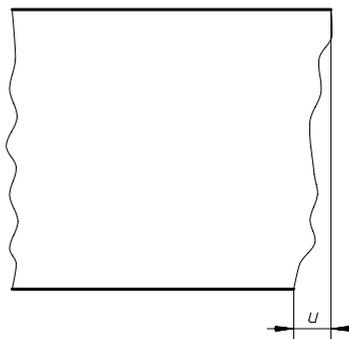


Figure 4 — Squareness and inclination tolerance

5.3.3 Measurement points

5.3.3.1 General

The number and position of measurement points depend on the size and shape of the workpiece, and in some cases on its intended use. 5.3.3.2 gives minimum recommendations for evaluation purposes.

5.3.3.2 Number of measuring faces

- a) For quality class 0 or I, all faces shall be measured.
- b) For quality class II, not less than half of the cut faces shall be measured.
- c) Measurements should be designed to take account of the fact that cut quality, and especially squareness, can be dependent on direction of cut.

5.3.3.3 Number of individual measurements

- a) For determining overall roughness quality (Q_z), one R_z measurement is required on each cut face of the part.
- b) for determining overall squareness quality (u_q) of the cut face, three u measurements are required on each side of the part.

5.3.3.4 Measuring position

For cuts less than 2 mm thick, roughness should be measured at the midpoint. For cuts more than 2 mm thick, roughness should be measured at a distance of two-thirds the workpiece thickness, measured from the upper surface.

5.4 Assigning a class to the cut

- a) Measurements of R_z (see 5.3.2) are used to calculate an overall "roughness quality":

Roughness measurements R_z for any one side are averaged to give a value R_s for the side.

The roughness quality Q_z is then given by:

$$Q_z = \Sigma(R_s)/N \tag{1}$$

where N is the number of sides.

- b) Similarly, the "squareness quality" is given by:

$$u_q = \Sigma(u_s)/N \tag{2}$$

- c) Values of Q_z and u_q falling into quality classes 0, I, II and N are shown in Figure 3. A cut is assigned the class corresponding to the worst of the two values obtained.

The roughness and squareness qualities for each class of cut can be expressed algebraically as given in table 3.

Table 3 — Algebraic expressions for roughness and and squareness quality factors

Quality class	Q_z μm	u_q mm
0	$\leq 10 + 0,002a$	$\leq 0,05 + 0,0025a$
I	$\leq 30 + 0,003a$	$\leq 0,1 + 0,015a$
II	$\leq 60 + 0,004a$	$\leq 0,25 + 0,025a$
N	$> 60 + 0,004a$	$> 0,25 + 0,025a$

NOTE a is the thickness of material, in the units stated

5.5 Qualitative evaluation

5.5.1 General

A number of the properties listed in 5.1 b) for qualitative assessment can be readily measured. However, their importance in assessing cut quality depends on the application of the end product. For this reason they are listed here with comments, but no quantitative relationship to cut quality is given. For benchmark purposes, comparative assessments may be made and reviewed in the light of the user's application, but care must be taken to control the parameters listed in Annex A if meaningful results are to be obtained.

5.5.2 Drag and top edge rounding

Methods of measuring these parameters are outlined in ISO 9013. They are regarded as key qualitative factors.

5.5.3 Profile accuracy

The recommended test profile and the various dimensional tests have been designed to provide an overall assessment of the cutting capability of the machine. In many cases the performance will be dominated by the quality of the cutting table.

Comparative tests may be defined by the user to meet individual needs but should, wherever possible, be carried out with the same cutting table.

5.5.4 Dross and oxidation level

ISO 9013 specifically discounts these parameters when assessing cut quality. Users with needs for a good performance level should create their own criteria. Comparative tests can often be carried out using colour photographs.

5.5.5 Kerf width, recast level, colouration and cracking

These can all be assessed by the use of suitable colour photographs of components or suitable metallographic section. A suitable calibration scale should be included in each picture.

5.5.6 Heat-affected-zone width

For strict assessment this will normally require the attention of a metallurgy laboratory.

For many purposes this will be irrelevant and surface discolouration can give sufficient indication for comparative purposes.

Annex A (informative)

Table of parameters to be considered

NOTE Acceptable categories are defined in table 1.

A Test to be performed

The test may be a

A.1 Standard test (1-, 2- or 3-dimensional)

or a

A.2 Routine manufacture

Serial No.		Acceptable categories			
1	Customer	2	5		
2	Order number	2	5		
3	Customer part number	2	5		
4	Drawing number	2	5		
5	Shop order number	2	5		
	B Operator's name	2			
	C Date	2			
	D Details of workpiece				
6	Name of material	2			
7	Standard classification of material	1	2		
8	Material composition	1	2	3	
9	Material production route (Batch No.)	1	2	3	
10	Thickness (mm)	2			
11	Hardness (HV)	2			
12	Tensile and yield strengths (MPa)	2			
13	Reduction of area and elongation (%)	2			
14	Surface preparation	1	2	3	4
15	Surface coating thickness (µm)	1	2	3	4
16	Details of surface coating	1	2	3	
17	Material treatment	1	2	3	
	E Laser source details				
18	Designation	0	5		
19	Model, manufacturer and serial number	0			
20	Date of installation	0	5		
21	Laser type	0			

F.1 Details required for a CO₂ laser

22	Type of flow and cavity	0			
23	Type of excitation	0			
24	Beam mode	0	1	2	3
25	Maximum and minimum beam waist value (mm)	1	2	3	
26	Beam divergence (mrad)	0	1	2	3
27	Maximum output power (W)	0	2		
28	Beam polarization (type)	0	1	2	3
29	Maximum pulse repetition rate (p/s)	0	2	5	
30	Minimum pulse duration (s)	0	2	5	
31	Maximum pulse energy (J)	0	2	5	
32	Beam propagation factor	0	2	3	4
33	Pointing stability (a) Short term (see ISO11145:1994)	0	3	4	
	(b) Long term (see ISO11145:1994)	0	3	4	

F.2 Details required for Nd:YAG laser

34	Rod diameter (mm)	0	2		
35	Slab size (mm)				
36	Resonator output beam diameter (mm)	0	2		
37	Beam divergence (mrad)	0	1	2	3 4
38	Maximum magnification	0	2		
39	Maximum pulse repetition rate (p/s)	0	2		
40	Maximum pulse duration (s)	0	2		
41	Maximum pulse energy (J)	0	2	3	
42	Maximum peak power (W)	0	2	3	
43	Maximum output power (W)	0	2		
44	Output power stability (%)	0	2	3	
45	Power ramping capability	0	2	5	
46	Pulse shaping capability	0	2	5	
47	Minimum beam diameter for fibre (mm)	0	2	5	

G Beam delivery system

48	Designation	0			
49	Model	0			
50	Manufacturer	0			
51	Serial number	0			
52	Installation date	0	5		
53	Beam delivery system description (schematic)	0			
54	Maximum distance source-focusing system (mm)	0	1	2	
55	Minimum distance source-focusing system (mm)	0	1	2	
56	Number of reflecting elements	0	2		
57	Number of transmitting elements	0	2		
58	Beam splitting	0	2	5	
59	Beam divergence correction	0	1	2	3 5
60	Polarizer device	0	1	2	3 5
	Flying optic system				
61	Number of controlled axes	0	1	2	
62	Travel limits (mm)	0	2		
63	Positioning accuracy (μm)	0	2		
64	Positioning repeatability (μm)	0	1	2	
65	Speed limits (m/s)	0	1	2	
66	Speed accuracy (%)	0	1	2	
67	Acceleration (m/s ²)	0	1	2	
68	Final beam diameter (mm)	0	1	2	
69	Final power density distribution	1	2	3	

70	Power loss in delivery system (%)	0	1	3	4
71	Power density measurement procedure	1	2	5	

H Nd:YAG and other lasers with fibre

72	Number of optical fibres	0	2	5	
73	Type of optical fibres	0	2	5	
74	Core diameter of optical fibres (mm)	0	2	5	
75	Numerical aperture of optical fibres				
76	Length of optical fibres (m)	0	2	5	
77	Minimum bending radius (mm)	0	2	5	
78	Maximum delivered average power (W)	0	1	2	
79	Maximum peak power delivered (W)	0	1	2	3 5
80	Power loss in fibre delivering (%)	0	2	3	5

I Beam-shaping focusing system

81	Designation	0			
82	Model	0			
83	Manufacturer	0			
84	Serial No.	0			
85	Installation date	0	5		
86	Focusing system description (schematic)	0			
87	Number of reflective elements	0	1	2	3
88	Number of transmissive elements	0	1	2	3
89	Beam splitting	0	2	5	
90	Focusing system aperture (mm)	0	1	2	
91	Focal length (mm)	0	1	2	
92	Depth of field (mm)	0	1	2	
93	Power loss in the focusing system (%)	0	1	3	
94	Focal point-focusing system distance (mm)	0	1	2	
95	Beam focus diameter				
96	Rayleigh length				

J Workpiece handling system

97	Designation	0			
98	Model	0			
99	Manufacturer	0			
100	Serial number	0			
101	Installation date	0	5		
102	Number of controlled axes	0	1	2	
103	Travel limits (m)	0	2		
104	Positioning accuracy (mm)	0	2		
105	Positioning repeatability (%)	0	1	2	
106	Speed limits (m/s)	0	1	2	
107	Speed accuracy (%)	0	1	2	
108	Acceleration (m/s ²)	0	1	2	

K Cutting data

109	Cutting beam direction (horizontal, vertical)	0	1	2	
110	Cutting direction	0	2		
111	Beam polarization at the workpiece (type)	0	1	2	
112	Polarization direction at the workpiece	0	1	2	5
113	Beam-workpiece angle (degrees)	1	2		
114	Beam-workpiece side angle (degrees)	1	2		
115	Beam focal position (mm from workpiece top surface)	1	2		

116	Cutting speed (m/min)	1	2		
117	Average beam power (W)	1	2		
118	Cutting cycle - full power (description)	1	2		
119	Ramp up time (s)	1	2	5	
120	Ramp down time (s)	1	2	5	
121	Piercing procedure	1	2	5	
122	Time to pierce				
	Operational mode				
123	Pulse repetition rate (Hz)	1	2	5	
124	Pulse duration (s)	1	2	3	5
125	Pulse energy (J)	1	2	3	5
126	Pulse rise (s)	1	2	3	5
127	Pulse fall (s)	1	2	3	5
128	Pulse diagram	1	2	5	
129	Beam oscillation (ampl, freq, descr)	1	2	3	5
130	Focal spot diameter (on two directions) (μm)	1	2	3	
131	Power density distribution at focus	1	2	3	4
132	Power density distribution measurement procedure	1	2	5	

L Gas assist system

133	Assist system description (schematic)	0	1	2	
134	Number of assist jets	0	1	2	3
135	Gas and gas mixture composition in the main jet	1	2	3	
136	Gas and gas mixture composition in the auxiliary jet(s)	1	2	3	5
137	Gas pressure in the main gas jet (bar)	1	2	3	
138	Gas pressure in the auxiliary gas jet(s) (bar)	1	2	3	5
139	Nozzle orifice diameter (mm)	0	2	3	
140	Nozzle shape	0	2	3	
141	Nozzle orientation angle (degrees)	0	2	3	
142	Stand-off distance (mm)	0	2		
143	Underside gas or mixture (l/min)	1	2	3	5
144	Underside gas flow (l/min)	1	2	3	5
145	Underside gas pressure (bar)	1	2	3	5

M Ambient conditions

146	Vibration				
147	Temperature ($^{\circ}\text{C}$)				
148	Humidity (%)				
149	Water cooling temperature range ($^{\circ}\text{C}$ to $^{\circ}\text{C}$)				