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Seamless precision steel tubes for engineering machinery hydraulic cylinder

工程机械液压缸用精密无缝钢管

(*English Translation*)

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Foreword

SAC/TC 183 is in charge of this English translation. In case of any doubt about the contents of English translation, the Chinese original shall be considered authoritative.

This document is drafted in accordance with the rules given in the GB/T 1.1—2020 *Directives for standardization—Part 1: Rules for the structure and drafting of standardizing documents.*

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This document was proposed by China Iron and Steel Association.

This document was prepared by SAC/TC 183 (Technical Committee 183 on Steel of Standardization Administration of China).

Seamless precision steel tubes for engineering machinery hydraulic cylinder

1 Scope

This document specifies designation, ordering information, dimensions, shapes, masses, tolerances, technical requirements, test methods, inspection rules, packaging, marking and quality certification of seamless precision steel tubes for engineering machinery hydraulic cylinder.

This document is applicable to seamless cold drawn or cold rolled precision steel tubes (hereinafter referred to as tube) from 80 mm to 500 mm in inside diameter used for engineering machinery hydraulic cylinder.

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.

GB/T 222, *Permissible tolerances for chemical composition of steel products*

GB/T 223.5, *Steel and iron—Determination of acid-soluble silicon and total silicon content —Reduced molybdosilicate spectrophotometric method*

GB/T 223.9, *Iron, steel and alloy—Determination of aluminum content—Chrome azurol S photometric method*

GB/T 223.12, *Methods for chemical analysis of iron, steel and alloy—The sodium carbonate separation-diphenyl photometric method for the determination of chromium content*

GB/T 223.14, *Methods for chemical analysis of iron, steel and alloy—The N-benzoy-N-phenyl - hydroxylamine extration photometric method for the determination of vanadium content*

GB/T 223.23, *Iron, steel and alloy—Determination of nickel content—The dimethylglyoxime spectrophotometric method*

GB/T 223.26，*Iron，steel and alloy—Determination of molybdenum content—The thiocyanate spectrophotometric method*

GB/T 223.37，*Iron，steel and alloy—Determination of nitrogen content—Indophenol blue spectrophotometric method after distillation separation*

GB/T 223.40，*Iron，steel and alloy—Determination of niobium content—The sulphochlorophenol S spectrophotometric method*

GB/T 223.53，*Methods for chemical analysis of iron，steel and alloy—The flame atomic absorption spectrophotometric method for the determination of copper content*

GB/T 223.59，*Iron，steel and alloy—Determination of phosphorus content—Bismuthphosphomolybdate blue spectrophotometric method and antimony phosphomolybdate blue spectrophotometric method*

GB/T 223.63，*Iron，steel and alloy—Determination of manganese content—Sodium（potassium）periodate spectrophotometric method*

GB/T 223.84，*Steel and iron—Determination of titanium content—Diantipyrylmethane spectrophotometric method*

GB/T 223.85，*Iron，steel and alloy—Determination of sulfur content—Infrared absorption method after combustion in an induction furnace*

GB/T 223.86，*Steel and iron—Determination of total carbon content—Infrared absorption method after combustion in an induction furnace*

GB/T 228.1，*Metallic materials—Tensile testing—Part 1：Method of test at room temperature*

GB/T 229，*Metallic materials—Charpy pendulum impact test method*

GB/T 2102，*Acceptance，packaging，marking and quality certification for steel tubular products*

GB/T 2975，*Steel and steel products—Location and preparation of samples and test pieces for mechanical testing*

GB/T 4336，*Carbon and low-alloy steel—Determination of multi-element contents—Spark discharge atomic emission spectrometric method（routine method）*

GB/T 5777，*Automated full peripheral ultrasonic testing of seamless and welded（except submerged arc-welded）steel tubes for the detection of longitudinal and/or transverse imperfections*

GB/T 6394，*Determination of estimating the average grain size of metal*

GB/T 7735，*Automated eddy current testing of seamless and welded（except submerged arc-welded）steel tubes for the detection of imperfections*

GB/T 12606，*Automated full peripheral flux leakage testing of seamless and welded（except submerged arc-welded）ferromagnetic steel tubes for the detection of longitudinal and/or transverse imperfections*

GB/T 17395，*Dimensions，shapes，masses，and tolerances of seamless steel tubes*

GB/T 20066，*Steel and iron—Sampling and preparation of samples for the determination of chemical composition*

GB/T 20123，*Steel and iron—Determination of total carbon and sulfur content—Infrared absorption method after combustion in an induction furnace（routine method）*

GB/T 20124，*Steel and iron—Determination of nitrogen content—Thermal conductimetric method after fusion in a current of inert gas（Routine method）*

GB/T 20125，*Low-alloy steel—Determination of multi-element contents—Inductively coupled plasma atomic emission spectrometric method*

GB/T 30062，*Terminology of steel pipes and tubes*

3 Terms and definitions

For the purposes of this document，the terms and definitions given in GB/T 30062 apply.

4 Designation

The steel designation consists of GJ，which means engineering machinery in Chinese，the specified minimum upper yield strength（expressed in megapascals）in stress relieved condition and quality class symbols（B，C，D，E）.

EXAMPLE GJ550D，where

GJ is the first letters of Chinese Pinyin of “Gong” and “Ji”；

550 is the specified minimum upper yield strength in stress relieved condition，550 MPa；

D is quality class symbol，D.

5 Ordering information

The purchase contract or order according to this document shall include but not limited to the fol-

lowing information：

a） this document number；

b） name of product；

c） steel grade；

d） dimensions；

e） ordering quantity（total mass or total length）；

f） delivery conditions；

g） special requirements.

6 Dimensions，shapes，masses and tolerances

6.1 Dimensions

6.1.1 The tubes are usually delivered by nominal inside diameter（*d*）and nominal wall thickness（*S*）. If outside diameter（*D*）and inside diameter or outside diameter and nominal wall thickness required by the purchaser，it shall be so stated in the contract.

6.1.2 The nominal inside diameter and nominal wall thickness of the tube shall be as specified in Table 1. If agreed between the supplier and the purchaser，tubes with other dimensions not listed in Table 1 may be supplied.

Table 1—Nominal inside diameter，nominal wall thickness and tolerances on inside diameter

Dimensions in millimeters

Inside diameter	Wall thickness																		
	6.0	7.5	8.0	9.0	10	11	12	14	15	17	18	20	22	25	28	30	35	40	45
	Permissible variations in inside diameter																		
80	±0.10	±0.10	±0.10	±0.10	±0.10														
90	±0.10	±0.10	±0.10	±0.10	±0.10														
100	±0.10	±0.10	±0.10	±0.10	±0.10														
110		±0.15	±0.15	±0.15	±0.15	±0.15	±0.15												

Table 1（*continued*）

Dimensions in millimeters

Inside diameter	Wall thickness																		
	6.0	7.5	8.0	9.0	10	11	12	14	15	17	18	20	22	25	28	30	35	40	45
	Permissible variations in inside diameter																		
125		±0.15	±0.15	±0.15	±0.15	±0.15	±0.15												
140			±0.15	±0.15	±0.15	±0.15	±0.15	±0.15	±0.15										
160			±0.15	±0.15	±0.15	±0.15	±0.15	±0.15	±0.15										
180				±0.15	±0.15	±0.15	±0.15	±0.15	±0.15	±0.15									
200				±0.15	±0.15	±0.15	±0.15	±0.15	±0.15	±0.15									
220					±0.15	±0.15	±0.15	±0.15	±0.15	±0.15									
240					±0.20	±0.20	±0.20	±0.20	±0.20	±0.20									
250					±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20					
260						±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20					
280						±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20	±0.20					
290							±0.20	±0.20	±0.20	±0.20	±0.20	±0.30	±0.20	±0.20	±0.20				
320							±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30				
340								±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30				
360								±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30	±0.30		
380									±0.30	±0.30	±0.30	±0.40	±0.30	±0.30	±0.30	±0.30	±0.30		
400									±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	
450										±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40
500										±0.40	±0.40	±0.20	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40	±0.40

6.1.3 Permissible variations in inside diameter and outside diameter of the tubes in cold worked conditions（+C，+LC）shall be as specified in Table 1 and Table 2. Permissible variations in inside

diameter and outside diameter of the tubes in heat treated conditions（+SR）shall be as specified in Table 3.

Table 2—Tolerances on outside diameter of the tubes in cold worked conditions（+C，+LC）

Outside diameter mm	Wall thickness/ Outside diameter （*S*/*D*）[a]	Permissible variations mm
92 to 214	≥0.05	±0.3
	0.025 to 0.05	±0.4
＞214 to 376	≥0.05	±0.5
	0.025 to 0.05	±0.6
＞376	≥0.05	±0.8
	0.025 to 0.05	±0.9
[a] If the tubes delivered by nominal outside diameter and nominal inside diameter，*S* is the calculated wall thickness（calculated with nominal outside diameter and nominal inside diameter）.		

Table 3—Tolerances on inside diameter and outside diameter of the tubes in heat treated conditions（+SR）

Wall thickness/ Outside diameter （*S*/*D*）[a]	Permissible variations
≥0.05	Required values in Table 1 and Table 2
0.025 to＜0.05	1.2 times required values in Table 1 and Table 2
[a] If the tubes delivered by nominal outside diameter and nominal inside diameter，*S* is the calculated wall thickness.	

6.1.4 If required by the purchaser，agreed between the supplier and the purchaser，and stated in the contract，tubes with the dimensional tolerances not listed in Table 1，Table 2 and Table 3 may be supplied.

6.1.5 If the tubes delivered by nominal inside diameter and nominal wall thickness，permissible variations in wall thickness shall be as specified in Table 4. If agreed between the supplier and the purchaser，tubes with the tolerances on wall thickness not listed in Table 4 may be supplied.

Table 4—Tolerances on wall thickness

Dimensions in millimeters

Nominal wall thickness（*S*）	6.0 to 9.0	＞9.0 to 15	＞15 to 20	＞20
Permissible variations	±7.5%*S*	±6.5%*S*	±5.5%*S*	±5%*S*

6.2 Unevenness in wall thickness

If the tubes delivered by nominal outside diameter and nominal inside diameter，unevenness in wall thickness shall not exceed 12% of the calculated wall thickness.

6.3 Lengths

6.3.1 Random lengths

The random lengths of the tubes shall be from 3 000 mm to 18 000 mm.

6.3.2 Cut-lengths and multiple lengths

6.3.2.1 If required by the purchaser, agreed between the supplier and the purchaser, and stated in the contract, the tubes may be supplied by cut-lengths or multiple lengths.

6.3.2.2 Cut-lengths and multiple lengths shall be in the range of random lengths. Permissible variations in cut-length shall be as follows:

a) tube length not greater than 5 000 mm, $^{+5}_{0}$ mm;

b) tube length greater than 5 000 mm, $^{+10}_{0}$ mm.

6.3.2.3 A cutting allowance shall be reserved for each cutting on the tubes delivered by multiple lengths as follows:

a) outside diameter not greater than 159 mm, 5 mm to 10 mm;

b) outside diameter greater than 159 mm, 10 mm to 15 mm.

6.4 Straightness

6.4.1 Tube shall comply with the requirements of straightness both over any one meter length and of full length. If not required in the contract, straightness class Ⅰ shall apply.

6.4.2 Classes for deviation from straightness over any one meter length shall be as follows:

a) class Ⅰ, not greater than 0.5 mm;

b) class Ⅱ, not greater than 0.3 mm;

c) class Ⅲ, not greater than 0.2 mm.

6.4.3 Classes for deviation from straightness of full length shall be as follows:

a) class Ⅰ, not greater than 0.05% of tube length;

b） class Ⅱ，not greater than 0.03% of tube length；

c） class Ⅲ，not greater than 0.02% of tube length.

6.4.4 If required by the purchaser，agreed between the supplier and the purchaser，and stated in the contract，other requirements of straightness both over any one meter length and of full length may apply.

6.5 End shape

Both tube ends shall be square cut. All burrs at the cut ends shall be removed.

6.6 Out-of-roundness

If the tubes delivered by nominal inside diameter and nominal wall thickness，out-of-roundness of inside diameter shall not exceed 80% of tolerances on inside diameter. The measurement positions for inside diameter shall be as specified in Table 5.

Table 5—Measurement positions for out-of-roundness of inside diameter

Wall thickness/ Outside diameter (S/D)[a]	Distance between measurement position and tube end mm
0.025 to＜0.05	≥30%D，but not less than 35
≥0.05	≥20%D，but not less than 25
[a] D is the calculated outside diameter（calculated with nominal inside diameter and nominal wall thickness）.	

6.7 Masses

6.7.1 The tubes may be delivered by either practical mass or theoretical mass. The theoretical mass per meter of the tube shall be calculated in accordance with GB/T 17395（density of steel is 7.85 kg/dm^3）.

6.7.2 When the tubes delivered by nominal inside diameter and nominal wall thickness，the calculated outside diameter shall be used for calculating the theoretical mass；When the tubes delivered by nominal outside diameter and nominal inside diameter，the calculated wall thickness shall be used for calculating the theoretical mass.

7 Technical requirements

7.1 Steel grades and chemical composition

7.1.1 The steel grades and chemical composition（heat analysis）shall comply with the requirements given in Table 6.

Table 6—Steel grades and chemical composition

No.	Grade	Chemical composition, in % by mass[a,b,c,d]												
		C	Si	Mn	V	Als	P	S	Nb	Ti	Mo	Cr	Ni	Cu	N
							Max								
1	GJ450B	⩽ 0.20	⩽ 0.50	⩽ 1.70	—	—	0.035	0.035	—	—	0.10	0.30	0.50	0.20	0.012
2	GJ450C				⩽ 0.15	⩾ 0.010[e]	0.030	0.030	0.07	0.20					
3	GJ450D	⩽ 0.18					0.030	0.025							
4	GJ450E						0.025	0.020							
5	GJ550B	0.12 to 0.20	0.10 to 0.50	1.30 to 1.70	0.05 to 0.15	0.010 to 0.040	0.025	0.020	0.07	0.20	0.10	0.30	0.50	0.20	0.012
6	GJ550D														
7	GJ550E														
8	GJ720D	0.14 to 0.23	0.10 to 0.50	1.30 to 1.70	0.05 to 0.20	0.010 to 0.060	0.025	0.025	—	—	0.10	0.30	0.30	0.25	—
9	GJ850D	0.14 to 0.23	0.10 to 0.50	1.30 to 1.70	0.05 to 0.20	0.010 to 0.060	0.025	0.025	—	—	0.10	0.30	0.30	0.25	—

[a] GJ450C(D,E) shall contain at least one of the grain refining elements such as Al, Nb, V and Ti. If necessary, one or more of grain refining elements may be added into the steel provided that the addition does not exceed the limits of the table, and when combined elements added, $w_{Nb} + w_V + w_{Ti} \leqslant 0.22\%$.

[b] GJ450B(C,D,E): $w_{Mo} + w_{Cr} \leqslant 0.30\%$.

[c] As residual elements in all grades, $w_{Cr} \leqslant 0.30\%$ and $w_{Ni} \leqslant 0.30\%$. If addition of them is necessary, the content of them shall be as specified in the table or agreement between the purchaser and the supplier.

[d] If conformity to the requirements of the nitrogen content in the table ensured by the supplier, nitrogen content analysis may be not needed. If nitrogen-stabilizing elements such as Al, Nb, V or Ti are added to the steel, the nitrogen content shall not be limited, and the content of nitrogen-stabilizing elements shall be noted in the quality certificate.

[e] For total aluminum content, $w_{Alt} \geqslant 0.020\%$.

7.1.2 If product analysis required by the purchaser, it shall be stated in the contract. The permissible variations of the product analysis for the tubes shall comply with the requirements specified in GB/T 222.

7.1.3 If required by the purchaser, agreed between the supplier and the purchaser, and stated in the contract, the tubes of other steel grades may be supplied.

7.2 Manufacturing method

7.2.1 Steel shall be made by electric arc furnace and external refining or oxygen converter and external refining, subsequently vacuum degassing treated. If agreed between the supplier and the purchaser, and stated in the contract, steel may be made by other higher demanded processes. If a certain melting method is required by the purchaser, it shall be specified in the contract.

7.2.2 The tubes shall be manufactured by a seamless process of either cold drawing or cold rolling. If a certain manufacturing method is required by the purchaser, it shall be specified in the contract.

7.3 Delivery conditions

The tubes shall be delivered in one of conditions listed in Table 7.

Table 7—Delivery conditions

No.	Delivery condition	Symbol	Description
1	Cold drawn (rolled) hard	+C	Not heat treated after final cold working
2	Cold drawn (rolled) soft	+LC	Appropriately cold worked after final heat treatment
3	Stress relieved	+SR	Stress relieved after final cold working

7.4 Mechanical properties

7.4.1 Tensile properties

The longitudinal tensile properties of tubes in various delivery conditions shall comply with the requirements specified in Table 8. The tensile properties of tubes of other grades shall be agreed between the supplier and the purchaser.

Table 8—Mechanical properties

No.	Grade	Delivery conditions								Impact test temp. ℃
		+C[a]		+LC[a]		+SR				
		Tensile strength R_m MPa	Percentage elongation after fracture A %	Tensile strength R_m MPa	Percentage elongation after Fracture A %	Tensile strength R_m MPa	Upper yield strength[b] R_{eH} MPa	Percentage elongation after fracture A %	Impact absorbed energy KV_2 J	
		Min								
1	GJ450B	680	8	650	10	600	450	12	15	20
2	GJ450C									0
3	GJ450D									−20
4	GJ450E									−40
5	GJ550B	720	10	680	12	640	550	15	27	20
6	GJ550D									−20
7	GJ550E									−40

Table 8（*continued*）

No.	Grade	Delivery conditions								Impact test temp. ℃
		+C[a]		+LC[a]		+SR				
		Tensile strength R_m MPa	Percentage elongation after fracture A %	Tensile strength R_m MPa	Percentage elongation after Fracture A %	Tensile strength R_m MPa	Upper yield strength[b] R_{eH} MPa	Percentage elongation after fracture A %	Impact absorbed energy KV_2 J	
		Min								
8	GJ720D	—	—	—	—	800	720	15	27	−20
9	GJ850D[c]	—	—	—	—	900	850	15	27	−20

[a] Affected by degree of deformation during cold working, yield strength will nearly be as high as the tensile strength, therefore, the following relational expressions are recommended:

— +C: $R_{eH} \geqslant 0.8R_m$;

— +LC: $R_{eH} \geqslant 0.7R_m$.

[b] If measurement of R_{eH} is impossible, proof strength ($R_{p0.2}$) may be determined instead of R_{eH}.

[c] The properties can be achieved by increasing the degree of cold drawing.

7.4.2 Yield-to-tensile strength ratio

If required by the purchaser, agreed between the supplier and the purchaser, and stated in the contract, yield-to-tensile strength ratio (R_{eH}/R_m or $R_{p0.2}/R_m$) may be calculated for the tubes quenched and high temperature tempered prior to cold drawing (rolling). Permissible range for yield-to-tensile strength ratio shall be determined by agreement between the purchaser and the supplier.

7.4.3 Impact test

Impact test shall be carried out with the longitudinal test pieces taken from the tubes not less than 6.5 mm in wall thickness and in +SR condition. The required values for Charpy V-notch impact absorbed energy of the standard test piece are given in Table 8. If the subsize test piece used, the required value for Charpy V-notch impact absorbed energy of the subsize test piece shall be that specified for a standard test piece multiplied by the reduction factor listed in Table 9. Impact test shall not be required for the tubes whose size is not enough to take the test piece of 10 mm × 5 mm.

Table 9—Absorbed energy reduction factor for subsize test piece

Test piece size	Test piece dimensions (width×thickness) mm	Reduction factor
Standard test piece	10×10	1
Subsize test piece	10×7.5	0.75
Subsize test piece	10×5	0.5

7.4.4 Residual stress

If required by the purchaser, agreed between the supplier and the purchaser, and stated in the contract, residual stress in the tube shall be determined ,the maximum values are shown in Annex A.

7.5 Grain size

If required by the purchaser, agreed between the supplier and the purchaser, and stated in the contract, the actual grain size of the tube shall be No. 5 or finer.

7.6 Non-destructive testing

7.6.1 Non-destructive testing shall be carried out for original tube prior to cold drawing (rolling) using one or more of the following methods:

a) ultrasonic testing according to GB/T 5777, acceptance level is U3;

b) eddy current testing according to GB/T 7735, acceptance level is E3H or E3;

c) flux leakage testing according to GB/T 12606, acceptance level is F3.

7.6.2 If required by the purchaser, agreed between supplier and purchaser, and stated in the contract, non-destructive testing may be carried out for each product tube, the testing method and acceptance lever shall be determined by agreement between the purchaser and the supplier.

7.7 Surface roughness

If tube surface roughness is required by the purchaser, it shall be so stated in the contract. The requirements shall be determined by agreement between the purchaser and the supplier.

7.8 Surface quality

7.8.1 The internal and external surfaces of the tubes shall be smooth and free of cracks, laps, rolling wrinkles, abscission layers and scabs. These defects shall be completely removed, and then the actual dimensions of tube shall comply with the permissible variation requirements.

7.8.2 The adhesion layer of phosphate and lubricant resulted from manufacturing processes on internal and external surfaces of the tube shall be permitted. The oxide film not affecting visual inspection on internal and external surfaces of the tube in heat treated condition shall be permitted.

8 Test methods

8.1 Sampling for chemical analysis of the tubes shall conform to the requirements of GB/T 20066. Chemical analysis is usually conducted according to GB/T 4336，GB/T 20123，GB/T 20124，GB/T 20125 or other routine methods. In case of arbitration，the analysis shall be conducted according to the provisions of GB/T 223.5，GB/T 223.9，GB/T 223.12，GB/T 223.14，GB/T 223.23，GB/T 223.26，GB/T 223.37，GB/T 223.40，GB/T 223.53，GB/T 223.59，GB/T 223.63，GB/T 223.84，GB/T 223.85，GB/T 223.86 and GB/T 20125.

8.2 The dimensions and shapes of each tube shall be measured using tools which satisfy the requirements for accuracy.

8.3 The internal and external surfaces of each tube shall be visually inspected under sufficient illumination or inspected with endoscope .

8.4 Two tubes per each test unit shall be checked for surface roughness at 3 positions with a Roughness Tester.

8.5 Methods of sampling and testing for other inspections or tests shall comply with the requirements specified in Table 10.

Table 10—Inspection or test，sampling quantity，sampling method and testing method

No.	Inspection or test	Sampling quantity	Sampling method	Testing method
1	Chemical composition	One per heat	GB/T 20066	8.1
2	Tensile test	Two from two tubes per test unit	GB/T 2975	GB/T 228.1
3	Impact test	Two groups of 3 test pieces from two tubes per test unit	GB/T 2975	GB/T 229
4	Residual stress	One from one tube per test unit	Annex A	Annex A
5	Grain size	Two from two tubes per test unit	GB/T 6394	GB/T 6394
6	Ultrasonic testing	Each tube	—	GB/T 5777
7	Eddy current testing	Each tube	—	GB/T 7735
8	flux leakage testing	Each tube	—	GB/T 12606

9 Inspection rules

9.1 Inspection and acceptance

Inspection and acceptance for the tubes shall be carried out by the supplier’s quality and technical supervision department.

9.2 Test unit

The tubes shall be inspected and accepted by test unit. Each test unit shall comprise the tubes of the same steel grade, the same heat number, the same dimensions and subjected to the same heat treatment (furnace charge) or in the same delivery condition. The quantity of each test unit shall not exceed 200 pcs.

9.3 Sampling quantity

Sampling quantity for various inspection or test of the tubes shall comply with the requirements given in Table 10.

9.4 Rules for re-test and assessment

The rules for re-test and assessment of the tubes shall be as specified in GB/T 2102.

10 Packaging, marking and quality certification

10.1 Rust-proof treatment shall be carried out usually using neutral oil for the internal and external surfaces of tube prior to delivery. Special rust-proof requirements shall be agreed between the purchaser and the supplier.

10.2 Packaging, marking and quality certification for the tubes shall be as specified in GB/T 2102.

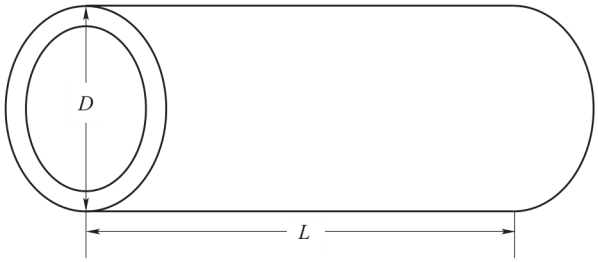
Annex A
（normative）
Circumferential opening displacement method for determination of residual stress and referenced values

A.1 Determination principles

Slit the tube wall along specified orientation and according to specified requirement, release residual stress in the tube, measure the dimensional change at identified position after the tube achieving a new stable condition, calculate the stress value using an empirical formula, which is the residual stress determined with circumferential opening displacement method.

A.2 Test piece

The test piece is shown in Figure A.1. Cut a length of 300 mm long from the tube, usually using electric discharge wire or saw machine.



Key

D nominal outside diameter or calculated outside diameter

L length of test piece

Figure A.1—Test piece of tube

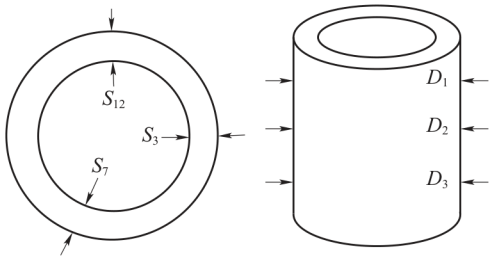
A.3 Test equipment

A.3.1 Vernier caliper: used for measuring length and outside diameter of test piece, accurate to not less than 0.02 mm.

A.3.2 Micrometer: used for measuring wall thickness of test piece, accurate to not less than 0.01 mm.

A.4 Test procedure

A.4.1 As shown in Figure A.2, identify the twelve, three and seven o'clock positions on circumference of the same cross-section of test piece, measure with micrometer and record the wall thickness at the above positions, S_{12}, S_3, S_7, determine the average thickness S_0.



Key

S_{12}, S_3, S_7 measured wall thickness at the twelve, three and seven o'clock positions on the same cross-section of test piece

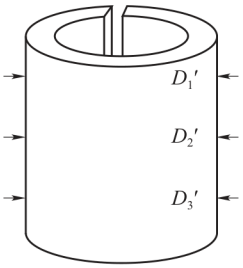
D_1, D_2, D_3 measured outside diameter at any 3 points lengthwise of the three o'clock position of test piece

Figure A. 2—Original dimensions of test piece

A. 4. 2 Measure with vernier caliper and record the outside diameter at any 3 points lengthwise of the three o'clock position, D_1, D_2, D_3, determine the average outside diameter D_0.

A. 4. 3 At the twelve o'clock position, use suitable cutting means such us electric discharge wire or saw machine, slit the tube wall parallel to the tube axis and along the radial direction. Cut the metal tube throughout whole length, cutting width is from 20 mm to 40 mm so that the cut faces are not touching.

A. 4. 4 Wait for 30 min after cutting the test piece, measure outside diameter D_1', D_2', D_3' at the same points where D_1, D_2, D_3 was measured (see Figure A. 3), determine the average outside diameter D' after stress relieving.



Key

D_1', D_2', D_3' measured outside diameter at 3 points lengthwise of the three o'clock position of opened test piece

Figure A. 3—Opened test piece

A. 5 Determination of residual stress

Residual stress is calculated by Formula (A. 1).

$$\sigma = \frac{(D' - D_0) E S_0}{D_0 D' (1 - \mu^2)} \tag{A. 1}$$

Where

σ is the residual stress, expressed in megapascals (MPa);

D' is the average outside diameter after stress relieving, expressed in millimeters (mm);

D_0 is the original average outside diameter, expressed in millimeters (mm);

E is the modulus of elasticity expressed in gigapascals (GPa), defined as 206;

S_0 is the average wall thickness, expressed in millimeters (mm);

μ is the Poisson's ratio, defined as 0.30.

A.6 Limited residual stress values

The reference maximum residual stress values of tubes of various grades are given in Table A.1.

NOTE If the residual stress exceeding the maximum value in the table, stiffness and stability of parts will be decreased, seriously affect the fatigue strength and brittle fracture resistance of the structure, even reduce the service life, therefore, it is usually necessary to control the residual stress of materials.

Table A.1—Reference maximum residual stress values of tubes of various grades

Grade	Maximum residual stress value MPa
GJ450B(C,D,E)	100
GJ550B(D,E)	150
GJ720D	200
GJ850D	250