SLOVENSKI STANDARD
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Wrought aluminium and aluminium alloy enclosures for gas-filled high-voltage switchgear and controlgear

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Kapselungen aus Aluminium und Aluminium-Knetlegierungen für gasgefüllte Hochspannungs-Schaltgeräte und -Schaltanlagen

Enveloppes en aluminium et alliage d'aluminium corroyé pour l'appareillage à haute tension sous pression de gaz

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ENGLISH VERSION

WROUGHT ALUMINIUM AND ALUMINIUM ALLOY ENCLOSURES FOR GAS-FILLED HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR

Enveloppes en aluminium et alliage d'aluminium corroyé pour l'appareillage à haute tension sous pression de gaz

Kapselungen aus Aluminium und Aluminium-Knetlegierungen für gasgefüllte Hochspannungs-Schaltgeräte und -Schaltanlagen

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee fur Elektrotechnische Normung

Central Secretariat: rue Bréderode 2, B-1000 Brussels

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FOREWORD

The European Standard has been prepared by CENELEC Technical Committee 17 C: High-voltage enclosed switchgear and controlgear.

The following dates are applicable:

- latest date of announcement of the EN at national level	(doa)	1989-12-15
- date of latest publication of a new harmonized national standard	(dop)	1990-06-15
- date of withdrawal of conflicting national standards	(dow)	1990-06-15

This document forms a supplement to EN 50 052 (1986) "Cast aluminium alloy enclosures for gas-filled high-voltage switchgear and controlgear", concerning enclosures for the same type of switchgear and controlgear but made of wrought aluminium and aluminium alloys. It is based on the general specifications given in IEC Publication 517 (1986) which are however not sufficient to satisfy the conditions for the service allowance of pressurized high-voltage switchgear and controlgear.

These specifications are appropriate for pressurized switchgear enclosures allowing an economic production without sacrificing aspects of safety. For unusual shapes dictated by electrical conditions they permit the verification of sound design by proof tests instead of calculations. Nevertheless this European Standard makes use of many internationally well acknowledged calculation rules and the Technical Committee will in addition pursue the progress in standardization in CEN/TC 121 and ISO/TC 44 on welding and allied processes.

For the time being reference can only be made to published international standards as far as they are appropriate for the purpose of production of enclosures to be used in gas-filled switchgear and controlgear.

The present EN has been established as an international specification for the design, construction, testing, inspection and certification of pressurized enclosures used in high-voltage switchgear and controlgear. This standard follows to that extent also Article 2 of the Directive 76/767/EEC.

The European Standard contains three normative technical annexes:

Annex A: Elastic analysis of the stress distribution in dished ends due to internal pressure.
Annex B: Welding procedure and welder performance tests.
Annex C: Sample of record form
and an informative annex:
Annex D: National deviations

List of standards referred to in this standard:

IEC 517:1986	Gas-insulated metal-enclosed switchgear for rated voltages of 72,5 kV and above.
ISO 6213:1983	Welding; Items to be considered to ensure quality in welding structures.
ISO 3134:1985	Light metals and their alloys; Terms and definitions; Part 1: Materials Part 3: Wrought products Part 5: Methods of processing and treatment
ISO 6520:1982	Classification of imperfections in metallic fusion welds, with explanations.
ISO/R 373:1964	General principles for fatigue testing of metals.
ISO/IEC Guide 2:1986	General terms and their definitions concerning standardization and related activities.
ISO 9000:1987	Guidelines for selection and use of the standards on quality management, quality system elements and quality assurance.

Wrought aluminium and aluminium alloy enclosures for gas-filled high-voltage switchgear and controlgear

CONTENTS

1 Introduction

This standard covers the requirements for the design, construction, testing, inspection and certification of gas-filled enclosures for use specifically in high-voltage switchgear and controlgear, or for associated gas-filled equipment. Special consideration is given to these enclosures for the following reasons:

(a) The enclosures usually form the containment of electrical equipment, thus their shape is determined by electrical rather than mechanical considerations.

(b) The enclosures are installed in restricted access areas and the equipment is operated by experts and instructed persons only.

(c) As the thorough drying of the inert, non-corrosive gas-filling medium is fundamental to the satisfactory operation of the electrical equipment it is periodically checked. For this reason, no internal corrosion allowance is required on the wall thickness of these enclosures.

(d) The enclosures are subjected to only small fluctuations of pressure as the gas-filling density shall be maintained within close limits to ensure satisfactory insulating and arc-quenching properties. Therefore, the enclosures are not liable to fatigue due to pressure cycling.

(e) The operating pressure is relatively low.

For the foregoing reasons, and to ensure the minimum disturbance hence reducing the risk of moisture and dust entering the enclosures which would prevent correct electrical operation of the switchgear, no pressure tests shall be carried out after installation and before placing in service and no periodic inspection of the enclosure interiors or pressure tests shall be carried out after the equipment is placed in service.

2 Scope and field of application

2.1 Type of equipment

This standard applies to fusion welded wrought aluminium and aluminium alloy enclosures pressurized with dry air, inert gases, for example sulphur hexafluoride or nitrogen or a mixture of such gases, used in indoor or outdoor installations of high-voltage switchgear and controlgear with rated voltages of 72,5 kV and above, where the gas is used principally for its dielectric and/or arc-quenching properties.

The enclosures comprise parts of electrical equipment not necessarily limited to the following examples:

Circuit-breakers

Switch-disconnectors

Disconnectors

Earthing switches

Current transformers

Voltage transformers

Surge arrestors

Busbars and connections

The scope covers also pressurized components such as the centre-chamber of live tank switchgear and controlgear, gas-insulated current transformers,etc.

2.2 Production

The production of the enclosures shall be in accordance with documented welding procedures which shall be carried out by well trained and supervised welding personnel. Where International Standards (ISO or CEN) are not available National Standards may be used.

NOTE
This standard will be revised as soon as possible when ISO or CEN standards covering the various aspects are available.

2.3 Quality assurance

It is the intention of this standard that the switchgear manufacturer shall be responsible for achieving and maintaining a consistent and adequate quality of product.

Sufficient examinations shall be made by the enclosure manufacturer to ensure that the materials, production and testing comply in all respects with the requirements of this standard and ISO 6213:1983. Inspection by the user's inspectors shall not absolve the switchgear manufacturer from his responsibility to exercise such quality assurance procedures as to ensure that the requirements and the intent of this standard are satisfied.

NOTE : Reference should be made to the ISO 9000 series of standards for / quality assurance systems.

3 Definitions

3.1 National standard

A technical specification established by general agreement with the important part of the concerned interests, approved by a recognized national standards organization and made available to the public (ISO/IEC Guide 2 : 1986).

3.2 Enclosure

A part of gas-insulated metal-enclosed switchgear retaining the insu gas under the prescribed conditions necessary to maintain safely the rated insulation level, protecting the equipment against external influences and providing a high degree of protection to personnel. (IEC 517:1986)

3.3 Manufacturer

Individual or body responsible for designing and producing the enclosure. In this standard this is the switchgear manufacturer.

3.4 Designer

Individual or body who determines the shape, dimensions and wall thickness of the enclosure and selects the materials and method of construction and testing.

3.5 Design pressure (of an enclosure)

Pressure used to determine the wall thickness of the enclosure. It is at least the upper limit of pressure reached within the enclosure at the design temperature. (IEC 517:1986)

3.6 Design temperature (of an enclosure)

Highest temperature reached by the enclosure which can occur under service conditions. This is generally the upper limit of ambient air temperature increased by the temperature rise due to the flow of rated normal current. (IEC 517:1986)

NOTE

Solar radiation should be taken into account when it has a significant effect on the temperature of the gas and on the mechanical properties of some materials. Similarly, the effects of low temperatures on the properties of some materials should be considered.

3.7 Alloy
A metallic substance consisting of a mixture of the basic metallic element (the element predominating by mass) and other elements such as alloying elements and impurities. (ISO 3134/1:1985)

3.8 Aluminium alloy
A metallic substance in which aluminium predominates by mass and the other elements exceed 1 % of the total content by weight.

3.9 Weld imperfections

3.9.1 Lack of fusion
Lack of union between weld metal and parent metal or weld metal and weld metal. (ISO 6520:1982, No.401)

3.9.2 Overlap
Excess of weld metal at the toe of a weld covering the parent metal surface but not fuesed to it. (ISO 6520:1982, No.506)

3.9.3 Undercut
A groove at the toe(s)(or at the root) of a weld run due to welding. (ISO 6520:1982, No.5011)

3.10 Heat treatment
Process in which the metal or the alloy in the solid state is subjected to one or more temperature cycles, to confer certain desired properties.

3.11 Fatigue
Change of the properties of a material due to repeated application of stresses or strains which leads, in particular, to cracks or rupture. (ISO/R 373:1964)

3.12 Tensile strength
The maximum unit stress related to the initial cross-section of the test specimen at which the material ruptures.

3.13 Test piece
Two or more parts of material welded together in accordance with a specified weld procedure, in order to make one or more test specimens.

3.14 Test specimen
Portion detached from a test piece, in specified dimensions, finally prepared as required for testing.

4 Materials

Any suitable aluminium or aluminium alloy is permissible; a list of examples of materials is given in table 1. The properties of the materials should be taken from the applicable standards.

NOTE 1
Contact with more noble metals, particularly copper and its alloys, can lead to heavy galvanic corrosion. Austenitic stainless steel is

Table 1 - Examples of Materials

AUSTRIA	SWITZERLAND	GERMANY	FRANCE	ITALY	SWEDEN	U.K.	SPAIN	INTERNATIONAL
Ö-NORM M 3430	SN 210 900	DIN 1725 Teil 1	AFNOR NF A50-411 NF A50-451	UNI	SS 14	BS 1470, 1471 1479, 4300 5500	UNE 38 301	ISO R 209
AlMgSi0,5	AlMgSi 0,5	AlMgSi0,5		3569			38 337 L 3441	AlMgSi 0,5
AlMg 3	Al Mg 3	AlMg 3	5754	3575			38 339 L 3390	Al Mg 3
AlMg 1	Al Mg 1	AlMg 1		5764	4104-06	5005	38 335 L 3350	Al Mg 1
AlMg4,5Mn	AlMg 4,5Mn	AlMg4,5Mn	5083	7790	4140-02	5083	38 340 L 3321	AlMg 4,5 Mn
AlMgSi 1	AlMgSi 1	AlMgSi 1			4212-06	6082	38 334 L 3451	Al Si 1 Mg
AlMg 2,5	AlMg 2,5				4120-02		38 336 L 3360	AlMg 2,5
	AlMg 2,7Mn		5454			5454		AlMg 3 Mn
			Al Type1100		4007-02			Al 99,0 Cu
			5086					Al Mg 4
			6061	6170		6061		AlMg 1 SiCu
			Al Cu * Type 2017					AlCu 4 MgSi *
						5154 A		Al Mg 3,5
					4005-02			
						5251		Al Mg 2
					4054-02			
					4010-02			

NOTE: The list is not exhaustive, other materials may be used from National Standards

* for non-welded parts only!

an exception to this rule because of its protective oxide film and can often be used in contact with aluminium.

Aluminium enclosures should be protected externally where, for example, they come into contact with mild steel supports.
Bitumen, thin zinc sheet (which gives sacrificial protection) or a combination of these are useful in this respect. Alternatively, the mild steel supports can be galvanized or zinc or aluminium sprayed.

NOTE 2
It should be noted that contact with certain gasket materials such as compressed asbestos fibre can cause corrosion of aluminium; the gasket manufacturer should be consulted.

5 Design

5.1 General

The rules for the design of enclosures of gas-insulated switchgear and controlgear prescribed in this clause are solely for the purpose of determining the dimensions and the minimum thickness to ensure safety of the enclosures against gross plastic deformation, incremental collapse and collapse through buckling with the materials given in clause 4.

The rules take into account that these enclosures are subjected to particular operating conditions (see clause 1) which distinguish them from conventional compressed air receivers and similar storage vessels.

The thicknesses determined by the various equations are minima and therefore, the specific nominal thickness shall be increased by the amount of any negative tolerance permitted by the material specification.

NOTE
There are designs of enclosures which differ in geometry from those for which equations are given in 5.7 and 5.8. These designs are permitted provided the calculation is justified or prove tests are carried out as prescribed in 7.5.3.

5.2 Corrosion allowance

The enclosures are filled in service with a non-corrosive thoroughly dried gas, therefore, no internal corrosion allowance is necessary.

5.3 Design considerations

The geometry of an enclosure can be determined by electrical rather than mechanical considerations. This constraint can result in an enclosure geometry which requires an unacceptable degree of calculation or which cannot be calculated at all.

In the case of such an enclosure or an enclosure for which calculations are not made, a proof test of the individual housing is necessary before the internal parts are added.

When designing an enclosure, account shall be taken of the following, if applicable:

(a) The possible evacuation of the enclosure as part of the filling process.

For enclosures of this type it is usually necessary to evacuate the air before introducing gas pressure, this ensures purity of the gas. The evacuated condition is therefore not an operational condition and in most cases enclosures designed for internal pressure will be suitable for the evacuated condition without buckling.

For certain long lengths and large diameters of busbar sections, however, it is possible that the enclosure will buckle due to external pressure. In such cases the design should be checked for external pressure and the enclosure strengthened, if necessary. Since this is not an operational condition,it is not a matter of safety.

(b) The full differential pressure possible across the enclosure wall.

(c) Superimposed loads and vibrations by external effects.

(d) Stresses caused by temperature differences including transient conditions and by differences in coefficients of thermal expansion.

(e) Effects of solar radiation.

Post weld heat treatment of aluminium and aluminium alloy enclosures is not normally necessary or desirable.

NOTE
Pressure stresses due to an internal electrical fault are not considered in the design of an enclosure since after such an occurrence the enclosure would be carefully checked and, if necessary, replaced.

For the case of arcing due to an internal fault, reference is made to IEC 517:1986.

5.4 Design pressure

The design is based on the design pressure (p) as defined in 3.5.

5.5 Design temperature

The selection of material and the determination of the design stress depend upon the highest wall temperature which can be expected during service at the design pressure (p).

5.6 Design stress basis

The nominal design strength (K) shall be selected from the material standard, where

K = yield strength (R_{ET}) or 0,2 % proof stress (R_p0,2) at the design temperature

S = safety factor against yield strength or 0,2 % proof stress = 1,5

Hence it follows the permissible design stress: $\sigma = K / 1,5$

For the materials listed in table 1 the nominal design strengths (K) in the annealed condition shall be used in the design of welded structures.

5.7 Calculation of shells, dished ends, openings, screws and bolts

For the purpose of calculation of shells, dished ends, bolts, screws and openings the following specific symbols are used:

D_a	external diameter of shells	mm
D_i	internal diameter of shells	mm
D_k	design diameter	mm
D_m	mean diameter of gaskets	mm
d_i	internal diameter of openings and branches	mm
t	required wall thickness	mm
l'_S	protruding length of branches	mm
t_A	required wall thickness at openings	mm
t_S	branch wall thickness	mm
x	distance over which the governing stress is assumed to act	mm
R	crown radius of dished ends	mm
r	knuckle radius	mm
h_1	height of the straight flange of dished ends	mm
h_2	depth of dished ends	mm
v	weld joint factor	--
v_A	weakening factor	--
p	design pressure	bar
p_B	buckling pressure	bar
P_s	total screw clamping force	N
P_i	loading of an area (A) with regard to internal pressure	N
A_b	design area of screw threads	mm^2
L	centre distance of branches	mm

β	design factor		
n	number of screws per flange joint		--

$$P_s / P_i = P'_s / P'_i$$

P'_i	loading per screw $= P_i / n$		N
P'_s	clamping force per screw $= P_s / n$		N

5.7.1 Cylindrical shells

The required wall thickness is:

$$t = \frac{D_a \cdot p}{20\ (K/1,5) \cdot v + p} \quad \text{(Equation 1)}$$

The minimum permissible wall thickness of cylindrical shells is 3 mm.

5.7.2 Spherical shells

The required wall thickness is:

$$t = \frac{D_a \cdot p}{40\ (K/1,5) \cdot v + p} \quad \text{(Equation 2)}$$

The minimum permissible wall thickness of spherical shells is 3 mm.

5.7.3 Conical shells

The determination of the wall thickness of conical shells is based on the stress in the meridional direction (bending stress) in the knuckle or the circumferential joint at the wide end of the cone and the stress in the tangential direction (membrane stress) away from the knuckle (see figures 1 to 4). The greater wall thickness calculated according to 5.7.3.1 or 5.7.3.2 is to be taken into consideration. For the shallow conical shells with an angle of slope to the axis of the cone $\varphi_1 > 70°$ the wall thickness shall be determined according to 5.7.3.3 even if smaller wall thicknesses as according to 5.7.3.1 and 5.7.3.2 are found.

In equations 3 and 7 the weld joint factor (v) refers to the circumferential joint and in equation 6 to the longitudinal joint.

If the distance between the circumferential joint and the knuckle is at least 0,5 x then in equations 3 and 7 is the weld joint factor v = 1,0.

The minimum permissible wall thickness of conical shells is 3 mm.

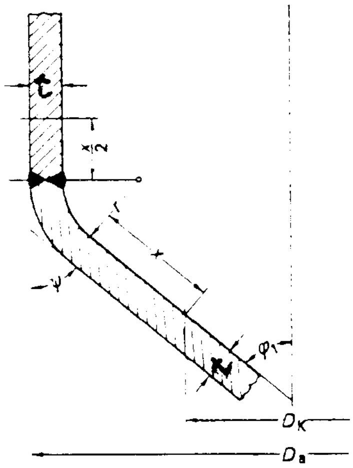

Fig. 1

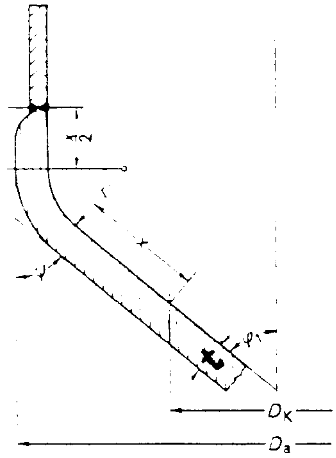

Fig. 2

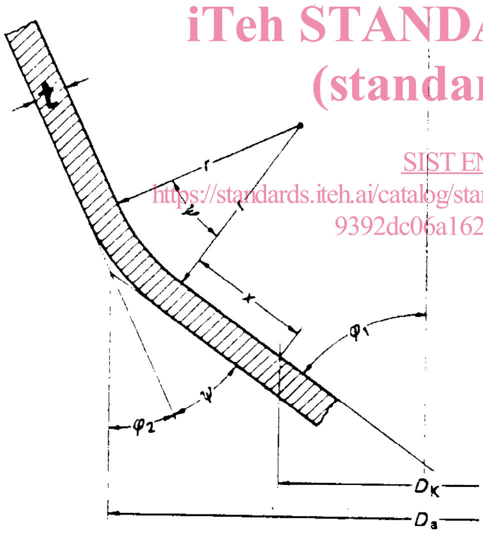

Fig. 3

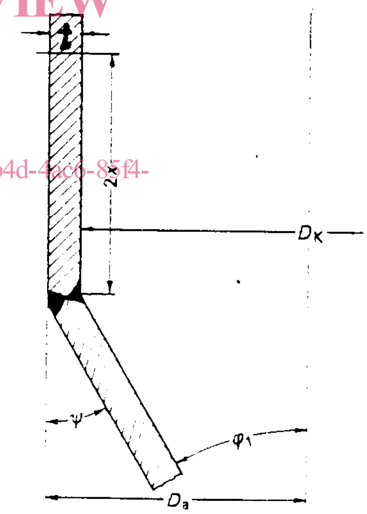

Fig. 4

Fig 1 to 4
Typical connections between cylindrical and conical shells.

5.7.3.1 Calculation based on the stress in meridional direction

The required wall thickness is:

$$t = \frac{D_a \cdot p \cdot \beta}{40\ (K/1{,}5) \cdot v} \qquad \text{(Equation 3)}$$

The design factor β is to be taken from table 2 or figure 5 depending on the difference Ψ between the angles of slope of two adjoining shells

$$\Psi = \varphi_1 - \varphi_2 \qquad \text{(Equation 4)}$$

and the ratio of the knuckle radius by the external diameter of the shell r/D_a.

A. Shells with knuckle (figures 1 and 2)

If the wide end of a conical shell is flanged to a knuckle then the wall thickness in the knuckle shall be determined according to equation 3 and shall be maintained away from the knuckle in the conical section over a distance of at least

$$x = \sqrt{D_a \cdot t} \qquad \text{(Equation 5)}$$

and along the cylindrical section over a distance of at least 0,5 x.

B. Shells without knuckle (figure 4)

Conical shells may be connected with each other or with cylindrical shells by means of welded butt joints providing the following is met:

a) $\Psi \leq 30°$

b) joints welded from both sides

c) the length of the two shells shall be at least 2 x according to equation 5

If deviating from b) the butt joints are to be welded from one side only, then equivalence with joints welded from both sides shall be demonstrated by a welding procedure test.

The wall thickness for both shells at the butt joint shall be determined under consideration of the bending stress in the circumferential seam according to equation 3.

Table 2 - Design factor β for conical shells and numerical factors cos φ and 1/cos φ

Angle φ resp. Ψ	β for a ratio of r/D_a												cos φ	$\frac{1}{\cos \varphi}$
	0,01	0,02	0,03	0,04	0,06	0,08	0,10	0,15	0,2	0,3	0,4	0,5		
10	1,4	1,3	1,2	1,2	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	0,985	1,015
20	2,0	1,8	1,7	1,6	1,4	1,3	1,2	1,1	1,1	1,1	1,1	1,1	0,940	1,064
30	2,7	2,4	2,2	2,0	1,8	1,7	1,6	1,4	1,3	1,1	1,1	1,1	0,866	1,155
45	4,1	3,7	3,3	3,0	2,6	2,4	2,2	1,9	1,8	1,4	1,1	1,1	0,707	1,414
60	6,4	5,7	5,1	4,7	4,0	3,5	3,2	2,8	2,5	2,0	1,4	1,1	0,500	2,000
70	10,0	9,0	8,0	7,2	6,0	5,3	4,9	4,2	3,7	2,7	1,7	1,1	0,342	2,920
75	13,6	11,7	10,7	9,5	7,7	7,0	6,3	5,4	4,8	3,1	2,0	1,1	0,259	3,861