Standards and Safety

(Luca Dassa - 2 June / 15 June 2024,

Sint-Michielsgestel, Netherlands)

MECHANICAL & MATERIALS ENGINEERING
FOR PARTICLE ACCELERATORS AND DETECTORS

DISCLAIMER

CHECK WITH EXPERTS

THE APPLICABLE RULES AND STANDARDS

IN YOUR FACILITY AND IN YOUR COUNTRY

OUTLINE

Why safety?

- Risk analysis
- Safety and rules/directives

Standards for pressure and cryogenic equipment

- Pressure Equipment Directive
- Harmonised standards
  - Material selection
  - Desing
  - Manufacturing
  - Inspection
  - Tests
- Safety devices
- Documentation
- Specificities for accelerator equipment

Standards for machinery

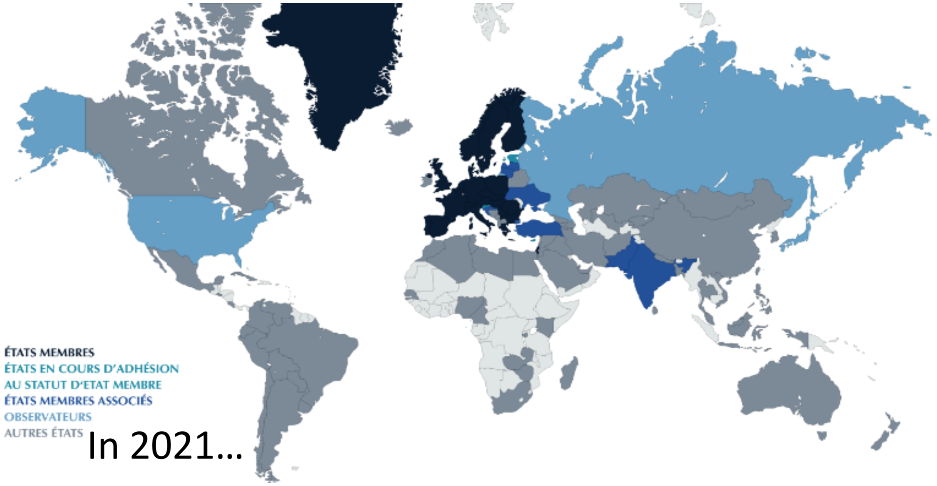
- Machinery directive
- Harmonised standards
- Automation
- Documentation

Standards for lifting equipment

Standards for big structures (buildings…)

Conclusions

Introduction



In 2021…

Budget holders

Users

Safety for?

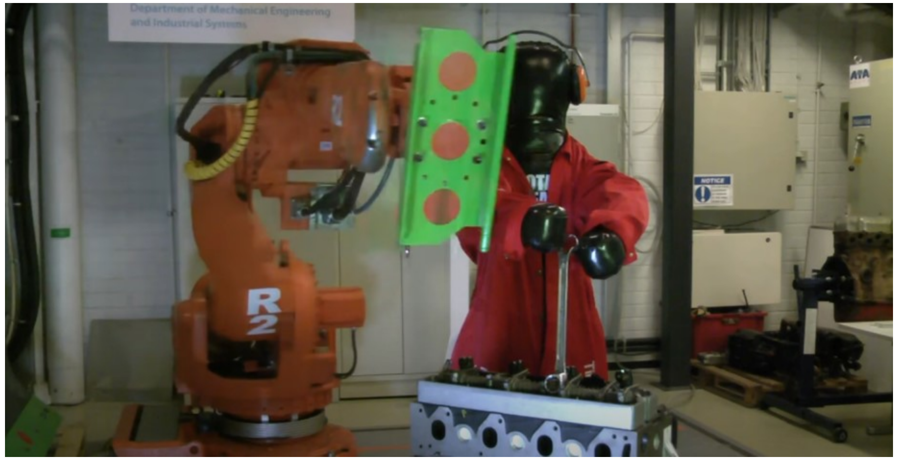
Environment

Maintenance people

WHY SAFETY AND STANDARDS?

Banagar A., Swamy R., 2015/03/01, Modelling, Stress and Welding Strength Analysis of Pressure Vessel, International Journal of Analytical, Experimental and Finite Element Analysis (IJAEFEA)

[We're going to need a bigger crane: Giant 630ft vehicle topples over in Scottish harbour | Daily Mail Online]



[Heavy industrial robot collision (youtube.com)]

Hazards shall be managed to reduce risks as much as possible

From 'REGULATION (EC) No 765/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 July 2008 setting out the requirements for accreditation and market surveillance relating to the marketing of products and repealing Regulation (EEC) No 339/93'

Article 20

Products presenting a serious risk

…

2. The decision whether or not a product represents a serious risk shall be based on an appropriate ***risk assessment*** *which takes account of the nature of the hazard and the likelihood of its occurrence. …*

From 'Pressure Equipment Directive (PED) 2014/68/EU Annex I'

1.2. In choosing the most appropriate solutions, the manufacturer shall apply the principles set out below in the following order:

— ***eliminate or reduce hazards*** *as far as is reasonably practicable;*

— ***apply appropriate protection measures*** *against hazards which cannot be eliminated;*

— where appropriate, ***inform users of residual hazards*** *and indicate whether it is necessary to take appropriate special measures to reduce the risks at the time of installation and/or use.*

Risk analysis

Different methodologies for risk analysis are available: **FMEA** is one of them.

Reference is IEC 60812:2018 - **Failure modes and effects analysis** (FMEA and FMECA)

Risk priority number (RPN) = Severity (of the event) × probability (of the event occurring) × detection (probability that the event would not be detected before the user was aware of it).

EDMS 2142606 FAILURE MODES AND EFFECTS ANALYSIS FOR THE LHC CRAB CRYOMODULE

*4.3 … In this study, the "mean" triplet (S,0,D) = (2,2,2) gives an RPN=2*2*2=8 and is the threshold value of RPN. It means that* ***mitigation measures shall be defined and implemented for all failure modes leading to RPNs equal or higher than 8.***

Additionally, the failure modes having one of the three factors equal to 4 shall also be mitigated.

Table 1 - Failure mode factor evaluation criteria (edms 1114042)

	FMEA Matrix factor						
Factor Ranking level	**Occurrence**		**Probability**	**Severity**		**Detection**	
4	Frequent	Likely to occur; happened more than 5 times over the last 10 thermal cycles	>0.5	Critical	Death from injury or illness, permanent disability or chronic irreversible illness	Low	Low chance the design control will detect potential cause/mechanism and subsequent failure mode before it reaches the final user
3	Probable	Incident may occur; happened 5 times over the last 10 htermal cycles	0.5	High	Injuries or temporary, reversible illnesses resulting in hospitalization of variable but limited period of disability.	Moderate	Moderate chance the design control will detect potential cause/mechanism and subsequent failure mode before it reaches the final user
2	Occasional	Unlikely to occur; happened once over the last 10 thermal cycles	0.1	Medium	Injuries or temporary, reversible illnesses not resulting in hospitalization and requiring only minor supportive treatment.	High	High chance the design control will detect potential cause/mechanism and subsequent failure mode before it reaches the final user
1	Improbable	Extremely unlikely to occur. Never happened over the last 10 thermal cycles	<0.1	Negligible	Slight injuries, no treatment needed	Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode before it reaches the final user

Crab cryomodule example

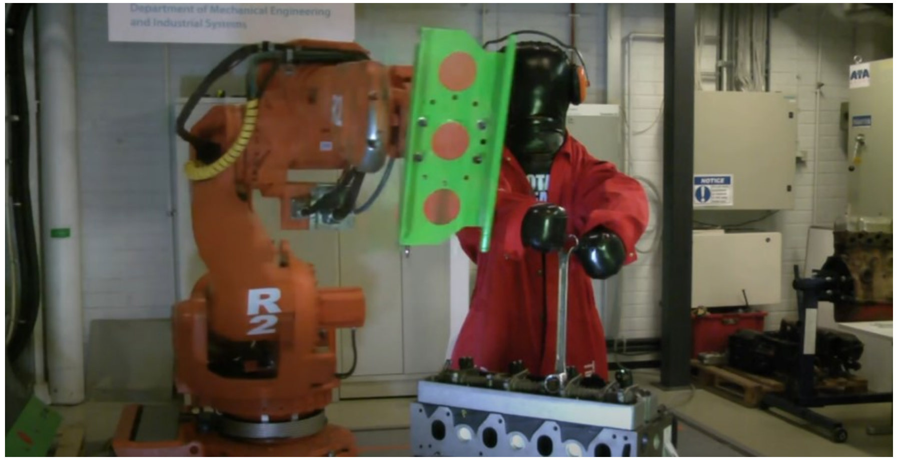
ID	Lifecycle step	Sub-Function	Associated components	Potential failure modes	Potential failure effects		Potential causes	Current design controls / Detection methods	Existing conditions				Recom-mended actions	Responsibility and target completion date	Action results			
					Local	Final			Occ	Sev	Det	RPN			Occ	Sev	Det	APN
10.8.1.3			Helium vessel	Overpressure in the helium vessel due to loss of insulation vacuum and heat transfer	Air in leak, cryo-condensation on the helium cryostat surface, heating of liquid helium	Opening of the safety devices of the helium vessel, He release in the tunnel, asphyxiation, cold burn	Mechanical shock of the vacuum cryostat during maintenance activities	As 10.8.1.1	1	3	1	3	No further measures required					
10.8.1.3*				Helium in leak to outer insulation vacuum due to full rupture of an inner bellow	Pressure increase in outer insulation vacuum	Opening of external insulation vacuum volume safety device, He release in the tunel	Mechanical fatigue of the bellows due to cyclic loads	Calculation note for the sizing of the vacuum vessel safety valve [11] + as 10.8.1.1	1	4	1	4	The vacuum vessel safety device shall be sized considering this failure as the MCI	SY-RF	1	2	1	2

https://edms.cern.ch/ui/file/2142606/1.0/FMEA_Crab_Cavities_1.0.pdf

WHY SAFETY AND STANDARDS?

Rules and directives

Banagar A., Swamy R., 2015/03/01, Modelling, Stress and Welding Strength Analysis of Pressure Vessel, International Journal of Analytical, Experimental and Finite Element Analysis (IJAEFEA)



Heavy industrial robot collision (youtube.com)

We're going to need a bigger crane: Giant 630ft vehicle topples over in Scottish harbour | Daily Mail Online

'Communities of people' decided to regulate some hazardous equipment (often hazard is linked to stored energy):

they created regulatory contexts, legal frameworks, rules and directives to respect

TO REGULATE THE MARKET EXCHANGES

Rules and directives

Governments created the rules

=> Focus on European Community

Laws — CE Marking Directives and Regulations

Overview of CE Marking Directives and Regulations

1. Machinery Directive
2. Low Voltage Directive
3. EMC Directive
4. Medical Devices Regulation
5. Personal Protective Equipment Regulation
6. Construction Products Regulation 305/2011
7. Pressure Equipment Directive
8. REACH Regulation
9. Restriction of Hazardous Substances Directive (RoHS)
10. ATEX Directive
11. Toys Safety Directive (2009/48/EC)
12. Radio Equipment Directive
13. Recreational Craft and Personal Watercraft Directive
14. Active Implantable Medical Devices Directive
15. Explosive for Civil Use (CIVEX) Directive
16. Noise Emission Directive
17. Gas Appliances Directive 2009/142/EEC
18. Lifts Directive 1995/16/EC
19. Pyrotechnic Directive 2013/29/EU
20. Measuring Instruments Directive
21. Ecodesign and Energy Efficiency Labelling

Who shall apply the laws?

The CE mark means that the manufacturer takes responsibility for the compliance of a product with all applicable European health, safety, performance and environmental requirements.
CE stands for "Conformité Européenne", the French for European conformity.

Ask always: who is the manufacturer?

Standards for pressure and cryogenic equipment

Pressure codes

Examples all around the word

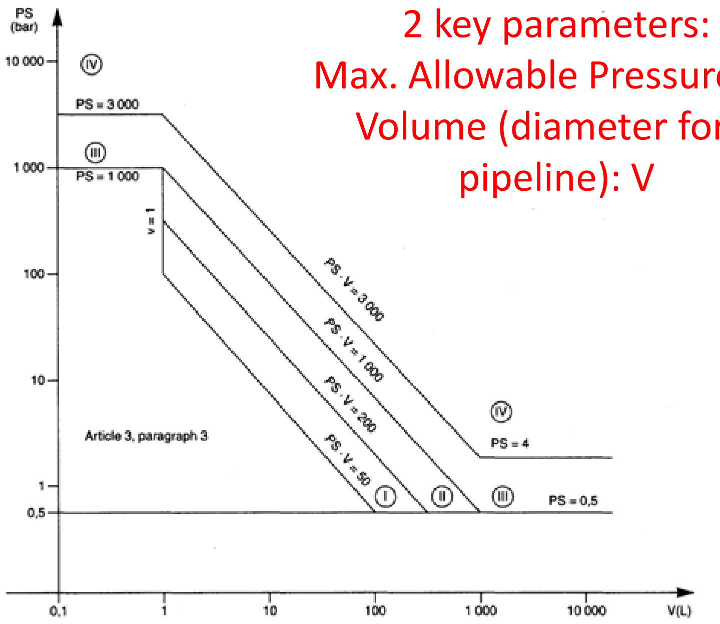
… and many others…

Focus on the European approach

Main content of Pressure Equipment Directive (PED) 2014/68/EU:

- Applies to internal pressure > 0.5 bar (gauge)
- Vessels must be designed, fabricated and tested according to the Essential Safety Requirements (ESRs) of Annex I (see next slide)

- The vessels are classified in different categories (SEP, I, II, III, IV), depending on the stored energy, expressed as Pressure x Volume (bar gauge x l) / Category IV represents the highest risk



Example: cryogenic He is classified in Group 2 (not-dangerous gas) / cryogenic liquids are treated as gas

2 key parameters:
Max. Allowable Pressure: PS
Volume (diameter for a pipeline): V

Desing your system to fall in the lowest possible category: minimise PS or V or both!

Conformity assessment gets heavier with risk

Category	Conf. assessment module	Comment
SEP	None	The equipment must be designed and manufactured in accordance with sound engineering practice. No CE marking and no involvement of notified body.
I	A	CE marking with no notified body involvement, self-certifying.
II	A1	The notified body will perform unexpected visits and monitor final assessment.
III	B1+F	The notified body is required to approve the design, examine and test the vessel.
IV	G	Even further involvement of the notified body.

- Establishes the conformity assessment procedures, depending on the category. For Cat II, III and IV involvement of Notified Body is mandatory

- ‘manufacturer’ means any natural or legal person who manufactures pressure equipment or an assembly or has such equipment or assembly designed or manufactured, and markets that pressure equipment or assembly under his name or trademark or uses it for his own purposes;

Annex I of the Pressure Equipment Directive (PED) 2014/68/EU:
…
The manufacturer is under an obligation to analyse the hazards and risks in order to identify those which apply to his equipment on account of pressure; he shall then design and construct it taking account of his analysis.

Some of the Essential Safety Requirements (annex I of Directive 2014/68/EU) concern
- Risk analysis
- Design for adequate strength / Calculation method
- Protection against exceeding the allowable limits of pressure equipment / Safety accessories
- Manufacturing procedures/ Permanent joining / Non-destructive tests / Heat treatment / Traceability
- Final assessment : Final inspection / Proof test
- Marking and labelling => CE marking
- Operating instructions
- Materials
- Specific quantitative requirements for some categories of pressure equipment : Allowable stresses / Joint coefficients / Hydrostatic test pressure (1.43 coefficient for test pressure)
- …

The pressure equipment shall be designed for loadings appropriate to its intended use and other reasonably foreseeable operating conditions. …
The allowable stresses for pressure equipment shall be limited having regard to reasonably foreseeable failure modes under operating conditions. To this end, safety factors shall be applied …

Annex III
The manufacturer shall establish the technical documentation.
The technical documentation shall make it possible to assess the conformity of the pressure equipment to the relevant requirements …

We do not discuss here the MARKET implications: we assume that accelerator facilities are not impacted.

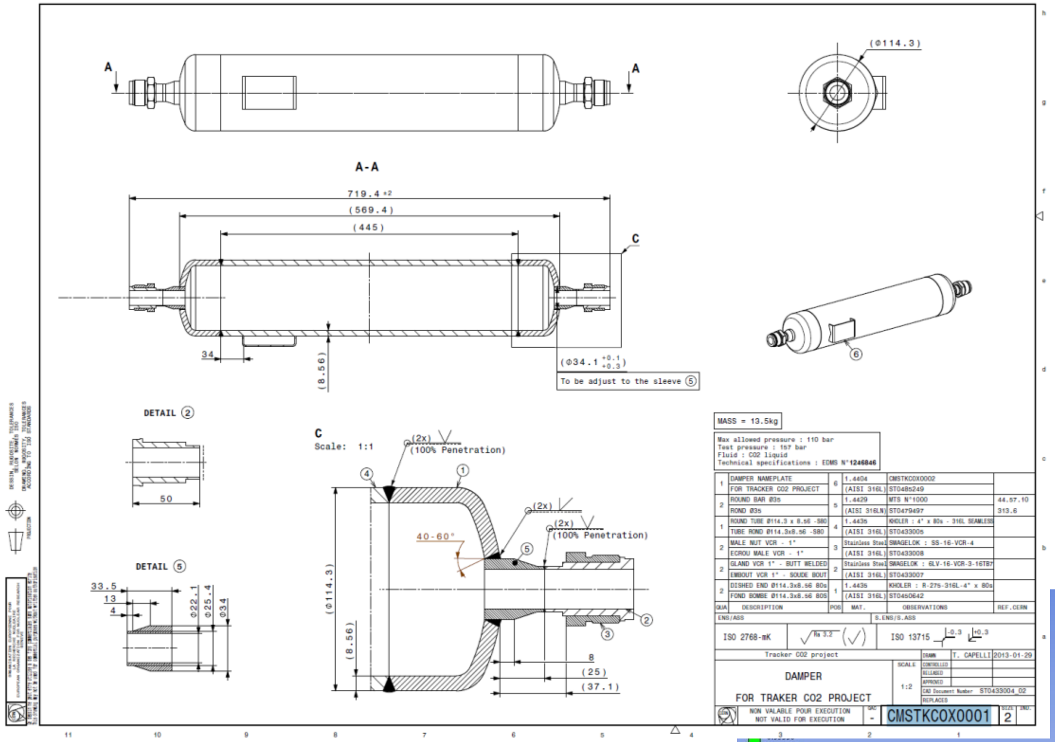
Technical standards

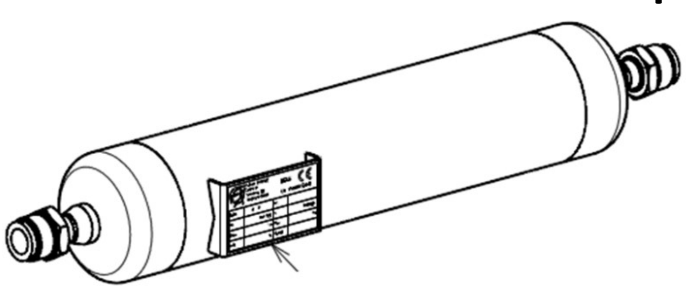
Rules / Laws / Directives	Standards			
Essential Safety Requirements / general statements	Technical detailed implementation (see next slides)			
European Union Directive: **European Directive 2014/68/EU** on the 'Approximation of the laws of the Member States concerning pressure equipment'	Harmonized Standards EN 13445 Unfired pressure vessels EN 13480 Metallic industrial piping. EN 13458 Cryogenic vessels. Static vacuum insulated vessels. EN 10028-1 Flat products made of steels for pressure purposes. General requirements EN 10028-7 Flat products made of steels for pressure purposes. Stainless steels EN 10216-5 Seamless steel tubes for pressure purposes. Technical delivery conditions. Stainless steel tubes EN 10217-7 Welded steel tubes for pressure purposes. Technical delivery conditions. Stainless steel tubes EN 10222-5 Steel forgings for pressure purposes. Martensitic, austenitic and austenitic-ferritic stainless steels EN 10272 Stainless steel bars for pressure purposes Harmonised Standards - European Commission (europa.eu)		Not Harmonized Standards French CODAP, AD 2000-Merkblätter, ASME Boiler and Pressure Vessel Code (BPVC), …	
Mandatory / legal obligation	Not mandatory / not legal obligation	Presumption of Conformity with **Essential Safety Requirements**	Not mandatory / not legal obligation	**Proof of conformity is at the charge of the manufacturer**

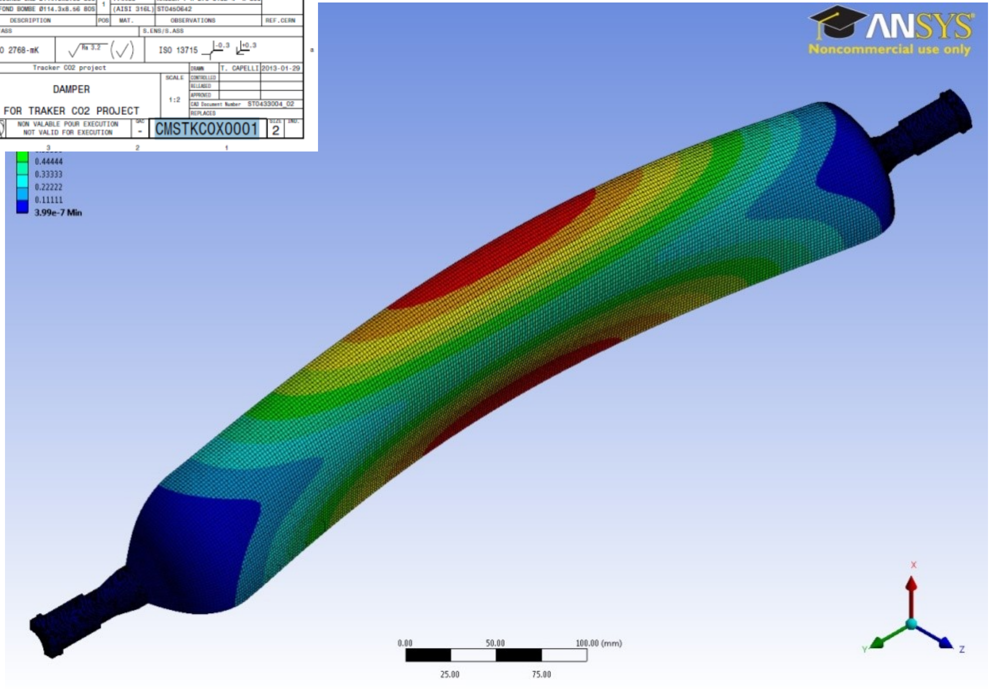
Use Harmonised Standards

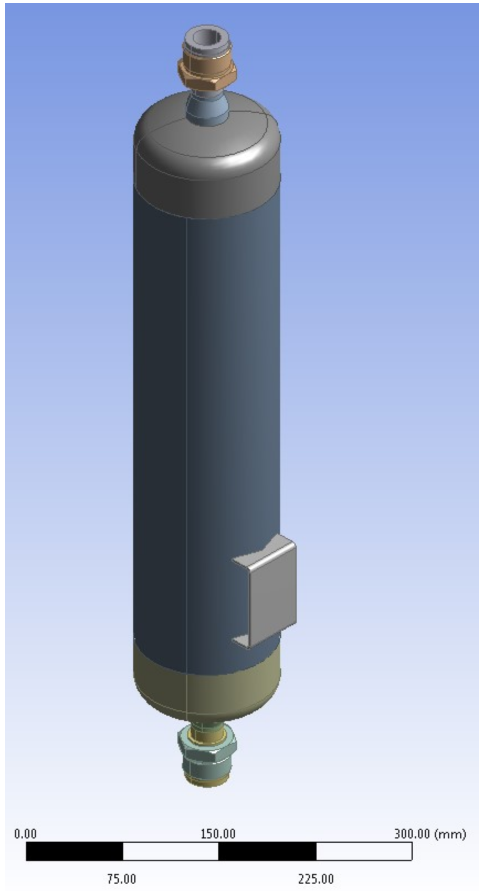
Example

$C0_2$ pressure dumper for CMS Pixel detector upgrade





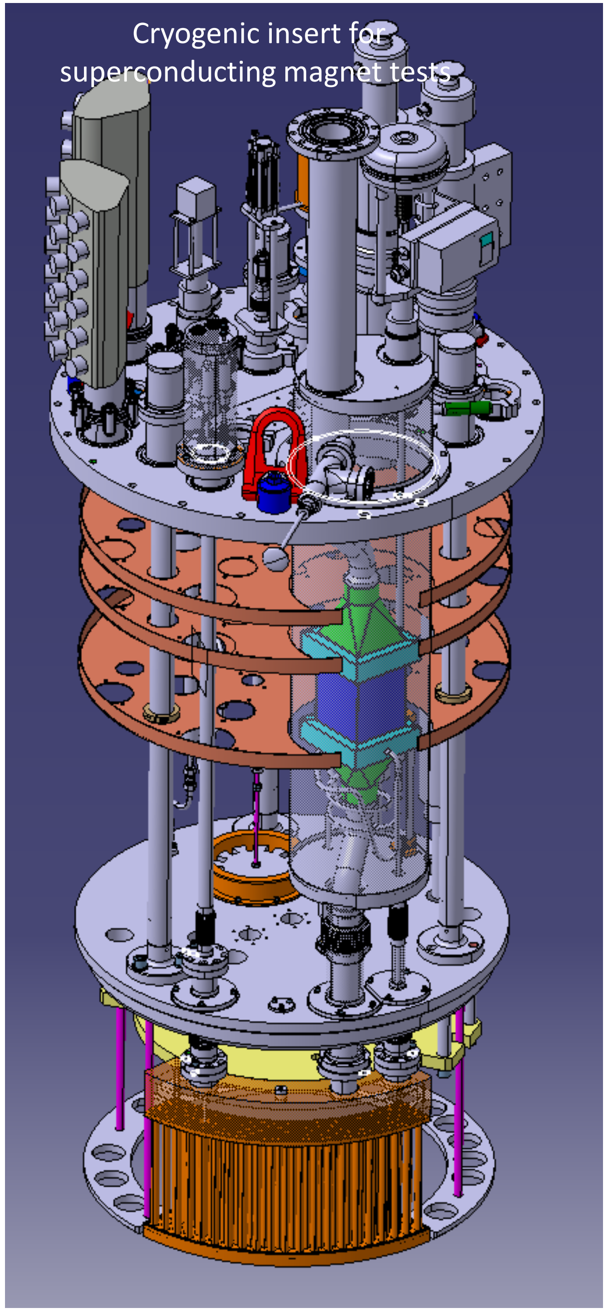


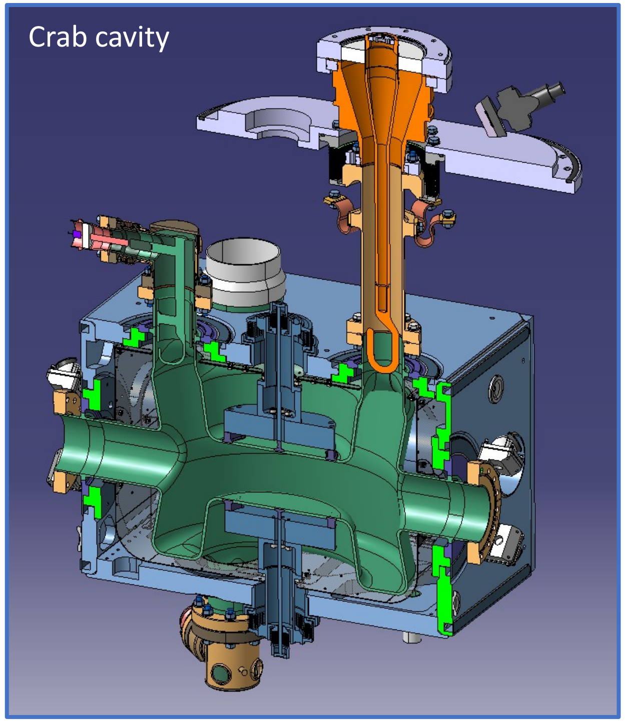


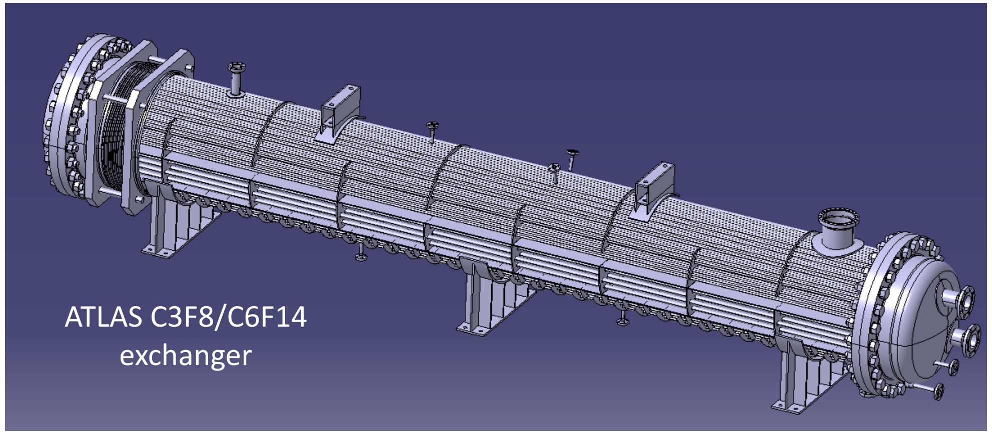
- Standard pressure equipment
- PS = 110 bar
- V=4 l
- Gas : CO_2
- Category II
- Complete follow-up according to EN13445
- Compliant with **European Directive 97/23/EC (superseded by 2014/68/EU)**
- CE marked

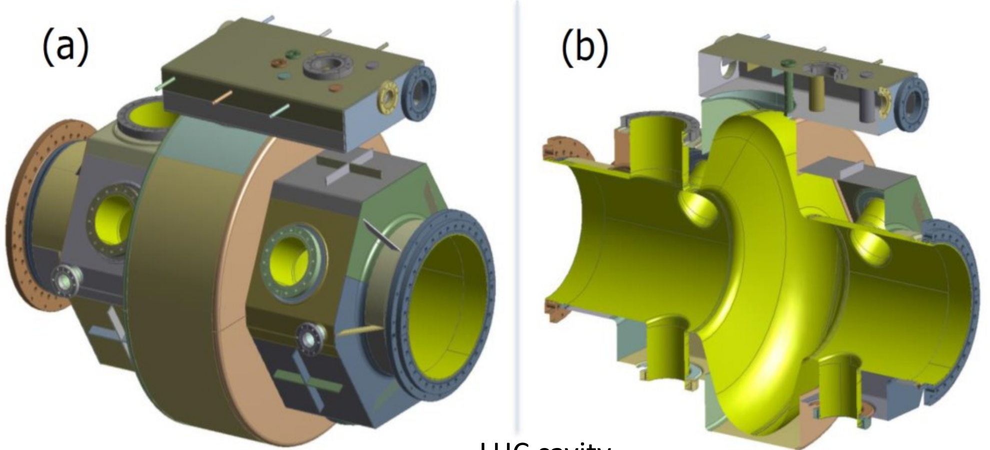
https://edms.cern.ch/nav/P:CERN-0000076703:V0/P:CERN-0000095872:V0/TAB3

More examples









LHC cavity

The first 5.5 m long 11 T MBH dipole prototype in its cryostat at CERN ready to be transported to the test bench

Technical standards

Afnor, Normes en ligne le 31/08/2015 à 16:41
Pour : CERN

ISSN 0335-3931

French standard

NF EN 13445-1 V1
12 December 2014

Classification index: **E 86-200-1**

ICS: 23.020.30

Unfired pressure vessels — Part 1: General

F : Récipients sous pression non soumis à la flamme — Partie 1 : Généralités
D : Unbefeuerte Druckbehälter — Teil 1: Allgemeines

French standard approved

by decision of the Director General of AFNOR.

Replaces the approved standard NF EN 13445-1 V5 of October 2009 and its amendment V5/A1, of March 2014.

Correspondence The European standard EN 13445-1:2014 (version 1:2014-09) has the status of French standard.

Summary This document defines the various types of unfired pressure vessels to which the six other parts of NF EN 13445 apply. It gives the terms, definitions, symbols and units used therein. It describes the rules for the application of standard NF EN 13445, the general principles on which the rules and preconditions for their application are based. It provides an index of important terms used in the standard EN 13445 with reference to the part in which they appear.

All parts NF EN 13445-1 to NF EN 13445-6 and EN 13445-8 are intended to support the essential requirements of the European Directive 97/23/EC "Pressure Equipment".

Descriptors **Technical International Thesaurus:** pressure vessels, specifications, design, manufacturing, inspection, quantities, symbols, safety devices.

Modifications With respect to the replaced documents, rewritten as a new edition (see Annex Y).

Corrections

Published and distributed by Association Française de Normalisation (AFNOR — French standard institute) — 11, rue Francis de Pressensé — 93571 La Plaine Saint-Denis Cedex — Tel.: + 33 (0)1 41 62 80 00 — Fax: + 33 (0)1 49 17 90 00 — www.afnor.org

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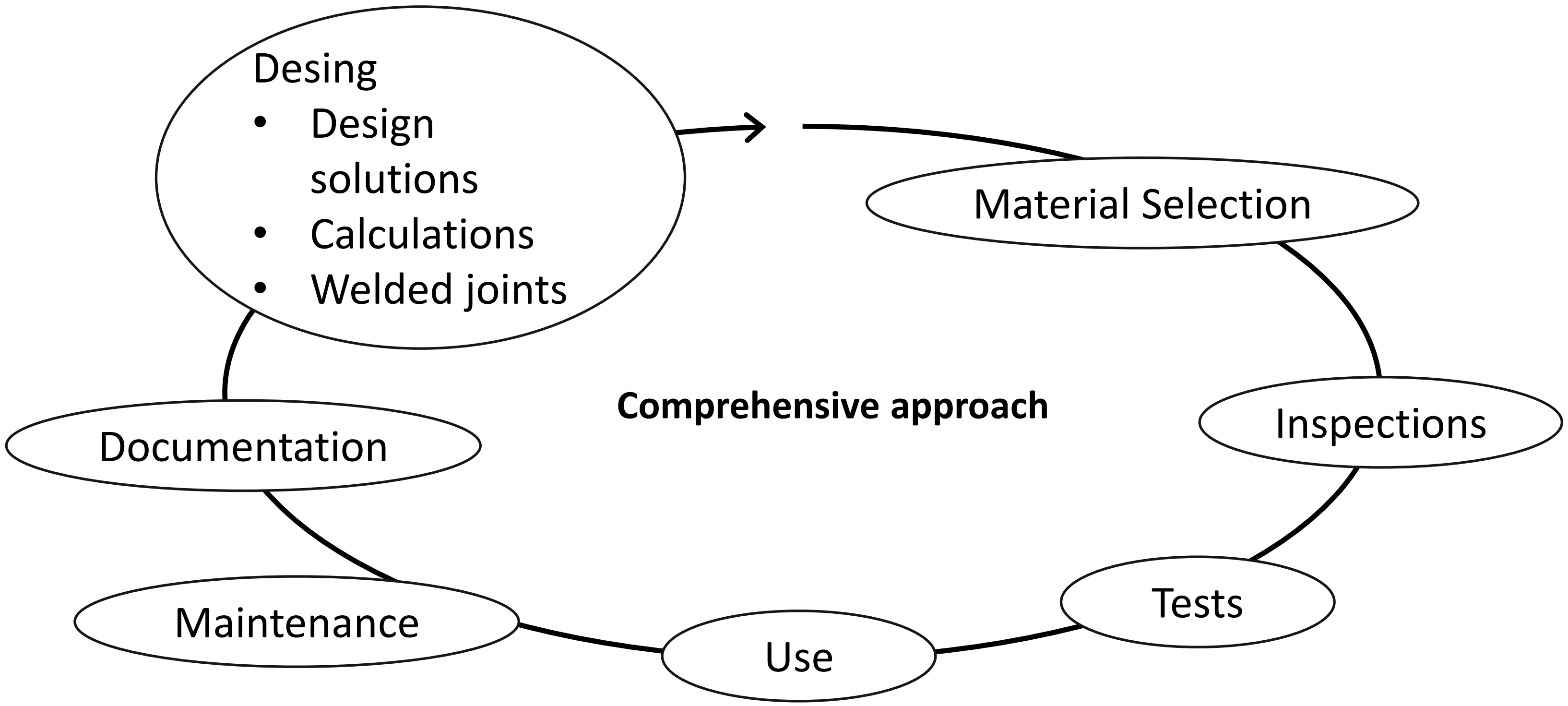
About 1200 pages!



EN 13445 Unfired pressure vessels
EN 13480 Metallic industrial piping.
EN 13458 Cryogenic vessels. Static vacuum insulated vessels.

Materials

- According to EN13445, select the right the stainless steel (be careful!).

  Use **Harmonized standards** :

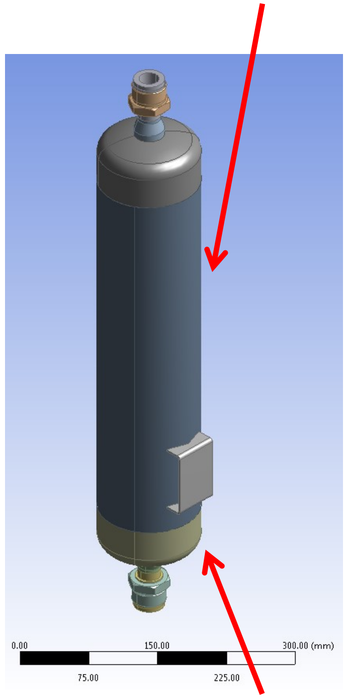
  - Plates and Sheets
    - EN 10028-1 Flat products made of steels for pressure purposes. General requirements
    - EN 10028-3 Flat products made of steels for pressure purposes. Weldable fine grain steels, normalized
    - EN 10028-7 Flat products made of steels for pressure purposes. Stainless steels
  - Tubes
    - EN 10216-5 Seamless steel tubes for pressure purposes. Technical delivery conditions. Stainless steel tubes
    - EN 10217-7 Welded steel tubes for pressure purposes. Technical delivery conditions. Stainless steel tubes
  - Bars
    - EN 10272 Stainless steel bars for pressure purposes

  … and many others!

- During design process, DON'T use real properties but properties you find in the harmonized standards.
- When you buy a commercial component: be careful! ASME materials: it is not impossible to use them but it is necessary to justify them!
- When a material is not considered in the standard, please discuss with experts.

Standard material certificate

https://edms.cern.ch/nav/P:CERN-0000076703:V0/P:CERN-0000095883:V0/TAB3



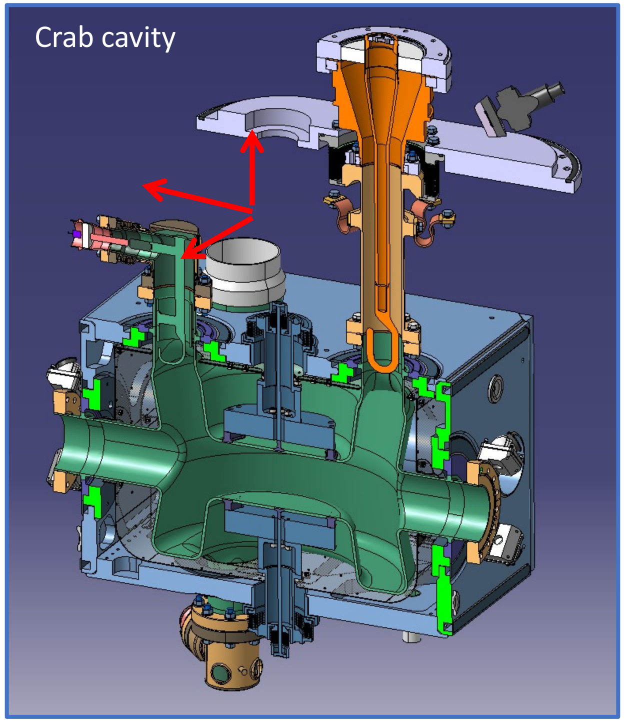
"Particular Material Appraisal"

https://edms.cern.ch/nav/P:CERN-0000076703:V0/P:CERN-0000095881:V0/TAB3

See talks of Stefano Sgobba and Ignacio A. Santillana

Avoid ASME materials

Actions and load cases



- Following the EN 13445, here the main steps:
  - Select the actions loading the vessel
  - Select the proper action combinations: load cases
  - Classify in ‘standard load case’, ‘test load case’, ‘accidental load case’ => different safety factors!
- Example of actions for a superconducting RF cavity
  - Pressure inside the vessel (with and without liquid)
  - Outer pressure (i.e. due to leak in insulation vacuum space)
  - Reactions at the supports (including seismic loads)
  - Loads imposed by piping
  - Shipping and handling
  - …
- Example of load case for a superconducting RF cavity
  - Leak test
  - Pressure test
  - Transport
  - Cool-down
  - Steady state
  - Warm-up
  - …

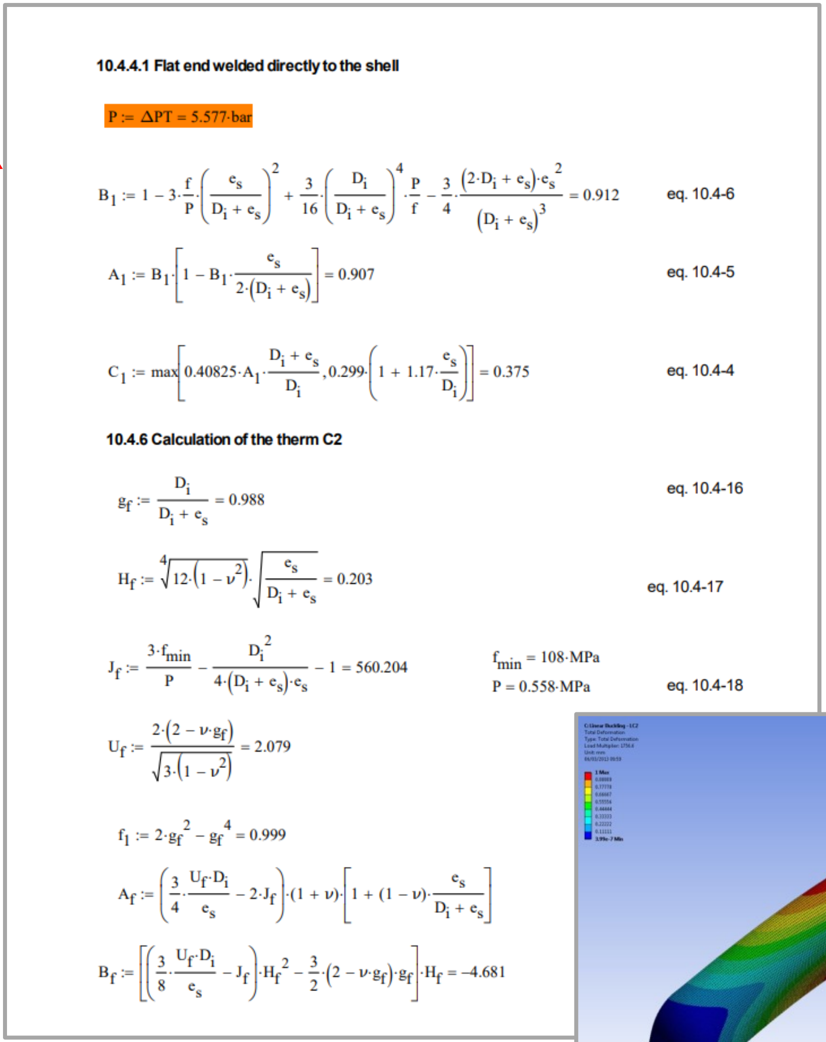
The risk analysis is very useful to avoid overlooking important actions and load cases

Main parameter to define: Maximum Allowable Pressure PS: it has legal implication, being it defined in the PED

Select the Design method*

- Design by formula
  - The most standard approach and easiest to cross check
  - Often long and tedious calculation procedures: spreadsheets are a must
  - **Only deals with pressure loads**
  - Rarely enough to calculate a magnet cryostat or a cryomodule (weight, interface loads, particular geometry, etc.)
- Stress analysis (ex: EN 13458-2 Annex A or EN 13445-3 Annex C)
  - Evaluation of stresses using a finite element code
  - Linear elastic analysis
  - Decomposition of stresses in primary, secondary, membrane, bending
  - Comparison with different allowable stresses depending on the load classification
- Design by analysis – Direct route (EN 13445-3 Annex B)
  - Applicable to any component under any action
  - When manufacturing tolerances specified by the code are exceeded
  - Finite element models including material and geometrical non-linearities

Based on FEA


10.4.4.1 Flat end welded directly to the shell

$P := \Delta PT = 5.577 \cdot bar$

$$B_1 := 1 - 3 \cdot \frac{f}{P} \cdot \left(\frac{e_s}{D_i + e_s}\right)^2 + \frac{3}{16} \cdot \left(\frac{D_i}{D_i + e_s}\right)^4 \cdot \frac{P}{f} - \frac{3}{4} \cdot \frac{(2 \cdot D_i + e_s) \cdot e_s^2}{(D_i + e_s)^3} = 0.912$$ eq. 10.4-6

$$A_1 := B_1 \cdot \left[1 - B_1 \cdot \frac{e_s}{2 \cdot (D_i + e_s)}\right] = 0.907$$ eq. 10.4-5

$$C_1 := \max\left[0.40825 \cdot A_1 \cdot \frac{D_i + e_s}{D_i}, 0.299 \cdot \left(1 + 1.17 \cdot \frac{e_s}{D_i}\right)\right] = 0.375$$ eq. 10.4-4

10.4.6 Calculation of the therm C2

$$g_f := \frac{D_i}{D_i + e_s} = 0.988$$ eq. 10.4-16

$$H_f := \sqrt[4]{12 \cdot (1 - \nu^2)} \cdot \sqrt{\frac{e_s}{D_i + e_s}} = 0.203$$ eq. 10.4-17

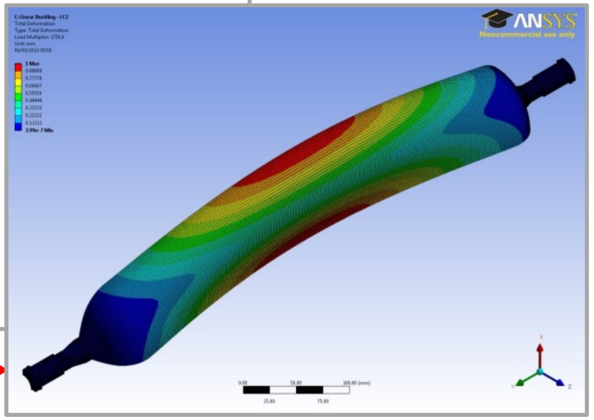
$$J_f := \frac{3 \cdot f_{min}}{P} - \frac{D_i^2}{4 \cdot (D_i + e_s) \cdot e_s} - 1 = 560.204$$ $f_{min} = 108 \cdot MPa$, $P = 0.558 \cdot MPa$ eq. 10.4-18

$$U_f := \frac{2 \cdot (2 - \nu \cdot g_f)}{\sqrt{3 \cdot (1 - \nu^2)}} = 2.079$$

$$f_1 := 2 \cdot g_f^2 - g_f^4 = 0.999$$

$$A_f := \left(\frac{3}{4} \cdot \frac{U_f \cdot D_i}{e_s} - 2 \cdot J_f\right) \cdot (1 + \nu) \cdot \left[1 + (1 - \nu) \cdot \frac{e_s}{D_i + e_s}\right]$$

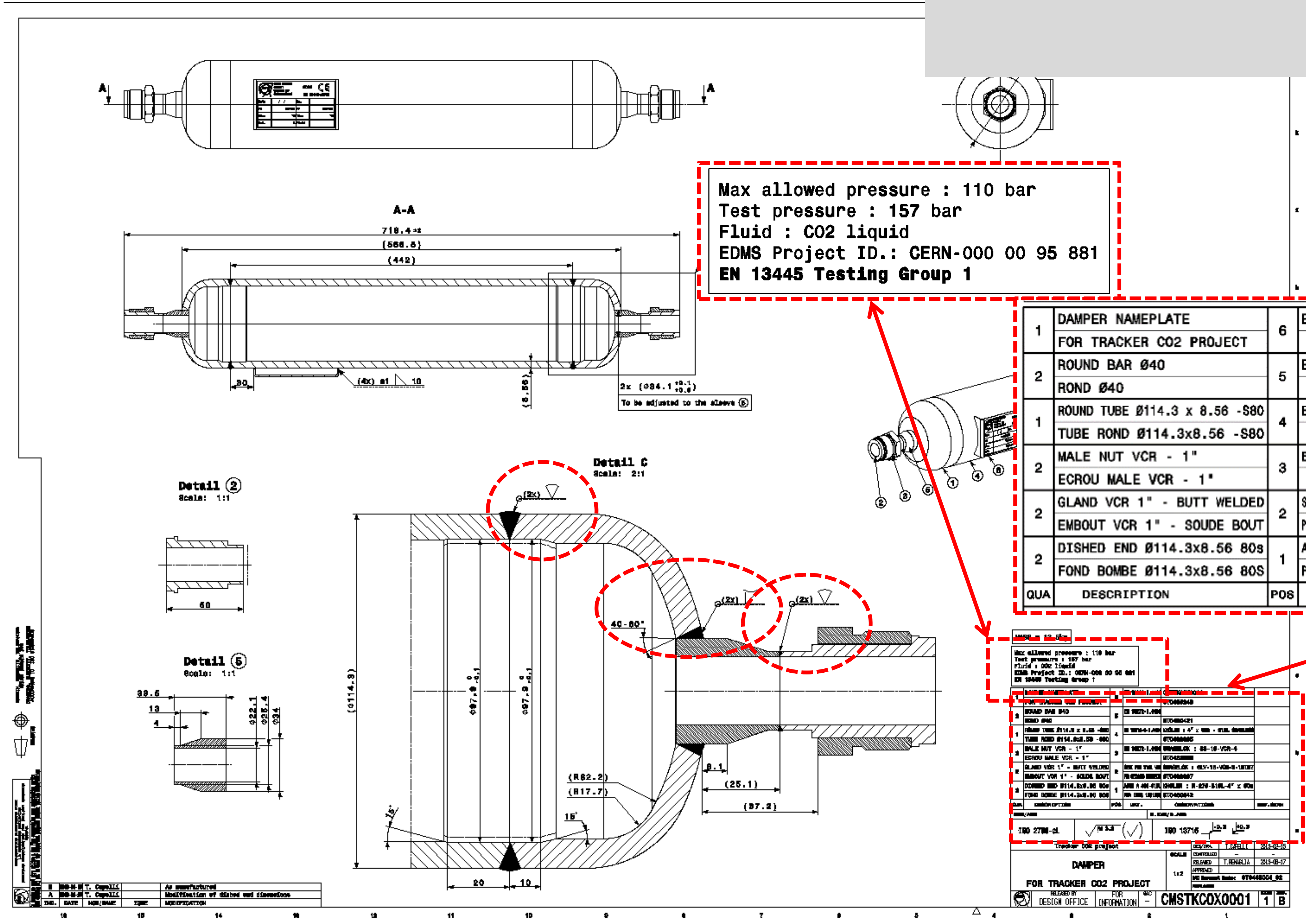
$$B_f := \left[\left(\frac{3}{8} \cdot \frac{U_f \cdot D_i}{e_s} - J_f\right) \cdot H_f^2 - \frac{3}{2} \cdot (2 - \nu \cdot g_f) \cdot g_f\right] \cdot H_f = -4.681$$



* "Design checks" is actually a better term. The verification of the final design **must** be done through one of these routes but it may be practical to use other formulas/methods during the preliminary design phase.

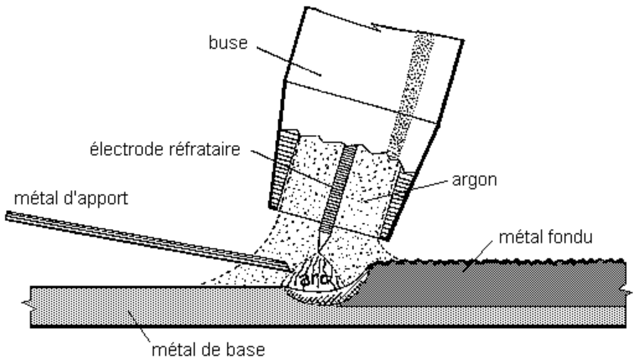
See talks of Martina Scapin and Federico Carra

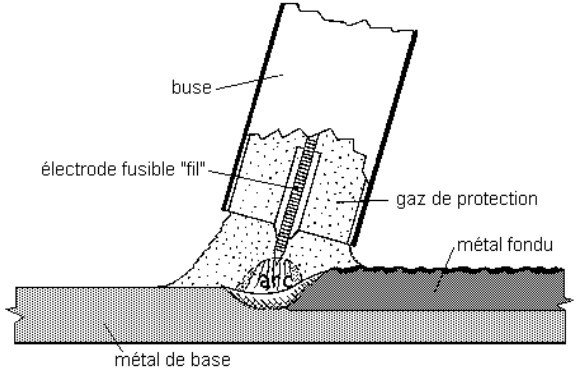
Design

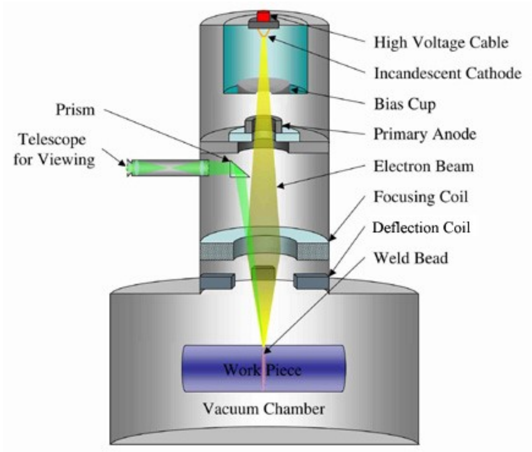


Max allowed pressure : 110 bar
Test pressure : 157 bar
Fluid : CO2 liquid
EDMS Project ID.: CERN-000 00 95 881
EN 13445 Testing Group 1

QUA	DESCRIPTION	POS	MAT.	OBSERVATIONS	REF.CERN
1	DAMPER NAMEPLATE FOR TRACKER CO2 PROJECT	6	EN 10088-1.4429	CMSTKC0X0002 ST0485249	
2	ROUND BAR Ø40 ROND Ø40	5	EN 10272-1.4435	ST0490421	
1	ROUND TUBE Ø114.3 x 8.56 -S80 TUBE ROND Ø114.3x8.56 -S80	4	EN 10216-5-1.4404	KHOLER : 4" x 80s - 316L SEAMLESS ST0433005	
2	MALE NUT VCR - 1" ECROU MALE VCR - 1"	3	EN 10272-1.4401	SWAGELOK : SS-16-VCR-4 ST0433008	
2	GLAND VCR 1" - BUTT WELDED EMBOUT VCR 1" - SOUDE BOUT	2	SEMI F20 316L VAR PED 97/23/EC CERTIFIED	SWAGELOK : 6LV-16-VCR-3-16TB7 ST0433007	
2	DISHED END Ø114.3x8.56 80s FOND BOMBE Ø114.3x8.56 80S	1	ASTM A 403-316L PMA EDMS 1281789	KHOLER : R-275-316L-4" x 80s ST0450642	







Permanent joints

The most commonly used processes in cryostat fabrication are:

- Tungsten Inert Gas (TIG - 141)
- Metal Inert Gas Welding (MIG - 131)
- Electron-beam welding (51)

Vacuum Brazing is another process used for permanently joining different materials

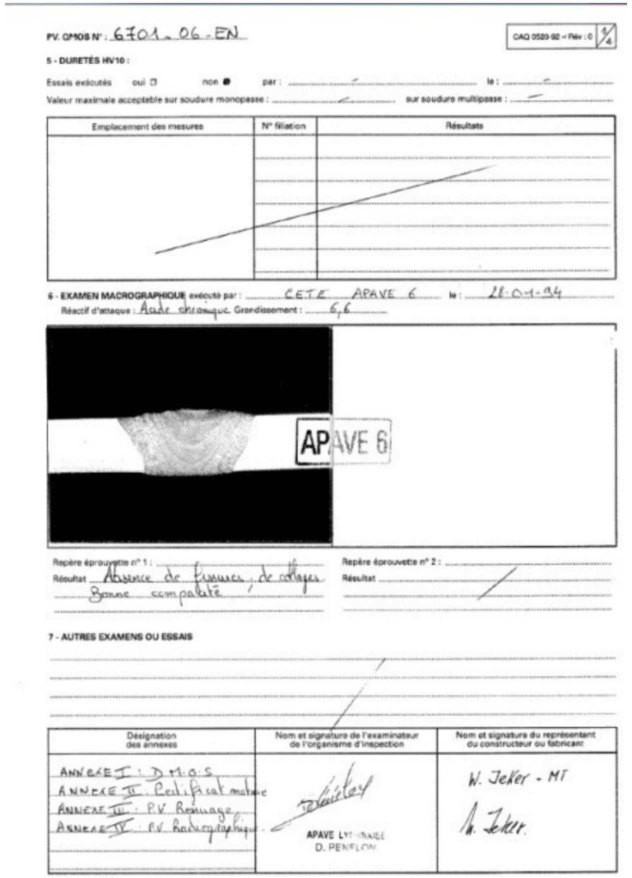
Full quality assurance of welds involves:

- Specification of quality levels for imperfections suitable to the application
- Qualification test of welding procedures and welders
- Welding inspection

See talks of J. M. Krumenacker, R. Girard and S. Mathot

CO2 example
https://edms.cern.ch/nav/P:CERN-0000076703:V0/P:CERN-0000095872:V0/TAB3

Welding book


PV. QMOS N° : 6701 - 06 - EN

CAQ 0520-92 – Rév : 0

5 - DURETÉS HV10 :

Essais exécutés oui non par : le :

Valeur maximale acceptable sur soudure monopasse : sur soudure multipasse :

Emplacement des mesures	N° filiation	Résultats

6 - EXAMEN MACROGRAPHIQUE exécuté par : CETE APAVE 6 le : 28-01-94

Réactif d'attaque : Acide chromique Grandissement : 6,6

APAVE 6

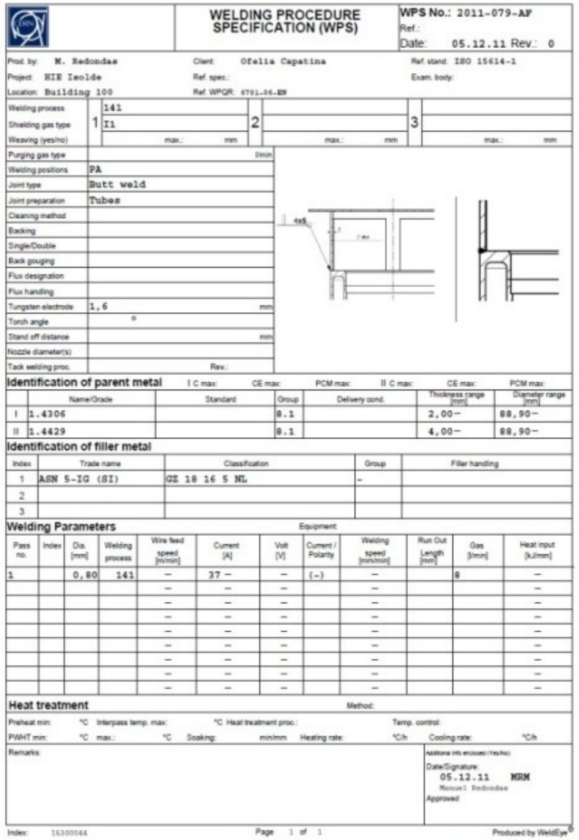
Repère éprouvette n° 1 : Résultat : Absence de fissures, de collages. Bonne compacité.

Repère éprouvette n° 2 : Résultat :

7 - AUTRES EXAMENS OU ESSAIS

Désignation des annexes	Nom et signature de l'examinateur de l'organisme d'inspection	Nom et signature du représentant du constructeur ou fabricant
ANNEXE I : D.M.O.S. ANNEXE II : Certificat matière ANNEXE III : P.V. Recuage ANNEXE IV : P.V. Radiographique	APAVE LYONNAISE D. PENELON	W. Jeker - MT

WPQR (Welding Procedure Qualification Record)


WELDING PROCEDURE SPECIFICATION (WPS)

WPS No.: 2011-079-AF
Date: 05.12.11 Rev.: 0

Prod. by: M. Redondas Client: Ofelia Capatina Ref. stand: ISO 15614-1
Project: HIE Isolde
Location: Building 100 Ref. WPQR: 6701-06-EN

Welding process: 141
Shielding gas type: I1
Welding positions: PA
Joint type: Butt weld
Joint preparation: Tubes
Tungsten electrode: 1,6

Identification of parent metal
I 1.4306 8.1 2,00– 88,90–
II 1.4429 8.1 4,00– 88,90–

Identification of filler metal
1 ASN 5-IG (SI) G2 19 16 5 NL

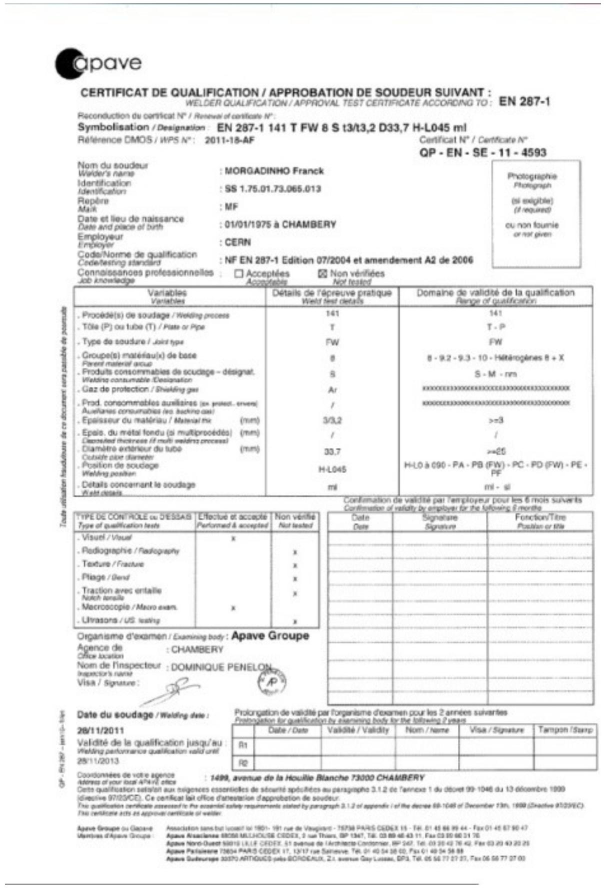
Welding Parameters
1 0,80 141 – 37 – (–)

Heat treatment

Date/Signature: 05.12.11 MRM

Produced by WeldEye

WPS (Welding Procedure Specifications)


apave

CERTIFICAT DE QUALIFICATION / APPROBATION DE SOUDEUR SUIVANT : EN 287-1
WELDER QUALIFICATION / APPROVAL TEST CERTIFICATE ACCORDING TO : EN 287-1

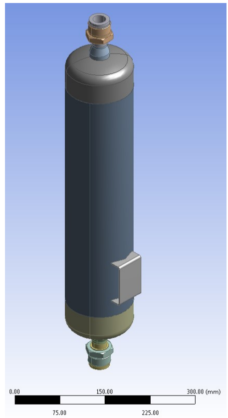
Symbolisation / Designation : EN 287-1 141 T FW 8 S t3/t3,2 D33,7 H-L045 ml
Référence DMOS / WPS N° : 2011-18-AF
Certificat N° / Certificate N° : QP - EN - SE - 11 - 4593

Nom du soudeur / Welder's name : MORGADINHO Franck
Identification : SS 1.75.01.73.065.013
Repère / Mark : MF
Date et lieu de naissance / Date and place of birth : 01/01/1975 à CHAMBERY
Employeur / Employer : CERN
Code/Norme de qualification / Code/testing standard : NF EN 287-1 Edition 07/2004 et amendement A2 de 2006

Organisme d'examen / Examining body : Apave Groupe
Agence de / Office location : CHAMBERY
Nom de l'inspecteur / Inspector's name : DOMINIQUE PENELON

Date du soudage / Welding date : 28/11/2011
Validité de la qualification jusqu'au : 28/11/2013

WQ (Welder Qualification)



Non-destructive tests (NDTs)

From EN 13445-5: 2014 Section 4.1

Each individual vessel shall be inspected during construction and upon completion. Inspections shall be made to ensure that in all respects the design, materials, manufacturing, and testing comply with the requirements of this standard. Documented evidence shall be prepared to verify implementation of this requirement.

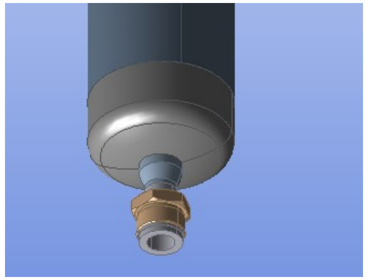
Different tipologies:
- Visual test: **always 100% visual test on EU standards!**
- Liquid penetrant test
- X-ray test
- Ultrasound test

Type and extents depend on materials and on joint coefficient (= depend on the design)

Performed
- by qualified testing personnel
- according to specific European Harmonized Standards

Remarks
- Brazed joints shall be testes as well

See talks of Gonzalo A. Izquierdo



CO_2 example
https://edms.cern.ch/nav/P:CERN-0000076703:V0/P:CERN-0000095890:V0/TAB3

Pressure test

For a component falling into the PED domain, the pressure test is MANDATORY!

The test pressure is **derived** from Maximum Allowable Pressure: according to EN 13445, usually (but not always) the test pressure is **1.43*PS**

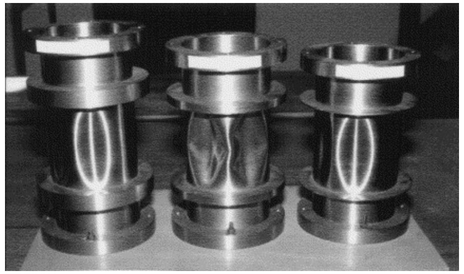
The test procedure is given in the EN 13445.

Is not a pressure test enough to grant the safety of a vessel?

An overpressure test is not enough to ensure safe operation over the lifetime of the equipment! Cyclic loads are not simulated.

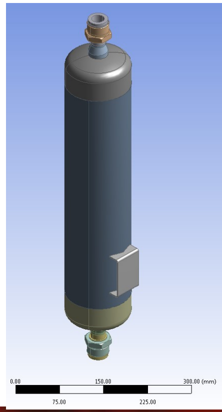
http://www.youtube.com/watch?v=AB9QvkvQuvM

http://www.youtube.com/watch?v=2WJVHtF8GwI



CO_2 vessel

https://edms.cern.ch/nav/P:CERN-0000076703:V0/P:CERN-0000095872:V0/TAB3



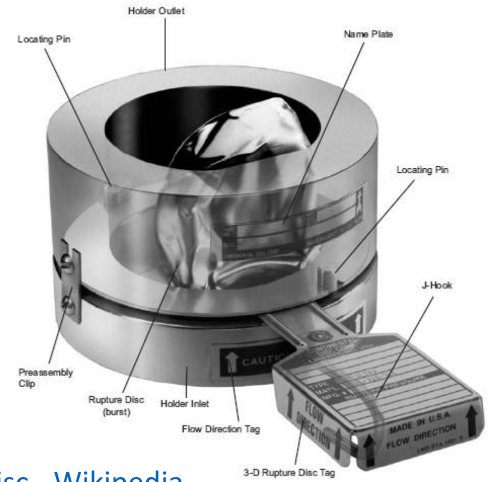
Annex I of the Pressure Equipment Directive (PED) 2014/68/EU Section 2.10:

Protection against exceeding the allowable limits of pressure equipment
Where, under reasonably foreseeable conditions, the allowable limits could be exceeded, ***the pressure equipment shall be fitted with… suitable protective devices****, unless the equipment is intended to be protected by other protective devices within an assembly.*

2 types of devices:

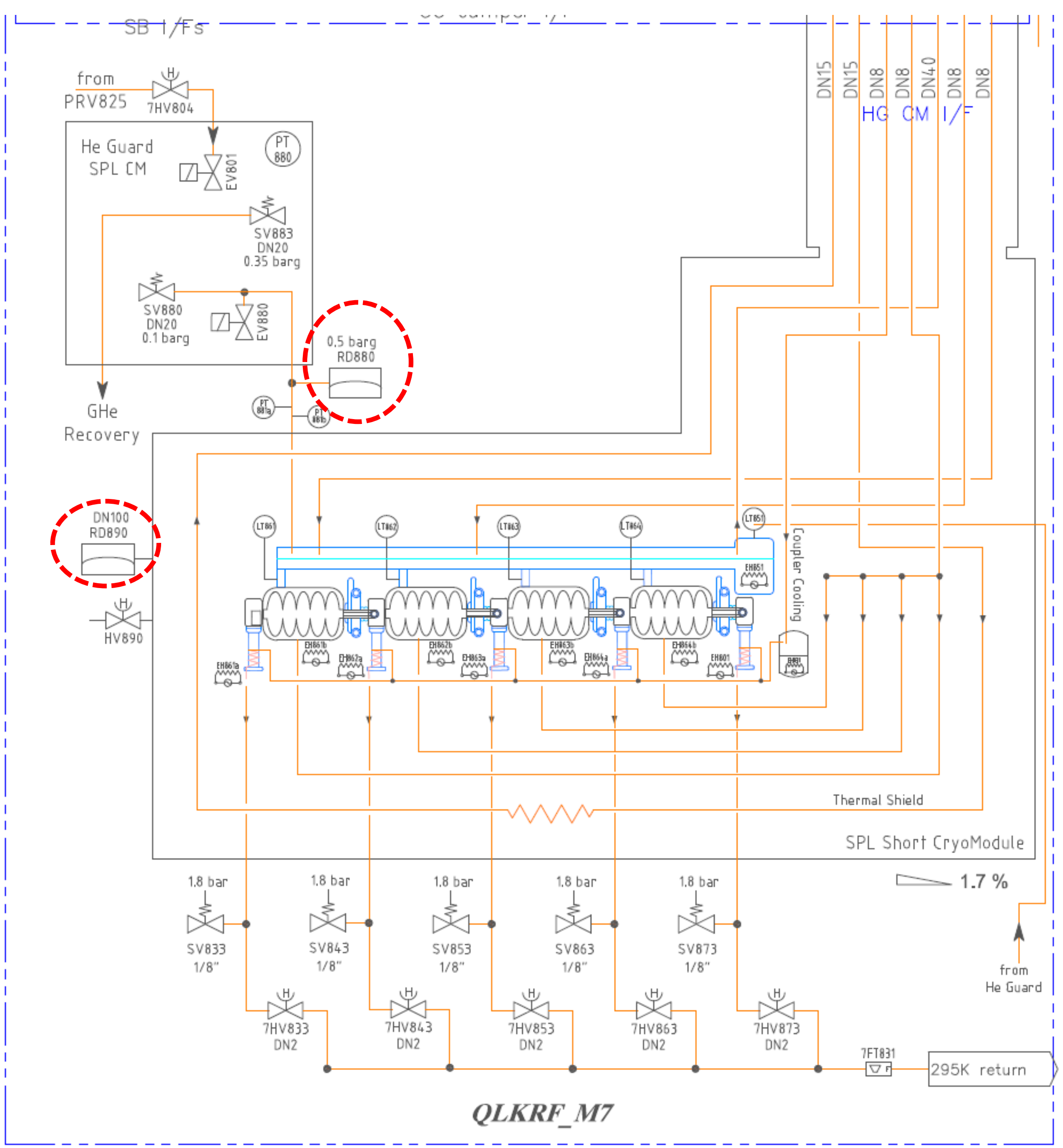
- Closeable valve [Cla-Val 50-01 Pressure Relief Valve 3D Animation (youtube.com)]
- Burst disc [Rupture Disc Burst (youtube.com)]

The set pressure shall be the Maximum Allowable pressure PS.
Relief area is evaluated according to the Maximum Credible Incident (MCI).



[Rupture disc - Wikipedia]

Courtesy of Leser



Safety devices

- Cryogenic vessels and lines and vacuum insulations volumes shall be protected by safety devices.

- Standards are available for sizing
  - EN ISO 4126-2013 / Safety devices for protection against excessive pressure
  - EN 13648:2008 / Cryogenic vessels - Safety devices for protection against excessive pressure
  - ISO 21013:2016 Cryogenic vessels -- Pressure-relief accessories for cryogenic service

Ask always where they are installed

Technical documentation

Annex III of the Pressure Equipment Directive (PED) 2014/68/EU, Section 2

*The **manufacturer shall establish the technical documentation**.*
The technical documentation shall make it possible to assess the conformity of the pressure equipment to the relevant requirements, …

The technical documentation shall, wherever applicable, contain at least the following elements:
— a general description of the pressure equipment,
— conceptual design and manufacturing drawings and diagrams of components, sub-assemblies, circuits, etc.,
— descriptions and explanations necessary for an understanding of those drawings and diagrams and the operation of the pressure equipment,
— a list of the harmonised standards… applied in full or in part..
— results of design calculations made, examinations carried out, etc.,
— test reports.

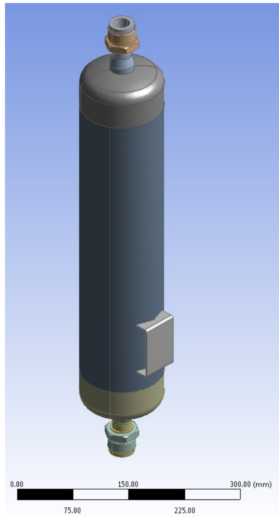
DOCUMENTATION IS THE BASIS FOR THE COMPLIANCE WITH RULES!

Please keep in mind "Safety Folder" instead of "Safety File"!
Foresee it since the beginning of the job!

The "Safety Folder" is very useful also during design phase: you can store drawings, calculations, …

For a small project

- CO2 Acessory for CMS
  - Design
    - Technical Description
    - Drawings
    - Calculations
    - Technical specifications
    - Change requests
    - Other
  - Fabrication
    - Traceability
    - Welding
      - 1269656 (v.1) Recapitulatif des soudures pour bouteille A
      - 1269658 (v.1) Recapitulatif des soudures Bouteille B
      - 1270705 (v.1) DRAWING FOLDER - Welding Qualification Samples
      - 1276675 (v.1) Welding Procedure Qualification Records (WPQRs) for welds drawing CRNHZMW_1274
      - 1276676 (v.1) Welders' qualification test certificates for welds drawing CRNHZMW_1274
      - 1276677 (v.1) Welding procedure specifications (WPSs) for welds drawing CRNHZMW_1274
    - Material Certificates
      - 1270709 (v.1) MATERIAL CERTIFICATE - KOHLER end-caps + seamless tube
      - 1270711 (v.1) MATERIAL CERTIFICATE - BOHLER Round bar DN40
      - 1270715 (v.1) MATERIAL CERTIFICATES - Swagelok VCR Fittings
      - 1272853 (v.1) MATERIAL CERTIFICATE - Nameplate EN 10088-1.4429
    - Non conformities
    - Procurement and Subcontracting
    - Tooling
    - Photos
  - Inspection and test
    - Tests
    - Inspection
  - 1293086 (v.2) EC DECLARATION OF CONFORMITY



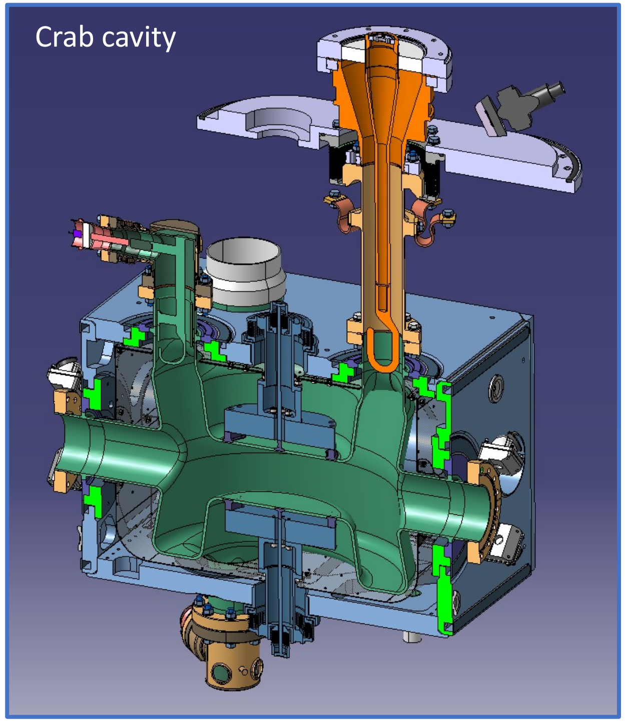
https://edms.cern.ch/project/CERN-0000095872

Accelerator components

If standards are applicable => follow the standard

If standards are not applicable =>
Some examples:
- **Cryogenic equipment with magnet inside (huge mass inside a pressure vessel)**
- **Exotic materials (Niobium, Copper OFE…)**
- **Bolted vessel with leak tight welded joints (not structural)**
- **Special flanges (pressurized vacuum flanges)**
- **…**

Example: an accelerating cavity…



Do not work alone!
Rise the concern immediately!

Essential Safety requirements are the reference

Discussion with Safety Unit to define the conformity approach

Inspiration from existing standards to find an approach to the design, manufacturing, inspection and testing which is granting the safety.

Accelerator components

CRAB cavities

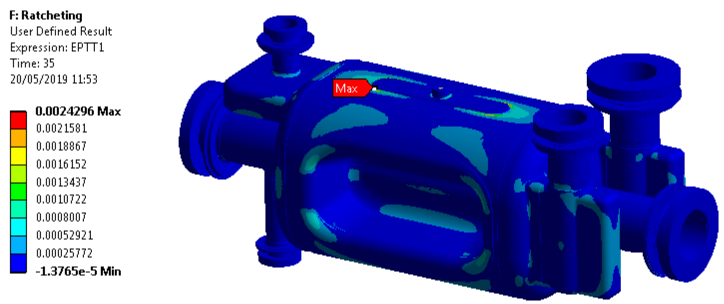
- Discussion and agreement with CERN Safety Unit (HSE)

- Advanced calculations
- Test campaigns for material behaviour at room T and at cold
- Dummy vessel test for bolt behaviour

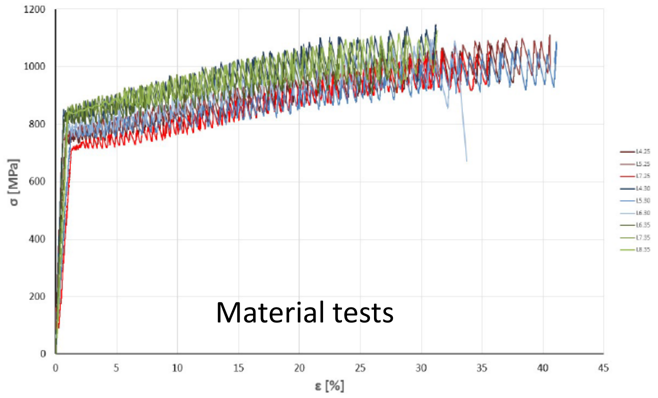
- Qualification of special joints

- Full SPS mock-up

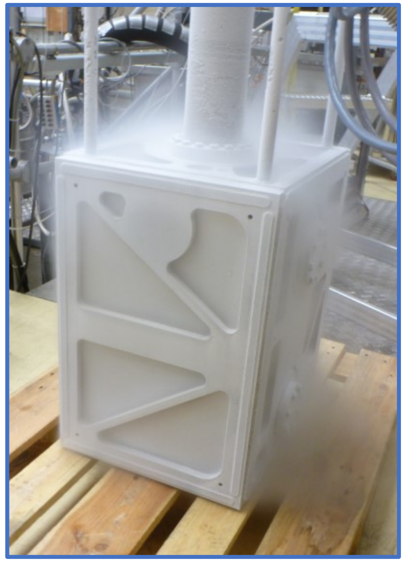
- Detailed manufacturing follow-up
- Notified body required for external companies



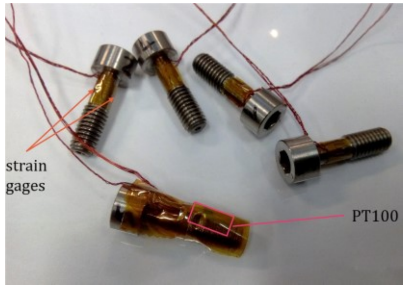
Calculations

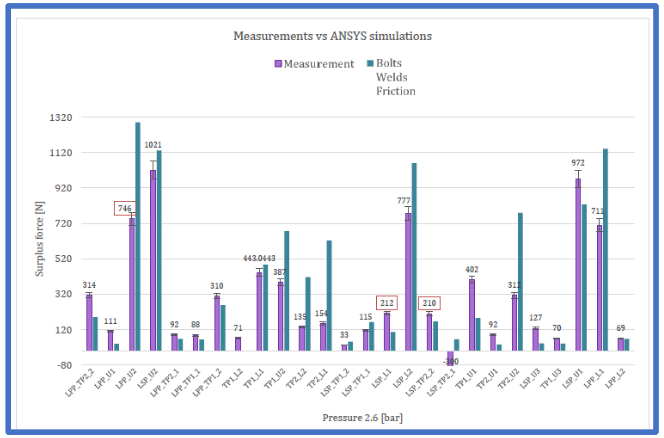


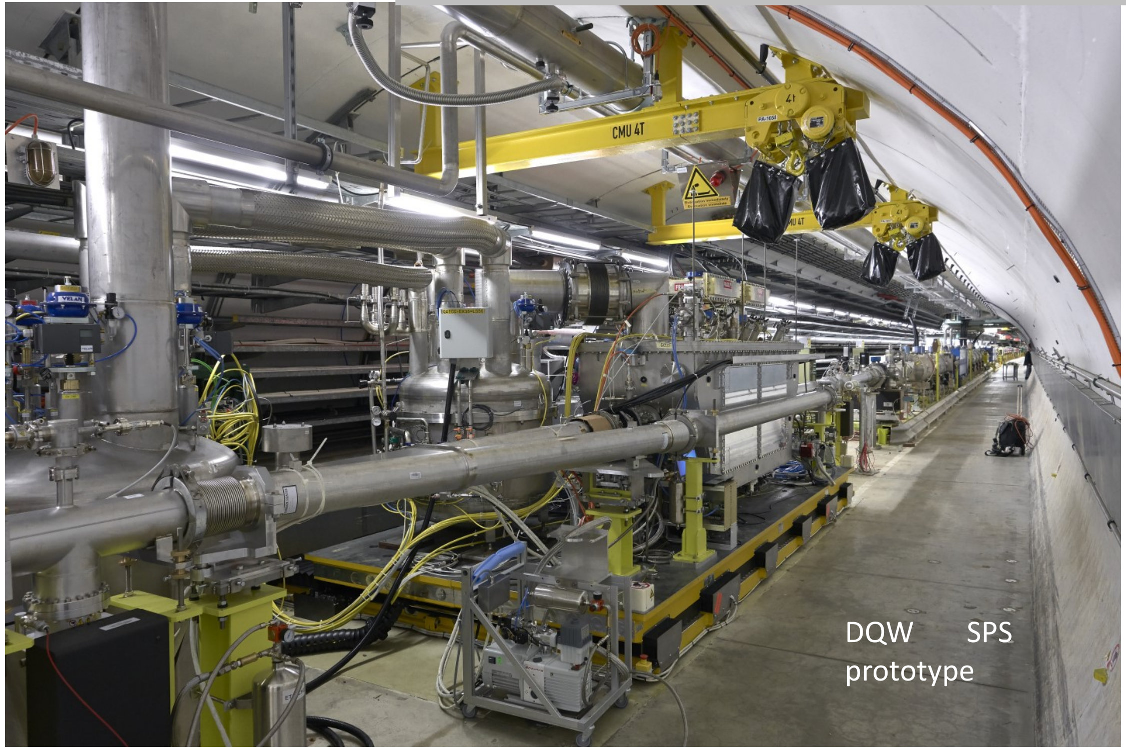
Material tests



Dummy vessel and bolt tests







DQW SPS prototype

Standards for machinery

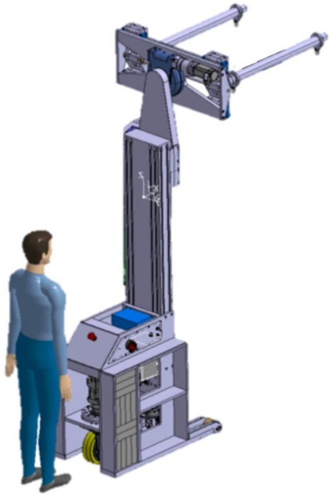
Focus on the European approach

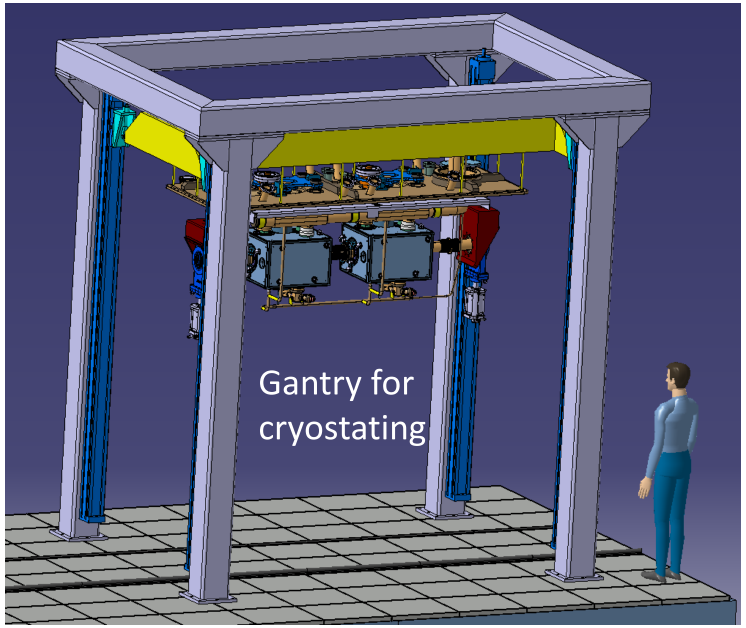
Machinery **DIRECTIVE 2006/42/EC** OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast):

- applies to Machinery: ‘*an assembly, fitted with or intended to be fitted with **a drive system other than directly applied human or animal effort**, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application*’
- Machinery must be designed, fabricated and tested according to the Essential Safety Requirements (ESRs) of Annex I (risk assessment is one of them)
- Notified Body is required only for specific machinery (Annex IV)
- Declaration of conformity, signed by the manufacturer, is mandatory
- ANNEX VII describes the Technical file for machinery

The EU **Machinery Regulation 2023/1230** becomes legally binding in all EU states on 20 January 2027 (key date regulation)!

Forklift truck for clean room





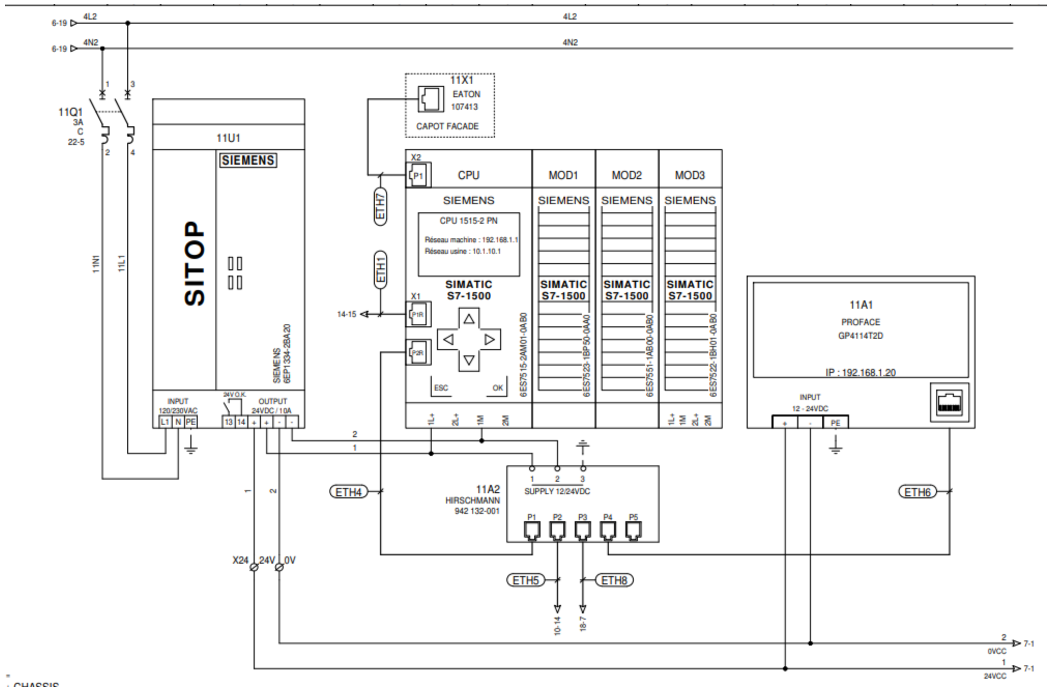
Technical standards

Rules / Laws / Directives	Standards	
Essential Safety Requirements / general statements	Technical detailed implementation (see next slides)	
European Union Directive: **Directive 2006/42/EC** of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast)	Harmonized Standards A-type standards specify basic concepts, B-type standards deal with specific aspects of machinery safety or specific types of safeguard that can be used across a wide range of categories of machinery. C-type standards provide specifications for a given category of machinery Here the list: Machinery (MD) - European Commission (europa.eu)	Not Harmonized Standards i.e. for some lifting device ASME B30.20, ASME B30.21, … and many others…
Mandatory / legal obligation	Not Mandatory / not legal obligation Presumption of Conformity with **Essential Safety Requirements**	Not Mandatory / not legal obligation **Proof of conformity is at the charge of the manufacturer**

Use Harmonised Standards

Machine control systems

- Machinery is today a mix of mechanics, electrics and electronics
- It is impossible to have a safe machine without a safe control system: control systems are classified according to their reliability (PL levels, SIL levels)



- The components of the control system shall be assembled with proper knowledge.
- Please contact always an experienced technician

Technical documentation

- Electric lift truck for Clean Room / Model: CERN-Alpha
  - management
  - technical file
    - risk analysis
      - 2213998 (v.0.5) Risk analysis for the clean room stacker
      - 2214007 (v.1) Compliance with Essential Safety and Health Requirements according to Directive 2006/42/CE
    - design
      - 2195055 (v.1) Study for the Electric / Power / Control scheme of a clean room stacker
      - 2258015 (v.1.0) Strength assessment (mechanical) of the fork lift truck for clean room
      - LHCACF_T0867 (v.0) LIFTER 2 CR SM18
      - 2314772 (v.0.4) Stability study
      - 2314776 (v.1.0) Study of drivetrain, lifting and rotation chains
      - LHCACF_T1233 (v.0) Lifter 2 CR SM18
      - 2646446 (v.1) Manufacturing pieces Lifteur 2 V2
      - LHCACF_T1294 (v.0) Lifter 2 CR SM18 V2
      - LHC-ACF_T-DF-0060 (v.1) Drawing folder - Lifter CR SM18 V2
      - 2773638 (v.1.0) Welded joints for the lift truck frame
    - manufacturing
      - 2194532 (v.1) Torque sensor Scaime
      - 2194540 (v.1) Gearbox Wittenstein
      - 2194543 (v.1) Vertical Drive Wheel Metalrota
      - 2194547 (v.1) Front Wheel Blickle
      - 2194552 (v.1) Linear Module Kynetic Systems
      - 2194562 (v.1) Rigth Angle gearbox Dynabox
      - 2194578 (v.1) Motor and control Kollmorgen
      - 2194598 (v.1) Gearbox Apex Dyna
      - 2194631 (v.1) Coupling Rotex
      - 2195127 (v.1) Motor and control Siemens
      - 2195156 (v.1) Linear guides SKF
      - 2195165 (v.1) Screw + Nut France Lineaire Industrie
      - 2195299 (v.1) Control command Compaut
      - 2195312 (v.1) Slew drive Cone (provided by ALTEAD)
      - 2262374 (v.1) Tansformer Murr Elektronik 86060
      - 2428556 (v.1) Collecteur electrique tournant ATC Production CE060A
      - 2693638 (v.1) Cooling Fan ebmpapst 634 HHU
      - 2724440 (v.1.0) Documentation proceedings the manufacturing of the frame
      - 2773981 (v.0.2) Electrical scheme
      - 2774660 (v.0.2) Documentation related to control system
      - 3064680 (v.1) Functional specifications for the control system (Perrin)
    - inspection and test
    - use
    - EC declaration
    - ownership
    - clean room floor (SM18)
    - 2195060 (v.1) Electric lift truck for Clean Room: machine description

Wired control system

https://edms.cern.ch/project/CERN-0000198978

Standards for lifting equipment

Machinery **DIRECTIVE 2006/42/EC** OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery

- Lifting accessories are a special case of Machinery directive, even if they are ‘static’, not motorized
- Most common category: **non-fixed load-lifting accessories**
- CE stamp required
- Technical file shall be delivered with the accessory

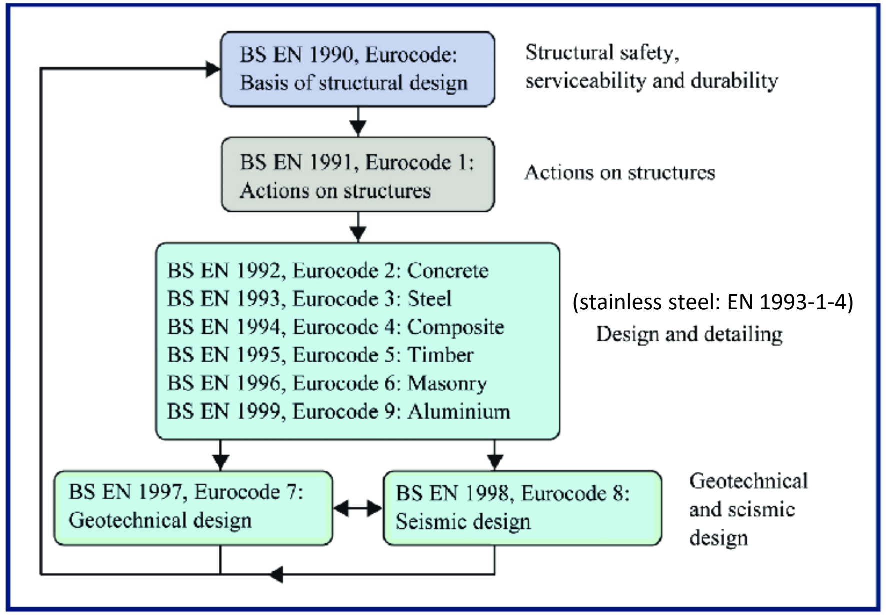
CRR-02932 - Palonnier SLINGSINTT pour aimant HL-LHC
- 2781410 (v.1) Image for Asset CRR-02932
- 2781797 (v.1) USER MANUAL R-2932
- 2781798 (v.1) PLAN ENSEMBLE R-2932
- 2781799 (v.1) CE CERTIFICATE R-2932
- 2781800 (v.1) NOTE DE CALCUL R-2932
- 2816117 (v.1) Rapport d'inspection de Sécurité Périodique de l'équipement CRR-02932
- 2816117 (v.2) Rapport d'inspection périodique Sécurité Générale du Bâtiment de l'équipement CRR-02932

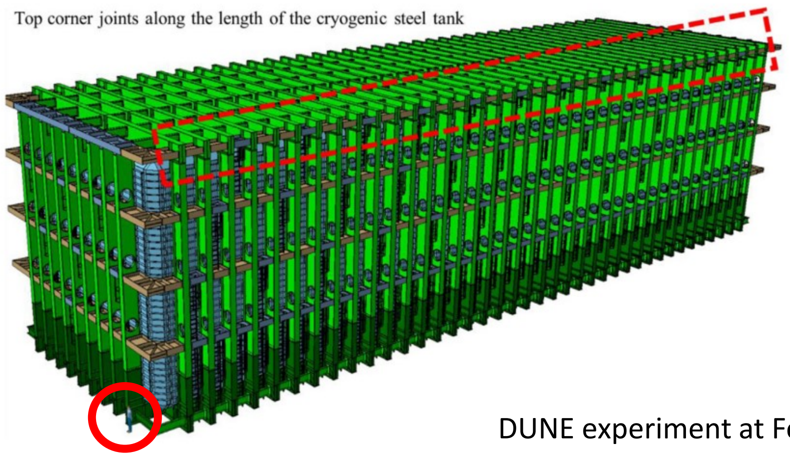
CRR-02932 - Palonnier SLINGSINTT pour aimant HL-LHC | Asset CRR-02932 (cern.ch)

Standards for big structures (buildings,…)

Eurocodes

Icarus WA104





DUNE experiment at Fermilab

Andrea CATINACCIO | M.Sc. Mech Eng | CERN, Genève | CERN | Physics Department (PH) | Research profile (researchgate.net)

- They are intended for structural design, mainly for civil engineering
- Application required for big structures at CERN
- WARNING: the legal context for the Eurocodes is slightly different from other European directives

Conclusions

Conclusions

- **Many domains of engineering are covered by rules and directives**: pressure equipment, cryogenic equipment, machinery, lifting accessory, buildings, …
- **Rules and directives have a legal status**: be sure you know the applicable rules to your working institution
- Technical standards are not mandatory. **Harmonized standards have a special importance**, due to the presumption of conformity
- **Standards impact the full lifecycle of the equipment**: design, manufacturing, inspection, test, operation, maintenance, repair
- **Documentation is of paramount importance** to demonstrate the **compliance** with the applicable rules. Among others, risk analysis is of primary relevance


CARTOONSTOCK
.com
Search ID: rman14314
"We're from the Galactic Bureau of Standards, and this planet is *way* out of compliance!"

Thank you for your attention

Questions?

Back-up slides

Definitions

Laws are based on broad principles, while rules are based on narrow technicalities in their application to specific cases and people involved in different situations.

Danger
"Danger" has a few meanings. It can be used as a substitute for risk, for example.
A "danger" is something or someone that can hurt you.
Dangers usually involve immediacy.
This is different from "hazard," in which the **exposure** might be extremely low, but there is a higher chance of great harm or death.
Let's look more closely at "hazard" now.

Hazard
A "hazard" is a source of danger or harm to a person or environment.
"Hazard" is a known threat. Yet, there is an unpredictable element to a "hazard."

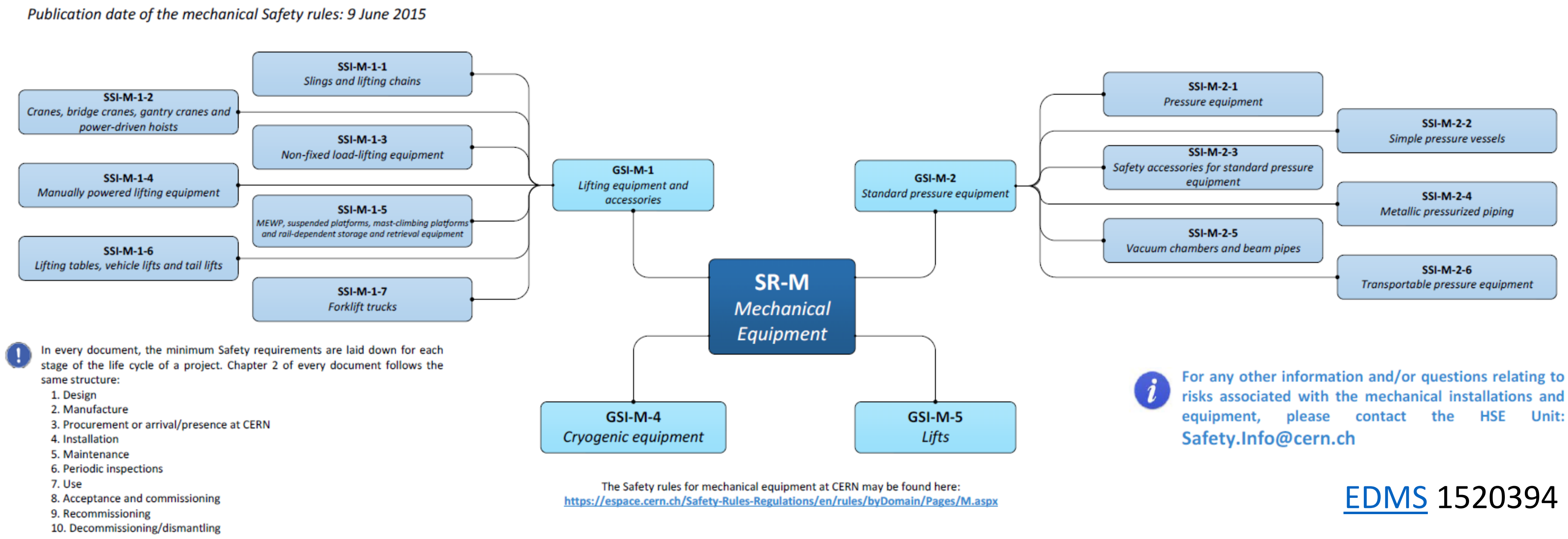
A hazard is something that can harm you, while a risk is the probability or likelihood of a hazard harming you

And in an accelerator facility?

At CERN

CERN Rules have priority on French and Swiss rules

Be aware! CERN is a special situation: it is SLIGHTLY DIFFERENT



EDMS 1520394

Somewhere else (at your facility, maybe)

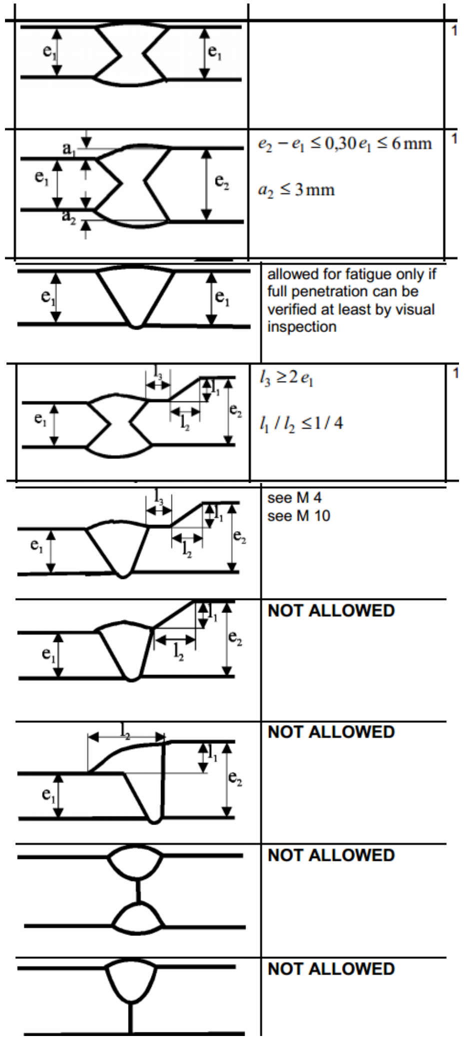
Most likely you must comply with legislation of the country

CHECK APPLICABLE RULES WITH EXPERTS!

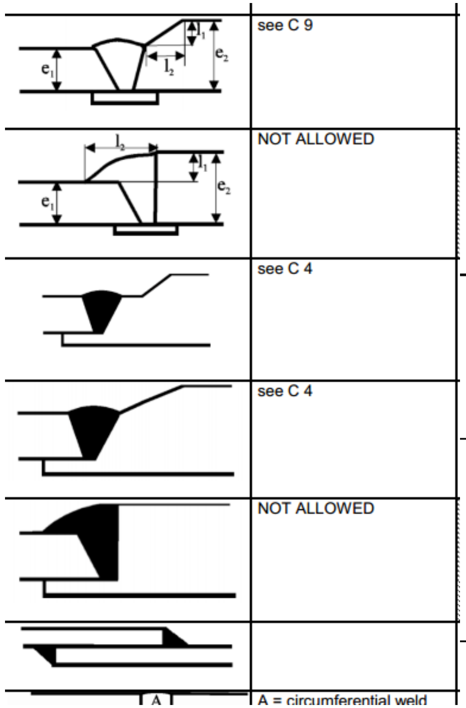
Standards for pressure and cryogenic equipment

EN 13445-3 annex A is a good reference for designing pressure bearing welds. EN 1708-1 is also a very useful harmonised standard. Some examples:

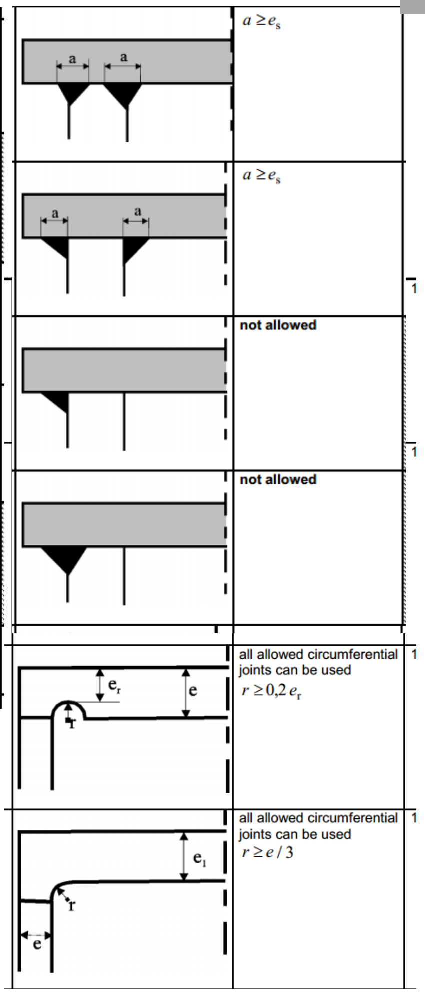
Longitudinal welds

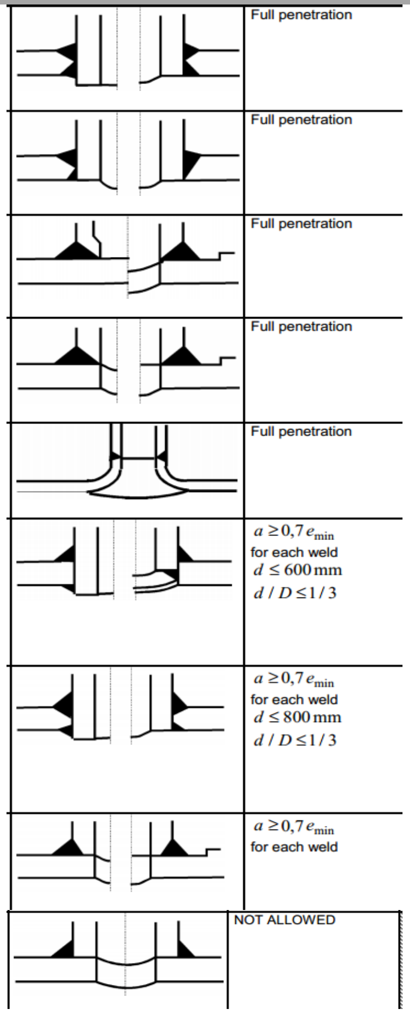


Circular welds



Flat ends





Materials

B.2.2.5 **Lowest minimum metal temperatures for austenitic stainless steels**

Solution annealed austenitic stainless steels according to Table B.2-11 can be applied down to temperature T_M without impact testing, except when impact testing is required by the material standard. E.g. EN 10028-7 requires impact testing at room temperature above 20 mm thickness for use at cryogenic temperatures (below -75 °C according to EN 10028-7:2007).

Table B.2–11 — Austenitic stainless steels and their lowest minimum metal temperature T_M

Material	Material number	T_M (in °C)
X1NiCrMoCu 31-27-4	1.4563	– 273
X1CrNiMoN 25-22-2	1.4466	
X1CrNi 25-21	1.4335	
X2CrNiMoN 17-13-3	1.4429	
X2CrNiMoN 17-11-2	1.4406	
X2CrNiMoN 18-12-4	1.4434	
X2CrNiMo 18-15-4	1.4438	
X2CrNiN 18-10	1.4311	
X2CrNiMo 18-14-3	1.4435	
X2CrNi 19-11	1.4306	
X6CrNiTi 18-10	1.4541	– 196
X1CrNiMoCuN 25-25-5	1.4537	
X1NiCrMoCuN 25-20-7	1.4529	
X1CrNiMoCuN 20-18-7	1.4547	
X1NiCrMoCu 25-20-5	1.4539	
X2CrNiMoN 17-13-5	1.4439	
X6CrNiMoTi 17-12-2	1.4571	
X3CrNiMo 17-13-3	1.4436	
X6CrNiMoNb 17-12-2	1.4580	
X2CrNiMo 17-12-3	1.4432	
X5CrNiMo 17-12-2	1.4401	
X2CrNiMo 17-12-2	1.4404	
X6CrNiNb 18-10	1.4550	
X5CrNi 18-10	1.4301	
X2CrNi 18-9	1.4307	
GX5CrNi9-10	1.4308	
GX5CrNiMo19-11-2	1.4408	
GX2NiCrMo28-20-2	1.4458	
GX2CrNi19-11	1.4309	
GX2CrNiMo19-11-2	1.4409	

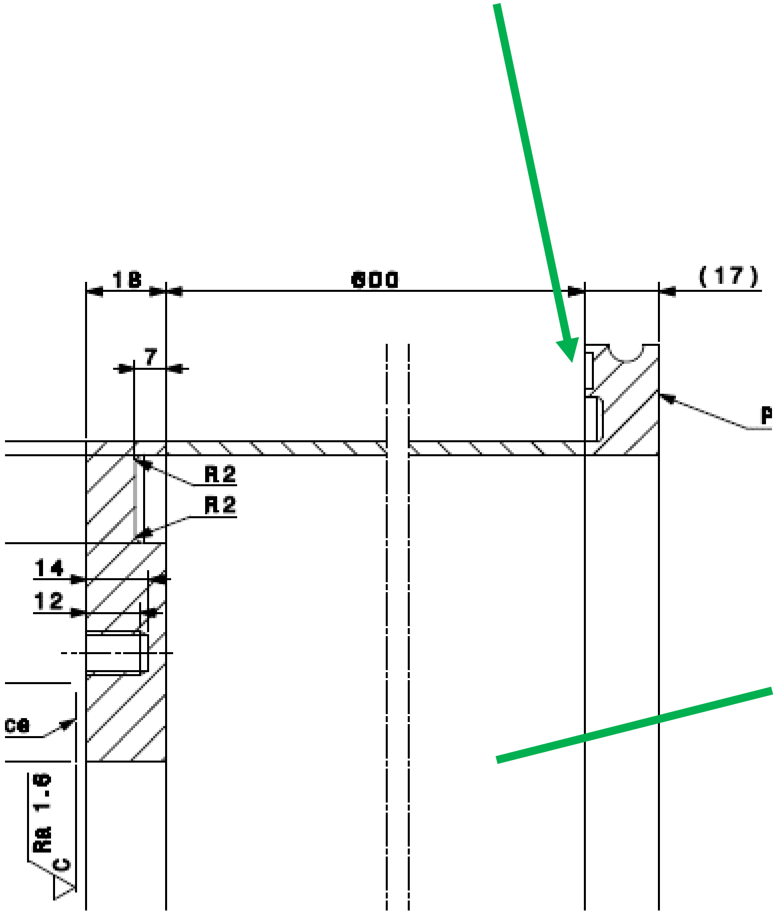
Not all the materials (304L, 316L, 316LN) are accepted for cryogenic use.

Harmonized standards:

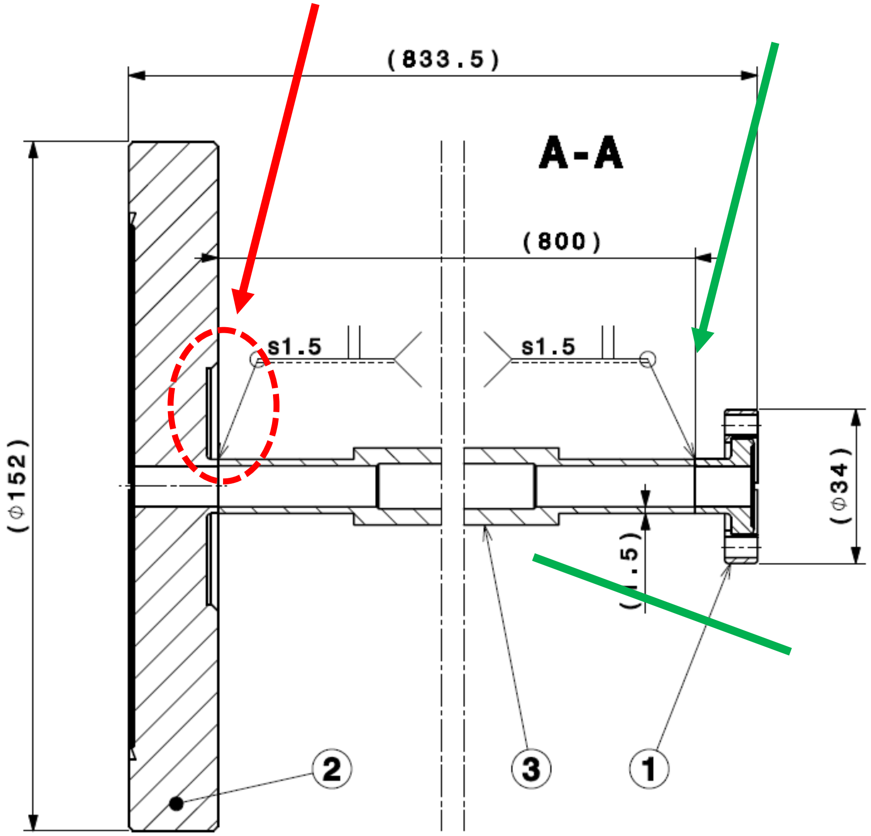
- EN13445-2:2014 -> Table B.2-11
- EN13458: not really clear
- EN1252-1:1998: the most important property is the material toughness at low temperature → > 27 J at -196 °C

See talks of Stefano Sgobba and Ignacio A. Santillana

NDTs



NDT is possible



NDT is not possible

Technical documentation

- HCACF_A004-UK000001 - RFD Cryomodule Prototype
  - HCACFVT004-UK000001 - RFD Vacuum Vessel Prototype
  - HCACFWM004-UK000001 - RFD Warm Magnetic Shield Prototype
  - HCACFTS004-CR000001 - RFD Thermal Shield Prototype
  - HCACFCC004-CR000001 - Miscellaneous material for UK
  - HCACFQC004-UK000001 - RFD Cryogenic lines Prototype
  - HCACFMC004-CR000001 - RFD FPC Main Coupler
  - HCACFMC004-CR000002 - RFD FPC Main Coupler
  - HCACFDC004-CR000001 - RFD Dressed Cavity Prototype CERN
    - HCACFHT004-CR000001 - RFD He Tank Prototype CERN (RFD Jacketed Cavity Prototype CERN)
    - HCACFHC006-CR000004 - CERN RFD V-HOM Coupler Prototype
    - HCACFHC007-CR000003 - CERN RFD H-HOM Coupler Prototype
    - HCACFPU004-CR000001 - CERN RFD Pick-up Antenna Prototype
    - HCVSSCA001-CR000005 - RFD BEAM SCREEN FULL ASSEMBLY (WP4 RFD Proto)
  - HCACFDC004-CR000002 - RFD Dressed Cavity Prototype CERN
  - HCVVGSC001-VT000001 - DN80 RF all-metal Gate Valve (WP4 RFD Proto)
  - HCVVGSC001-VT000002 - DN80 RF all-metal Gate Valve (WP4 RFD Proto)
  - HCVVGSC001-VT000003 - DN80 RF all-metal Gate Valve (WP4 RFD Proto)
  - HCVVGSC001-VT000004 - DN80 RF all-metal Gate Valve (WP4 RFD Proto)
  - HCVBMCC032-CR000001 - Short CWT Cavity line (SPS)
  - HCVBMCC033-CR000001 - Short CWT Secondary line
  - HCVBMCC034-CR000001 - Long CWT Cavity line
  - HCVBMCC035-CR000005 - Long CWT Secondary line
  - HCVBMCI014-CR000001 - Inter Cavities RF Bridges (SPS RFD)
  - HCVBMCI015-CR000001 - Inter Beam Screen RF Bridge (SPS RFD)
  - HCACFCC010-UK000001 - MLI RFD prototype
  - HCACFAH037-UK000001 - RFD Blade Support Assembly
  - HCACFAH037-UK000002 - RFD Blade Support Assembly
  - HCACFAH037-UK000003 - RFD Blade Support Assembly
  - HCACFAH037-UK000004 - RFD Blade Support Assembly
  - HCACFAH051-UK000001 - Cavity Support System
  - HCACFAH051-UK000002 - Cavity Support System
  - HCACFAH055-UK000001 - RFD Cold-Warm-Transition Supports prototypes
  - HCACFAH055-UK000002 - RFD Cold-Warm-Transition Supports prototypes
  - HCACFAH055-UK000003 - RFD Cold-Warm-Transition Supports prototypes
  - HCACFAH055-UK000004 - RFD Cold-Warm-Transition Supports prototypes
  - HCACFQC456-CR000001 - CRAB SM18 M7 test - Jumper assembly
  - CRPSD-00517 - RD820 Crab Cavity CM RFD PROTO_Disque Elfab OE6 1.1Bar DN100
  - CRPSV-21449 - SV820B Crab Cavity CM RFD PROTO_Soupape Circle Seal 532B 0.7Bar NPT 1"1/4M
  - CRPSV-21448 - SV820A Crab Cavity CM RFD PROTO_Soupape Circle Seal 532B 0.7Bar NPT 1"1/4M

MTF Application - Equipment Main Page (HCACF_A004-UK000001) (cern.ch)

For a big project: crab cryomodule

QUALITY AND SAFETY: complementary

Standards for machinery

Partly compl. machinery

Machinery **DIRECTIVE 2006/42/EC** OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast):

‘**partly completed machinery**’ means an assembly which is almost machinery but which cannot in itself perform a specific application. A drive system is partly completed machinery. Partly completed machinery is only intended to be incorporated into or assembled with other machinery or other partly completed machinery or equipment, thereby forming machinery to which this Directive applies;

Machinery Directive

DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC

Article 1

Scope

...

2. The following are excluded from the scope of this Directive:

...

(h) machinery specially designed and constructed for research purposes for temporary use in laboratories;

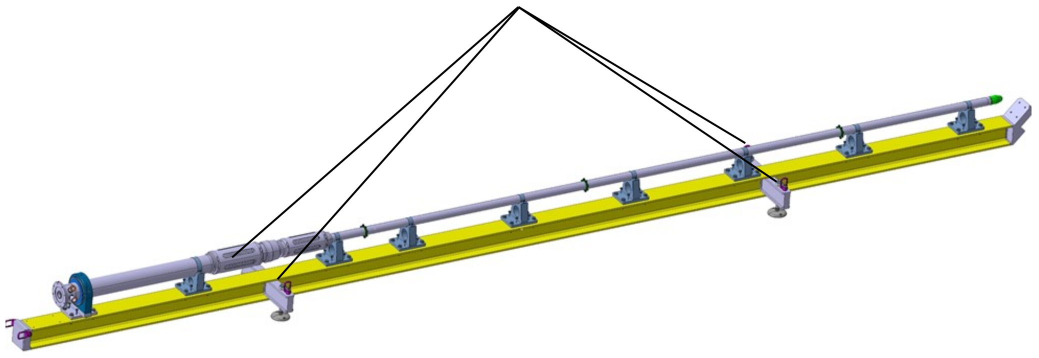
- What does 'temporary' mean?
- May an accelerator be qualified as a 'laboratory' following the Directive scope?

Standards for lifting equipment

Lifting equipment

Lifting procedure

The lifting procedure shall be studied carefully! => impact on the design and on the instruction => impact on safety!



HOW?

Standards for big structures (buildings,…)

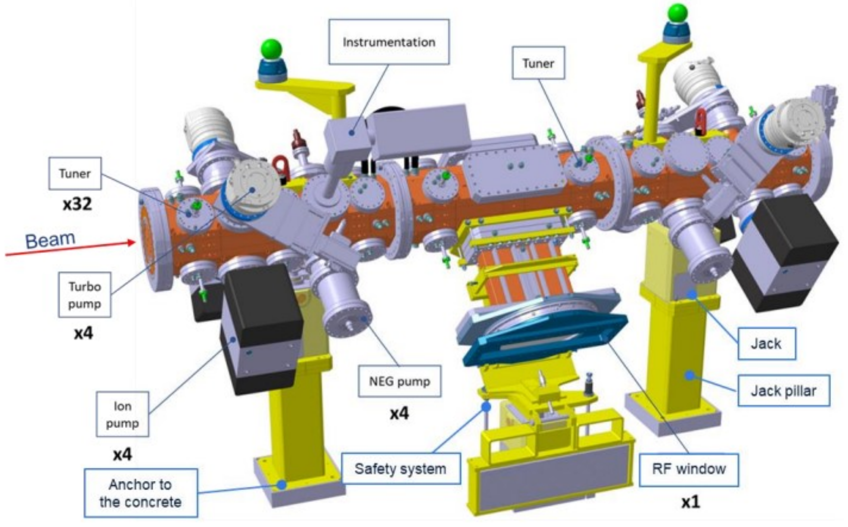


Figure 1. CAD view of the RFQ cavity and its equipment composed by pumps (Ions, Turbo, and NEG), instrumentation and tuner. The RF window, its support and the safety system are shown, as well as the sacks and jack pillars

[2591528_Report_LB_RFQ_Safety_Assessment_V2_3_docx_cpdf.pdf (cern.ch)]

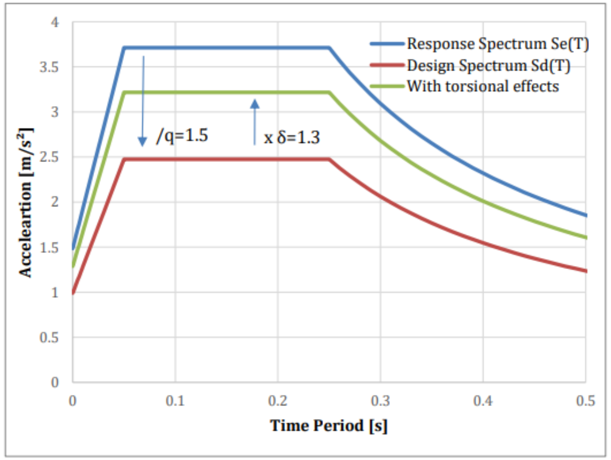


Figure 5. Part of the horizontal design acceleration spectrum used for seismic assessment calculated form the Elastic Response Spectrum after considering the ductility of the structure and the torsional effects

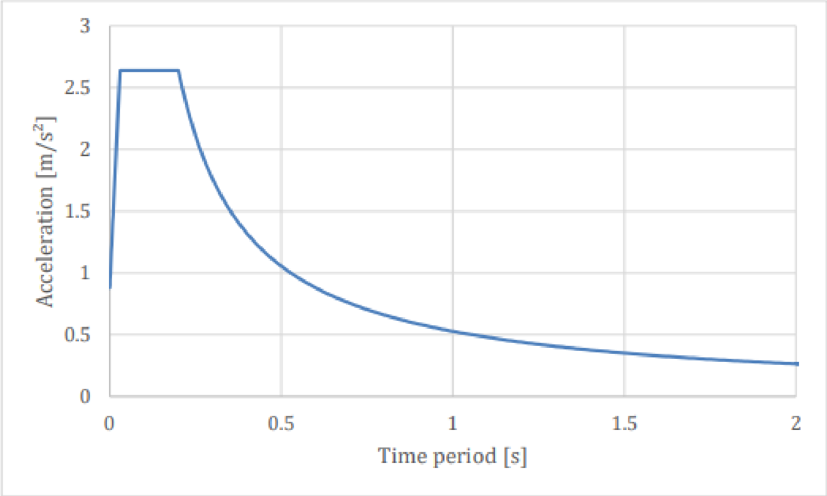


Figure 6. Vertical design acceleration spectrum used for seismic assessment

WARNING :

Eurocode 3 requires partial safety factors on loads (actions)

DIMENSIONNEMENT DES ASSEMBLAGES SOUDES

Calcul suivant Eurocode 3
EN 1993-1-8:2005

Formation T47B
Version 0.2
Page 14

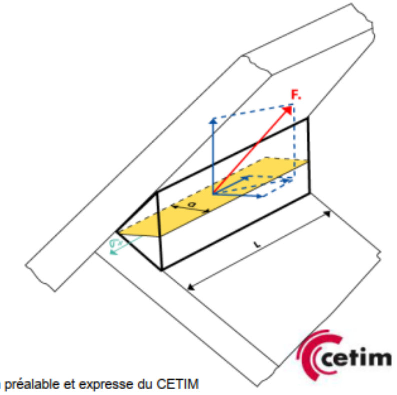
Domaine d'application : bâtiments et ouvrages de génie civil en acier

$$\beta_w \sqrt{\sigma_\perp^2 + 3\left(\tau_\perp^2 + \tau_{//}^2\right)} \leq \frac{f_u}{\gamma_{M2}}$$

et

$$\sigma_\perp \leq 0.9 \frac{f_u}{\gamma_{M2}}$$

	f_u	β_w	γ_{M2}	f_u / γ_{M2}	$f_u / \beta_w \gamma_{M2}$
S235	360	0.8		288	360
S275	410	0.85		328	385
S355	470	0.9	1.25	376	417
S420	520	1		416	416
S460	540	1		432	432



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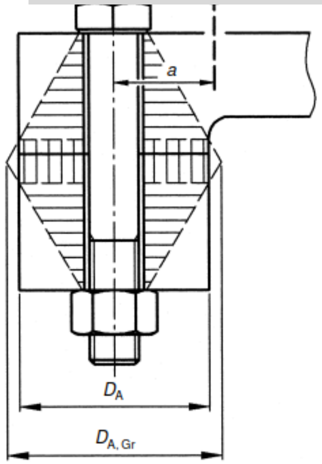
Guidelines

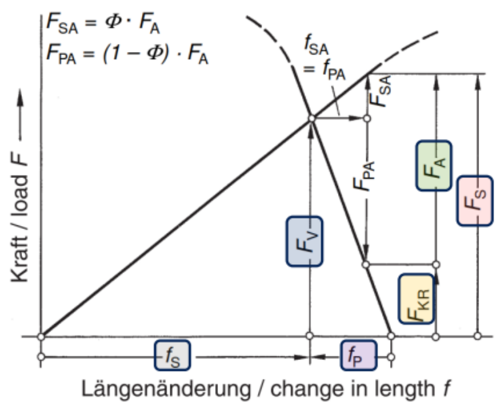
List of guidelines

Guidelines are available all around the word. Here some example of used guidelines at CERN

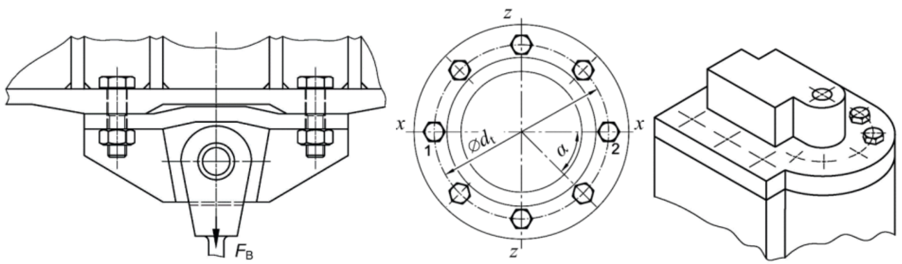
- US Military standards: MIL-STD-810H, MIL-STD-2073-2073-1
- NASA documentation: NASA Reference Publication 1228 (1990) Fastener Desing Manual
- ITER design handbook (restricted access): Remote Handlining Handbook
- VDI: see https://www.vdi.de/en/home/vdi-standards => VDI 2230

- VDI 2230-1 Systematic calculation of highly stressed bolted joints / Joints with one cylindrical bolt
- Formula available for manual calculations

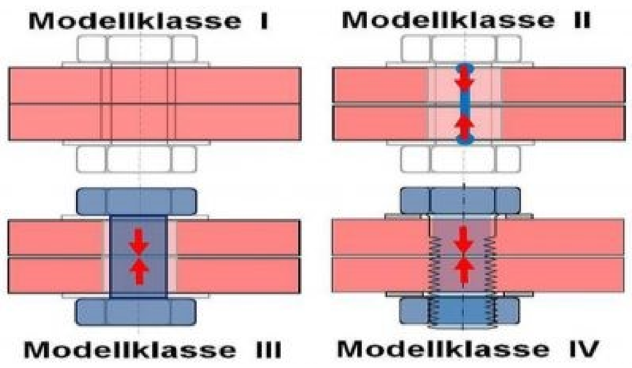




- VDI 2230-2 Systematic calculation of highly stressed bolted joints / Multi bolted joints



4 strategies for FE modelling of a bolt



- See EDMS 1866760 Application of FE-analysis in Design and Verification of Bolted Joints according to VDI 2230 at CERN"

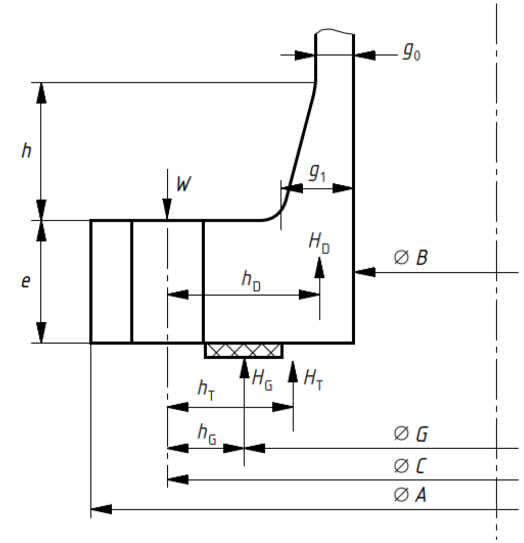
VDI 2230 NOT VALID FOR ALL APPLICATIONS! See next table

Table 1. Outline of BJs (adapted from [2])

Single-bolted joints		Multi-bolted joints						Bolted joints
concentric or eccentric		in a plane	axial symmetry			symmetrical	asymmetrical	bolt axes
cylinder or prismatic body	beam	beam	circular plate	flange with sealing gasket	flange with plane bearing face	rectangular multi-bolted joint	multi-bolted joint	
①	②	③	④	⑤	⑥	⑦	⑧	joint geometry
M_y, F_y, M_z, M_x, F_z, F_x	F_y, M_z, F_x	F_y, M_z, F_x	p	F_y, p, M_z, M_x	M_y, F_y, M_z, M_x	M_y, F_y, F_z, M_z, M_x, F_x	M_y, F_y, F_z, M_z, M_x, F_x	relevant loads
axial force F_A; transverse force F_Q; working moment M_B	axial force F_A; transverse force F_Q; moment in the plane of the beam M_Z	axial force F_A; transverse force F_Q; moment in the plane of the beam M_Z	internal ressure p	axial force F_A (pipe force); working moment M_B; internal pressure p	axial force F_A; torsional moment M_T; working moment M_B	axial force F_A; transverse force F_Q; torsional moment M_T; working moment M_B	axial force F_A; transverse force F_Q; torsional moment M_T; working moment M_B	forces and moments
VDI 2230		limited treatment by VDI 2230		DIN EN 1591 AD 2000 Note B7	limited treatment by VDI 2230			calculation procedure
bending beam theory with additional conditions			plate theory		limited treatment using simplified models			
finite element method (FEM)								

- EN 13445-3

(W is the design bolt load for assembly condition)



Eurocode 3 (EN 1993-1-8 Design of joints) and bolts: bolts not used in the same way! Bolts are mainly working in shear