TÜRK LOYDU

RULES FOR THE CLASSIFICATION OF NAVAL SHIPS

Chapter 111 - Submarines

January 2022

This latest edition incorporates all rule changes. The latest revisions are shown with a vertical line. The section title is framed if the section is revised completely. Changes after the publication of the rule are written in red colour.

Unless otherwise specified, these Rules apply to ships for which the date of contract for construction as defined in TL- PR 29 is on or after 1st of January 2022. New rules or amendments entering into force after the date of contract for construction are to be applied if required by those rules. See Rule Change Notices on TL website for details.

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Chapter 111 – Submarines

Section 16 - Rescue System

Annex A - Design of the Pressure Hull

Annex B - Fabrication Tolerances for the Pressure Hull

AMENDMENTS

Revision	RCS No.	EIF Date*
Section 01	02/2023	01.07.2023

* Entry into Force (EIF) Date is provided for general guidance only, EIF dates given in Rule Change Summary (RCS) are considered valid. In addition to the above stated changes, editorial corrections may have been made.

SECTION 1

RULES FOR CLASSIFICATION OF SUBMARINES

Page

A. Classification and Characters of Classification

1. Classification

1.1 The following Rules for Classification and Construction constitute the basis for the Classification of submarines.

In addition to these Rules, relevant Chapters of other **TL** rules apply.

1.2 For the purpose of these Rules, submarines comprise:

Manned military floating and surface-independent vessels.

Further definitions, see Section 2, B.

Deep Sea Rescue Vehicles (DSRV) and submarine rescue systems are to be classified according to Chapter 52 – Diving Systems.

1.3 The Classification covers the entire submarine including its structural elements, machinery and electrical equipment. Other systems and components may be included in the Classification and/or Certification procedure upon request of the Naval Authority.

1.4 The Certificate of Classification for submarines is issued by the Head Office of **TL**. It is to be kept on board.

1.5 Submarines classified by **TL** will be included in the **TL** data file observing the secrecy requirements of the Naval Authority. An extract of these submarine data will be entered in the Register published by **TL**, if the Naval AAuthority agrees.

1.6 Submarines are required to carry a log book in which details of repairs etc. are entered. The log book is to be presented to the Surveyor on request.

1.7 Submarines which are not to be classed by **TL** but which are constructed in accordance with the Rules and under the survey of **TL** may receive an appropriate Submarine Certificate from **TL**, see B.

2. Characters of Classification

2.1 The Character of Classification is:

- for the hull :

  +1 Np **SUBMARINE**

- for the machinery :

  +M U, [M U]

For definition of Class designations, see – Chapter 101 Classification and Surveys, Section 2.

2.2 For submarines and their equipment which are non-standard design, **TL** reserve the right to impose additional tests, to order a specific survey Schedule and to make relevant entries in the Submarine Certificate and the Register.

3. Validity of Class

For the validity of Class, see Chapter 101– Classification and Surveys, Section 1, D.

4. Classification of Submarines

4.1 For Classification of submarines built or converted under the survey of and in accordance with the Rules of **TL**, see Chapter 101– Classification and Surveys, Section 1, E.1.

4.2 For Classification of submarines not built under the survey of **TL**, see Chapter 101– Classification and Surveys, Section 1, E.2.

5. Surveys for Maintenance of Class

For surveys for maintenance of Class, definitions and due dates, see Chapter 101– Classification and Surveys, Section 3, A. and B.

6. Performance and Scope of Surveys

For performance and scope of surveys, see also Chapter 101– Classification and Surveys, Section 3, C., as far as applicable

6.1 Annual Surveys

The Annual Survey of the submarine shall include at least the following tests and checks:

6.1.1 Inspection of the documents relating to the submarine and scrutiny of the maintenance records.

6.1.2 A tightness test is to be performed on the pressure hull at an internal underpressure of at least 0,05 bar below atmospheric pressure.

6.1.3 The pressure hull and external structure including all fixtures, penetrations, doors and covers, seals, locking systems etc. are to be inspected for visible damage, cracks, deformation, corrosion attacks and fouling.

6.1.4 All other pressure vessels, heat exchangers and filters, as well as valves, fittings and safety equipment are to be subjected to external inspection.

6.1.5 The entire machinery installation including the electrical equipment is to be subjected to external inspection.

6.1.6 The function of the electrical power supply is to be tested.

6.1.7 Insulation measurements are to be performed on the electrical equipment.

6.1.8 The accuracy of all important instrument readings is to be checked, e.g. depth gauge, gas analyzer, etc

6.1.9 Wherever appropriate, all emergency and safety systems are to undergo a functional test.

6.1.10 High-pressure hoses (dynamic load characteristics) are to be checked for visible damage and tightness.

6.1.11 The communication system is to be subjected to a functional test.

6.1.12 The functional efficiency of the total system, especially the manoeuvring and diving equipment is to be checked by means of a trial dive.

6.2 Intermediate Surveys

Extended annual surveys are referred to as intermediate surveys. The intermediate survey falls due at half the nominal time interval between two Class Renewal Surveys (i.e. p/2). If p is an uneven number of years, the survey may be carried out on the occasion of the preceding or following annual survey. If p is an even number of years, the intermediate survey replaces the annual survey.

An Intermediate Survey is an Annual Survey extended as follows unless it coincides with the Class Renewal Survey in accordance with 6.3:

6.2.1 Performance of a tightness test on pressure hull penetrations and closing appliances, e.g. by application of an underpressure inside the submarine.

6.2.2 Pressure chambers/diver's lockouts are to undergo a tightness test at maximum operating depth.

6.2.3 Tightness test on diving/ballasting, regulating/compensating and trimming systems.

6.2.4 Verification of the set pressures of safety valves and of safety and alarm systems.

6.2.5 Functional tests on mechanical and electrical equipment.

6.2.6 Functional and tightness tests on life support systems.

6.2.7 Functional tests on fire warning and extinguishing systems.

6.2.8 Functional tests on all alarm systems.

6.2.9 Functional test and purity check on all breathing gas compressors.

6.2.10 After ten years, all compression chambers and all pressure vessels, heat exchangers and filters which cannot be subjected to satisfactory internal inspection are to undergo a hydrostatic pressure test.

6.3 Class Renewal Surveys

A Class Renewal Survey is performed every p years. The following tests and examinations are to be carried out in addition to the inspections called for under 6.1 and 6.2:

6.3.1 A tightness test is to be performed on the pressure hull at an internal underpressure of at least 0,18 bar below atmospheric pressure.

6.3.2 Dimensional checks and non-destructive tests (wall thickness, cracks etc.) are to be performed on the pressure hull and lockouts. Where necessary, buoyancy aids, cladding and layers of thermal insulation are to be removed for this purpose.

6.3.3 Bouyancy tests are to be performed.

6.3.4 In the case of pressure vessels, heat exchangers and filters which cannot be satisfactorily inspected internally and those whose satisfactory condition cannot be fully verified by internal inspection, another non-destructive test method is to be used.

6.3.5 Where surveys are performed on a submarine or parts thereof during the period of Class, the scope of which corresponds to a Class Renewal Survey, then the regular Class Renewal Survey for the parts concerned may at the operator's request be deferred accordingly.

6.4 Damage Surveys

6.4.1 If the submarine or its ancillary systems has suffered damage affecting its Class or if such damage may be assumed, a Damage Survey is to be carried out.

6.4.2 Following damage, the submarine is to be presented for survey in such a way that a satisfactory inspection can be carried out. The extent of the Damage Survey will be determined by **TL** in each individual case.

6.5 Extraordinary Surveys

6.5.1 When any modification is made in respect of design, mode of operation or equipment, and after major repairs to the submarine, an Extraordinary Survey is to be carried out.

6.5.2 Where modifications are made to the submarine which affect its buoyancy or stability, appropriate heeling and trim experiments are to be performed in the presence of the Surveyor.

B. Surveys Other Than Classification

1. Surveys by Special Agreement

Where surveys are required by the Naval Authority, international agreements or other provisions, **TL** will perform them on request, and by official order in accordance with the relevant provisions

2. Surveys Relating to the Safety of Equipment

2.1 For all components with an important safety aspect (e.g. pressure vessels, heat exchangers and filters etc.), **TL** will, on request, examine the drawings, carry out all the necessary surveys, acceptance tests and pressure tests and issue the relevant certificates.

2.2 On request, **TL** will also perform the subsequent surveys required for pressure vessels, heat exchangers and filters.

C. Certification

On request, **TL** will issue an appropriate Certificate in respect of submarines or parts thereof which, while not classified by **TL,** are built under the survey of and in accordance with the Rules of **TL** or other recognized rules for the construction of submarines.

D. Workmanship

1. General

1.1 Requirements to be complied with by the Shipyard and the manufacturers

1.1.1 Every manufacturing plant shall be provided with suitable equipment and facilities to enable proper handling of the materials, manufacturing processes, structural components, etc. **TL** reserve the right to inspect the plant accordingly or to restrict the scope of manufacture to the potential available at the plant.

The manufacturing plant shall have at its disposal sufficiently qualified personnel. **TL** is to be advised of the names and areas of responsibility of all supervisory and control personnel. **TL** reserve the right to require proof of qualification.

1.1.2 The shipyard or manufacturing plant and its subcontractors have to get approval from **TL** for the type of work they provide for the manufacture and installation of naval submarines. Approval can only be given if the conditions defined in detail in the **TL** Material Rules are complied with.

1.1.3 The fabrication sites, stores and their operational equipment shall also comply with the requirements of the relevant Safety Authorities and Professional Associations. The shipyard or manufacturing plant is alone responsible for compliance.

1.2 Quality control

1.2.1 The Shipyard shall operate a quality assurance system, such as ISO 9001 or equivalent.

1.2.2 As far as required and expedient, the manufacturer's personnel has to examine all structural components both during the manufacture and on completion, to ensure that they are complete, that the dimensions are correct and that workmanship is satisfactory and meets the standard of good shipbuilding practice.

1.2.3 Upon inspection and corrections by the manufacturing plant, the structural components are to be shown to the **TL** Surveyor for inspection, in suitable sections, normally in unpainted condition and enabling proper access for inspection.

1.2.4 The Surveyor may reject components that have not been adequately checked by the plant and may demand their re-submission upon successful completion of such checks and corrections by the plant.

2. Structural Details

2.1 Details in manufacturing documents

2.1.1 All significant details concerning quality and functional ability of the components concerned shall be entered in the manufacturing documents, workshop drawings, etc. This includes not only scantlings but,where relevant, such items as surface conditions (e.g finishing of flame cutting edges and weld seams), and special methods of manufacture involved as well as inspection and acceptance requirements and, where relevant, permissible tolerances.

A production standard which considers the special requirements for the manufacturing of naval submarines has to be defined by the Shipyard or manufacturing plant and approved by **TL**.

2.1.2 If, due to missing or insufficient details in the manufacturing documents, the quality or functional ability of the component cannot be guaranteed or is doubtful, **TL** may require appropriate improvements. This includes the provision of supplementary or additional parts, e.g. reinforcements, even if these were not required at the time of plan approval.

SECTION 2

GENERAL REQUIREMENTS

A. Scope

1. The following requirements contain additional requirements for the Classification and construction of submarines and are complementary to other relevant **TL** Rules.

2. In the case of submarines with a diver's lockout, the parts concerned are also required to conform to **TL** Rules, Chapter 52 - Diving Systems in addition to the Rules set out in the following.

3. Designs differing from the Rules of Construction may be permitted provided that they have been recognized by **TL** as equivalent.

4. Submarines or parts thereof whose development is based on new principles and which have not yet been sufficiently tested in practical operation require special approval by **TL.**

5. In the cases mentioned in 3. and 4., **TL** is entitled to require the submission of additional documentation and the performance of special tests.

6. **TL** reserves the right to impose demands additional to those contained in the Rules in respect of all types of submarines when such action is necessitated by new knowledge or practical experience, or to sanction deviations from the Rules in specially justified cases.

7. National regulations existing alongside **TL** Rules are unaffected.

B. Definitions

1. Breathing Gas

All gases/mixtures which are used for breathing during underwater operations.

2. Compression Chamber

Chamber for accommodation of persons at more than atmospheric pressure.

3. Control Station

Central area at which all essential indicators, control and monitoring devices, communication systems of the submarine are arranged.

4. Collapse Diving Depth

Calculated external pressure liable to cause collapse of the pressure hull.

5. Collapse Diving Pressure CDP

Overpressure corresponding to the collapse diving depth.

6. Diving Pressure

The overpressure, corresponding to the relevant diving depth, to which a submarine is exposed during underwater operations.

7. Emergency Condition

Condition where the safety of the boat and the personal on board cannot be established any more by one or more systems for normal operation but back-up systems for life support, diving/ballasting, regulating/ compensating, trimming, freeing, internal and external communication power supply and power distribution, hydraulic oil supply, steering and rudder indication, lighting, fire detection and alarm, locating equipment, etc. have to be used to allow safe operation of the boat under reduced capability.

8. Exostructure

External cladding, supporting structures and fixtures outside the pressure hull which normally are not designed to withstand the diving pressure.

9. Life Support Systems

Systems for breathing gas supply, purification, exchanging and conditioning of the atmosphere in the pressure hull, for the supply of water and food and for the removal of waste.

10. Lockouts

A trunk including 2 hatches in a submarine for locking in and out at diving pressure.

11. Mating System

The equipment necessary for the connection and disconnection of a submarine with a DSRV or a submarine rescue system.

12. Nominal Diving Depth

The maximum depth to which the submarine is designed to dive an unlimited number of times. This depth corresponds to the nominal diving pressure.

13. Nominal Diving Pressure

Overpressure corresponding to the maximum operating depth (nominal diving depth).

14. Pressure Gas Cylinder

A pressure vessel for the storage and transport of gases under pressure.

15. Pressure Hull

The main component of a submarine which accommodates the crew at atmospheric pressure and withstands the external diving pressure.

16. Pressure Vessel

A vessel, heat exchanger or filter capable of withstanding an internal or external working pressure of 1 bar or over.

17. Rescue System

Systems and equipment used for recovering the submarine and rescuing its crew.

18. Submarine

A manned surface-independent unit capable of operating underwater.

19. Test Depth

The test depth corresponds to the external overpressure under test conditions. The depth is measured to the underside of the pressure hull.

20. Total System

The submarine including its mating, working and supply systems and ancillary equipment.

C. Documents for Approval

1. General

1.1 Before the start of manufacture, plans of the total system and drawings of all components subject to compulsory inspection, wherever applicable and to the extent specified below, are to be submitted to **TL** in triplicate.

1.2 The drawings shall contain all the data necessary to check the design and loading of the equipment. Wherever necessary, calculations relating to components and descriptions of the system are to be submitted.

1.3 Once the documents submitted have been approved by **TL**, they become binding on the manufacturer. Any subsequent modifications require **TL**'s consent before they are implemented.

1.4 **TL** reserve the right to request additional documentation if the submitted one is insufficient for an assessment.

2. Total System

The following documents are to be submitted:

2.1 A description of the submarine with details of its mode of operation, the proposed application and the essential design data including:

- Maximum diving depth

- Maximum operating time and maximum survival time

- Maximum number of persons in pressure hull

- Divers' compression chamber

- Diving procedure

- Speed (surfaced and submerged)

- Type of propulsion and manoeuvring equipment

- Weight of vessel, deadweight and ballast, displacement (submerged)

- Further requirements defined by the Naval Authority.

2.2 General arrangement plan and drawings showing design details of the submarine, including specifications for materials, manufacture and testing.

2.3 A comprehensive presentation of the intended corrosion protection measures.

2.4 Trial program.

3. Pressure Hull

3.1 Drawings and calculations for the pressure hull are to be submitted with all essential particulars and details necessary for appraising the safety and including the specifications for materials, manufacture, welding and testing. The drawings are to show all the internal and external fixtures of the pressure hull (e.g. strengthening ribs, machine bedplates, mountings etc.), welding details, etc.

3.2 In addition, component drawings of the pressure hull equipment are to be submitted including:

- Entry and exit hatches

- Door panels and door frames

- Block flanges

- Pressure hull penetrations and their arrangement

- Pressure bulkheads

- Lockouts

3.3 Drawings and descriptions of the space allocation and internal arrangements are to be submitted.

4. Exostructure

Plans and sectional drawings of the vessel's envelope and supporting structure are to be submitted including details of such pressure hull fixtures as diving/ballasting tanks, stabilizing fins, rudders, streamlining elements, extension devices, snorkels, anchors, etc.

5. Diving/ballasting, Regulating/compensating and trimming tanks

Arrangement details of diving/ballasting, regulating/ compensating and trimming tanks with calculated proof of the vessel's static diving capability and stability when submerged and on the surface, including the intermediate conditions occurring when the submarine is diving or surfacing both normally and under emergency conditions.

6. Pressure Vessels, Heat Exchangers and Filters

Drawings of the pressure vessels, heat exchangers and filters are to be submitted with all essential particulars and details necessary for appraising the safety of the equipment and including the specifications for materials, manufacture, welding and testing.

7. Piping Systems, Pumps and Compressors

7.1 Schematic diagrams of all piping systems including details of:

- Materials

- Maximum allowable working pressure/ temperature

- Dimensions (diameter, wall thickness)

- Media carried
- Type of valves and connections used
- Type of hoses used

7.2 Description of pumps, compressors and their drives together with all important design and operating data.

8. Control Systems for Depth, Positive and Negative Buoyancy and Trim

Description of the control systems for depth, positive and negative buoyancy and trim, including the necessary piping diagrams and component drawings. This includes drawings of:

- Compressed air system for blowing diving/ballasting tanks
- Freeing systems
- Regulating/compensating and trimming system

9. Propulsion and Manoeuvring Equipment

Drawings and descriptions are to be submitted of the propulsion and manoeuvring equipment including engines, gears, couplings, shafting, propellers and rudders with details of:

- Method of power generation
- Mode of operation and control of the systems
- Power consumption (type and quantity)
- Method of power transmission to propulsion unit
- Seals of pressure hull penetrations
- Operating range and response time of rudder

10. Electrical Equipment

The following are to be submitted:

10.1 A general arrangement drawing of the electrical equipment containing at least the following information:

- Voltage rating of the systems
- Power or current ratings of electrical consumers
- Switchgear, indicating settings for short-circuit and overload protection; fuses with details of current ratings
- Cable types and cross-sections

10.2 The power balance of the main and emergency/redundant power supply systems.

10.3 Drawings of switchgear and distribution equipment with parts lists.

10.4 Complete documentation for electric motor drives with details of control and monitoring systems.

10.5 Battery installation drawing with details of battery types, chargers and battery room ventilation.

10.6 Details of electrical penetrations pressure hull, bulkheads, watertight or airtight bulkheads.

10.7 Diagrams showing allocation of pressure hull penetrations.

10.8 Diagrams showing arrangement of emergency light fittings.

10.9 Calculation of short-circuit conditions with details of circuit-breakers, power protection switches and fuses

10.10 Hazardous area lay out

10.11 A list of electrical components installed in hazardous area including the type of exprotection of these components. The ex certificates have to be added.

11. Control and Monitoring, Communications, Navigation and Locating Systems

The following are to be submitted:

11.1 Description of the complete instrumentation layout.

11.2 Description of the control and operating elements for the submarine and its equipment.

11.3 Description of the navigational and diving instrumentation, including speed and position indicators.

11.4 A description of the safety and alarm systems.

11.5 Arrangement drawings/block diagrams of monitoring systems including lists of measuring points.

11.6 Documentation for electronic components such as instrument amplifiers, computers and peripheral units.

11.7 General diagrams and equipment lists for the communication systems and signalling equipment.

11.8 General diagram and description of the surveillance/camera system, if applicable.

11.9 Descriptions, general diagrams and equipment lists for the locating equipment.

12. Life Support Systems

The following are to be submitted:

12.1 Piping diagrams, block diagrams and descriptionsof the systems and equipment used for breathing gas supply, circulation, purification and conditioning of the atmosphere in the pressure hull, including the monitoring equipment, for both under normal and emergency conditions.

12.2 Calculated proof of the adequate capacity of the breathing gas supply and air renewal systems under normal and emergency conditions.

12.3 Description of the facilities for supplying water, food and medicines and for the removal of waste.

13. Fire Protection and Fire-extinguishing Equipment

The following are to be submitted:

13.1 Description of preventive fire precautions

13.2 Fire protection plans

13.3 Details of the nature and quantity of combustible materials in the submarine.

13.4 Drawings and descriptions of:

- Fire detectors
- Fire alarms
- Fire extinguishers
- fire extinguishing system

13.5 Analysis of the potential dangers in the event of fire.

14. Rescue System

14.1 Systems and equipment

Drawings and descriptions of the systems and equipment used for recovering the submarine and rescuing the crew are to be submitted.

14.2 Safety plan

The safety plan indicating where damage control equipment is stored and exit route is to be submitted. The frequency of checking and certifying the equipment must be submitted with the plan.

15. Mating System

15.1 Description of system with details of operating parameters.

15.2 Design drawings of mechanical, electrical, hydraulic and pneumatic operating equipment.

D. Tests and Trials

1. General

1.1 Submarines and their ancillary equipment are subject to constructional and acceptance testing. As a minimum requirement, this shall include verification of compliance with the approved documents, inspection of workmanship, verification of materials and the relevant documentation and checking of dimensional tolerances. In addition, all the tests prescribed in the following are to be performed and documented, wherever applicable.

1.2 For series-manufactured parts, test procedures other than those prescribed may be agreed with **TL** provided that they are recognized as equivalent by **TL**.

1.3 **TL** reserves the right to extend the scope of the tests where necessary and also to subject to test those parts for which testing is not expressively required by the Rules.

1.4 Parts subject to compulsory inspection are to be replaced by tested parts. This is also applicable to spare parts.

1.5 Where submarines are equipped with a diver's lockout, the components and equipment concerned are also to be subjected to the tests prescribed in the **TL** Rules, Chapter 52-Diving Systems.

2. Total System

On completion, the submarine is to be subjected to a functional and acceptance test in accordance with the approved trial programme. This shall include at least the following individual tests:

- Inspection of assembly (where not already performed during supervision of manufacture)

- Measurement of weight and buoyancy and checking of stability under normal and emergency conditions

- Inspection of internal equipment, partition bulkheads with doors, floors and ladders

- Testing of all safety devices

- Functional testing of diving/ballasting, regulating/ compensating and trimming system

- Functional testing of mechanical and electrical equipment

- Heeling or trimming experiment submerged

- Testing of the ballast release system (if provided)

- Trial trip on surface with verification of buoyancy

- Trial trip submerged

- Functional testing of life support systems

- Verification of the accuracy of all important instrument readings

- Insulation test on the electrical equipment

3. Pressure Hull

3.1 On completion of the machining work and any necessary heat treatment, pressure hulls are to be subjected to a hydraulic external pressure test. This test may be performed either in a pressurized environment or as part of a submersion test carried out on the completed submarine. The test pressure is to be determined in accordance with Section 4, Table 4.4.

Pressure hull compartments in which an internal overpressure may occur are to be subjected to a hydraulic internal pressure test at 1.5 times the maximum allowable working pressure of the compartment.

After the pressure tests, the pressure hull is to be examined for leaks, permanent deformations and cracks.

3.2 Pressure hull penetrations and closing appliances are to be tested for tightness by the application of a negative pressure of at least 0.2 bar from inside the boat/system.

3.3 If pressure hull windows are fitted, they are to be subjected to a hydraulic pressure test. The test may be performed after installation together with the pressure hull or individually in a testing device. The test pressure is to be determined in accordance with 3.1.

After the pressure test, windows may exhibit no scratches, cracks or permanent deformation.

4. Exostructure

4.1 A check is to be carried out on the arrangement, mounting and fastening of such equipment items as stairways, gratings, handrails, bitts, masts, navigating lights, towing devices and draught marks.

4.2 External structural components such as anchors, rudders, etc. are to be subjected to a functional test.

5. Diving/ Ballasting, Regulating/ Compensating and Trimming Tanks

5.1 Closed diving/ballasting tanks are to be subjected to a tightness test using air at an excess pressure of about 0,2 bar.

5.2 Regulating/compensating and trimming tanks are to be subjected to a hydraulic pressure test at 1,5 times the maximum allowable working pressure.

6. Pressure Vessels, Heat Exchangers and Filters

6.1 Pressure vessels are to undergo a hydraulic pressure test before being insulated or painted. The test may result in no leakage or permanent deformation of the vessel walls.

6.2 The test pressure applied to pressure vessels, heat exchangers and filters shall generally be equivalent to 1,5 times the maximum allowable working pressure.

6.3 Pressure vessels which may be subjected to external overpressure equivalent to the maximum allowable diving depth of the submarine are to be subjected to an external pressure test. The test pressure shall be at least equal to that applied to the pressure hull.

7. Piping Systems, Pumps and Compressors

7.1 Pipes

7.1.1 On completion but before being insulated or painted, all pipes are to undergo a hydraulic pressure test at 1,5 times the maximum allowable working pressure.

7.1.2 After installation on board, all pipes are to undergo a tightness test at 0,8 times the maximum allowable working pressure.

7.1.3 Pipes for breathing gas and oxygen are to be tested for cleanliness.

7.2 Pumps and compressors

7.2.1 Pump and compressor components subjected to pressure are to undergo a hydraulic pressure test.
For pumps the test pressure shall be 1,5 times the maximum allowable working pressure for compressors, 1,5 times the delivery pressure of the compressor stage concerned.

7.2.2 On completion, pumps and compressors are to be subjected to a tightness test at their maximum allowable working pressure. In addition, a performance test is to be carried out. With breathing gas compressors, the final moisture content and any possible contamination of the compressed gas are also to be determined. The safety devices are also to be checked.

8. Control systems for depth, positive and negative buoyancy and trim

8.1 Diving/ballasting, regulating/compensating, trimming and freeing systems are to be subjected to a functional test under normal and emergency conditions. The measuring devices as well as the safety and alarm equipment are to be checked.

8.2 The diving/ballasting tank venting systems and the operating elements are to be subjected to a functional test.

9. Propelling and Manoeuvring Equipment

9.1 The installation of the propelling and manoeuvring equipment is to be checked.

9.2 The entire propulsion plant is to be subjected to a functional test, surfaced and submerged.

10. Electrical Equipment

10.1 In principle all electrical machines, components, including steering and control positions, cables and lines are to be tested in the manufacturer's works in accordance with **TL** Rules, Chapter 105-Electrical Installations.

10.2 All electrical systems and equipment are to be inspected and tested before the submarine is put into service.

10.3 Electrical protective devices are to be checked; in addition, an insulation test is to be performed on the electrical equipment in the pressure hull.

11. Control and Monitoring, Communications, Navigation and Locating Equipment

11.1 Indicating and monitoring instruments are to be tested for the accuracy of their readings and their limit value settings.

11.2 Automatic control systems are to be checked for satisfactory performance under service conditions.

11.3 Normal and emergency communications equipment is to be subjected to a functional test.

11.4 Proof is required of the autonomy of the safety systems.

12. Life Support Systems

12.1 A functional test is to be carried out to verify the satisfactory functioning of the life support system under normal and emergency conditions.

12.2 The arrangement of the O_2, CO_2 and H_2 measuring devices is to be inspected, and they are to be checked for the accuracy of their readings and their limit value settings.

12.3 The sanitary facilities are to be checked to ensure that they are functioning properly.

12.4 The installation of the ventilation system is to be inspected and the operation of the fans and fire flaps is to be checked.

12.5 A functional test of the waste removal system is to be carried out at NDD.

12.6 A functional test of the signal ejector is to be carried out at the NDD. In case that a manual emergency operation mode is provided for the signal ejector this additional test shall be carried out at a diving depth of 50 m to avoid dangerous situation to the crew during operation.

12.7 As far as applicable functional or other tests of the rescue system used for recovering the submarine and rescuing the crew.

13. Fire Protection

13.1 The fire behaviour of the internal fittings and equipment is to be checked by reference to the relevant test Certificates and symbols, as applicable.

13.2 A check is to be made as to whether the electrical heating systems and heaters are fitted with protection against overheating.

13.3 Fire alarm, detection and extinguishing appliances and, if provided, the fire extinguishing system are to be subjected to a functional test.

14. Ballast Release Systems

If a ballast release system is installed it is to be subjected to a functional test in shallow water. In the course of this test it shall be proved that the release gear functions properly even with the submarine at the maximum permissible inclination and that adequate stability of the unit is maintained after release.

15. Mating System

15.1 Where a mating device is provided, a test is to be performed to verify that release and transfer can only take place when the trunk is not under pressure.

15.2 The safety devices are to be checked.

E. Marking

1. All valves, fittings, controls, indicators and warning devices are to be provided with identification plates made of a material which is at least flameretardant. The identifying marks are to be clear and unmistakable (e.g. stating the short designation and/or the function of the item concerned).

2. All pressure vessels and pressure gas cylinders are to be prominently and permanently marked with the following details:

- Name of manufacturer
- Serial number and year of manufacture
- Maximum allowable working pressure
- Test pressure
- Capacity (in litres)
- Empty weight (of gas bottles)
- Date of test and test stamp

3. Permanently installed pressure gas cylinders, pressure vessels and gas piping systems are, in addition, to be marked with a permanent colour code in accordance with Table 2.1 and with the chemical symbol designating the type of gas concerned, if not otherwise defined by the Naval Authority. The marking of pressure gas cylinders shall be visible from the valve side.

Table 2.1 Marking of gas systems

Type of gas	Chemical symbol	Colour code
Oxygen	O_2	White
Nitrogen	N_2	Black
Air	-	White and Black
Helium	He	Brown
Oxygen/helium gas mixture	O_2/He	White and Brown

4. The mating appliance is to be fitted with a prominent and permanently mounted name plate containing at least the following information in easily legible characters:

- Name of manufacturer
- Serial number and year of manufacture
- Date of test and test stamp

SECTION 3

PRINCIPLES FOR DESIGN AND CONSTRUCTION

A. General Principles

1. Submarines are to be designed and constructed in such a way that failure of any single component cannot give rise to a dangerous situation.

2. A safety envelope calculation showing the allowable diving depth in relation with the submarine's velocity is to be submitted to **TL.** The following cases have to be investigated:

- Jamming of hydroplanes at max. angle

- Flooding

3. Submarines and their components are to be designed to meet the service conditions stated in the specifications.

4. Submarines are to be designed and built to ensure safe operation and facilitate proper maintenance and the necessary surveys.

5. Submarines should be equipped for all-round vision when navigating on the surface.

6. Submarines with a diver's lockout are to be designed and constructed to ensure the safe transport and the safe exit and entry of the divers under pressure. In addition, the diver's lockout provided shall also comply with the **TL** Rules Chapter 52 - Diving Systems.

B. Environmental Conditions

1. General

As a minimum requirement, the design, selection and arrangement of all machinery, instruments and equipment located on board of submarines are required to conform to the environmental conditions stated in the following. Environmental conditions other than those stated may be approved for submarines for service only in particular areas of the world.

2. Inclined Positions

Satisfactory operation shall be ensured at (static and dynamic) inclinations of up to 22,5° in any direction measured in relation to the as-installed datum if not otherwise agreed between the Naval Authority and **TL**. Short time (less than 10 minutes) inclinations of up to 45° shall not adversely affect operation and shall not cause damage, particularly to machine supports.

3. Water

The design of submarines and components is generally to be based on seawater within the temperature range from - 2 °C to + 32 °C, with a salt content of 3,5 % and a density of 1028 kg/m3. A value of 0,1 bar/m is to be applied when converting diving depth to pressure.

4. Seastates

Submarines are to be designed for sea states defined by the Naval Authority. At least allowance shall be made for accelerations of 2 g rms downwards and 1 g rms upwards in the vertical and 1 g rms each in the longitudinal and transverse directions (g = 9,81 m/s^2).

5. Climate

In all spaces, oil and salt-impregnated air ranging in temperature from 0 to 55°C is to be anticipated. Atmospheric humidity may attain 100 % in the lower temperature range. Condensation is liable to occur. In specially protected control rooms, a relative atmospheric humidity of 80 % at a reference temperature of 40°C is to be assumed.

Equipment and instruments shall continue to function satisfactorily despite fluctuations in the air pressure inside the pressure hull ranging from 0,7 to 1,3 bar. In the diver's and escape lockout and in compression chambers, equipment and instruments should be designed for 1,5 times the maximum allowable working pressure.

6. Vibrations

Machinery shall not cause any vibration which imposes unacceptable stresses on other machines, equipment or the hull of the vessel. The **TL** Rules Chapter 104 - Propulsion Plants, Section 1, D.2. are to be complied with.

C. Noise and Shock

Noise emissions should be kept to a minimum.The requirements for noise and shock are to be defined by the Naval Authority and agreed with **TL**. See also Chapter 102 - Hull Structures and Ship Equipment, Section 16.

D. Hatches, Doors and Access Ports

1. Submarines are to be equipped with entry and exit hatches as defined by the Naval Authority. They shall be capable of being operated from both sides. Each entry/exit hatch is to be designed to allow safe entry into and safe exit from the submarine without water penetrating into the interior.

2. Entry/exit hatches are to be provided with a closing mechanism which enables sufficient pressure to be exerted on the hatch seal even when surfaced. The design of the closing mechanism shall further ensure that the hatch cannot be opened until pressure equalization has taken place.

3. Provision is to be made to enable doors to be opened from both sides. Door casings or hatches are to be provided with pressure-equalizing valves.

4. Doors and access ports for persons shall have a clear diameter of at least 500 mm. That of diver entry and exit hatches shall be at least 600 mm.

E. Equipment

1. Anchors

Submarines are to be equipped with at least one suitable anchor including the necessary hoisting and lowering gear with indication device.

2. Bitts

Submarines are to be equipped with bitts etc. mooring the unit. Compare **TL** Rules, Chapter 102 - Hull Structures and Ship Equipment, Section 18, F.

3. Lights, Signal Shapes and Sound Signals

Submarines are to be equipped with lights, signal shapes and sound signals in accordance with the 1972 International Regulations for the Prevention of Collisions at Sea (COLREGS 1972).

Requirements of the Naval Authority have to be observed.

4. Position İndicators, Radio Direction Finders and Locating Equipment

According to their mode of operation and application, submarines are to be provided with suitable equipment for locating the unit when travelling on the surface.

5. Marker Buoy

Submarines are to be equipped with a marker buoy which can be released from inside the submarine in an emergency. If not otherwise defined by the Naval Authority, the marker buoy shall be fitted with an automatic distress signal transmitter.

F. Corrosion Protection and Corrosion Allowance

1. Corrosion Protection

Submarines and all their accessories are to be effectively protected against corrosion.

Parts of the submarine which are later rendered inaccessible by the design of the unit shall be given permanent corrosion protection during construction.

Anti-corrosion coatings applied to the interior of submarines shall meet the requirements under B.3., B.5. and Section 4, B.1.1.

2. Corrosion Allowance

The following corrosion additions apply provided an effective corrosion protection system is used and continuously maintained. Different additions required by the Naval Authority may be accepted by **TL.**

3. Additions for Steel

Based on the calculated values the scantling determination requires the corrosion addition t_K to the theoretical plate thickness:

- t_K = 0,5 mm in general

- t_K = 0,7 mm for lubrication oil, gas oil or equivalent tanks

- t_K = 1,0 mm for water ballast and wastewater tanks

- For special applications t_K shall be agreed with **TL**

- For all elements of the submarine's structure which are forming a boundary of tanks, the t_K values for tanks have to be considered.

SECTION 4

PRESSURE HULLS

Page

A. General

1. The following requirements apply to pressure hulls of submarines in which the crew is accommodated at atmospheric pressure.

2. The documents to be submitted to **TL** for approval are stated in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Design Principles

1. Internal Fittings and Equipment of the Pressure Hull

1.1 For equipment, fittings, insulation, paintwork and preservative coatings inside pressure hulls, use may only be made of those materials and media which do not release any toxic or severe irritant gases under the atmospheric conditions mentioned in Section 3, B.5. Wherever possible, this also applies to the effects of heat.

1.2 Wherever possible, only non-combustible or at least flame-retardant materials and media shall be used inside the pressure hull.

1.3 Battery spaces are to be so designed that they can accommodate the equipment needed for ventilation, air circulation, acid measurement and cooling.

1.4 Tanks located within the pressure hull are to be functionally designed and provided with sufficient ventilation and drainage facilities in each case. All tanks are to be provided with suitable inspection openings.

2. Allocation of Space

As far as possible, spaces occupied by the crew are to be separated from that in which machinery and equipment is installed and are to be acoustically and thermically insulated. Details about accommodation, sleeping facilities, sanitary arrangements etc. to be defined by the Naval Authority.

C. Materials

1. General

1.1 Materials shall be suitable for the purpose intended and for the processes applied, e.g. welding, and shall meet the requirements stated below. Materials for which no special requirements are stated in this Section are subject to recognized standards. See also Chapter 103 – Special Materials for Naval Ships.

1.2 The manufacturing, processing and testing of materials are subject to the **TL** Material Rules.

2. Approved Materials

2.1 Rolled or forged steels and steel castings with guaranteed ductility and toughness are normally to be used for pressure hull fabrication. Steel plates, profiles and bars shall be made of fine-grained special steels which comply with 3. and conform to recognized standards such as DIN EN 10028-3 or to manufacturer's specifications which have been examined and approved by **TL.** Approved materials for pressure hulls are listed in Table 4.2.

2.2 Materials other than those mentioned in 2.1, e.g. austenitic stainless steels, may be used provided they have been proved to be suitable for the intended application. If no recognized standards are available, the relevant specifications are to be submitted to **TL** for examination and approval. The use of brittle materials such as grey cast iron is not permitted.

3. Special Requirements Applicable to Materials For Pressure Hulls

3.1 Ductility

All metals shall have sufficient ductility (in terms of the elongation measured by tensile test). The elongation at fracture shall conform to the values stated in the standard or material specification and shall not be less than 16 %.

3.2 Impact energy

Steel grades have to conform to the impact energy values measured by notched bar impact test stated in

the standard or material specification. In addition:

- Plates shall have an impact energy of at least 30 Joule measured on ISO V-notch transverse specimens at a test temperature corresponding to the plate thickness in accordance with Table 4.1.

- Steel profiles and bars welded direct to the pressure hull, e.g. reinforcing rings or stiffeners, shall have an impact energy of at least 27 Joule measured in ISO V-notch longitudinal specimens at a test temperature of 0 °C.

Table 4.1 Test temperature for notched bar impact test

Plate thicknessı [mm]	Test temperature [°C]
≤ 20	0
> 20 ≤ 40	-20
> 40 ≤ 60	-40
> 60	by agreement

3.3 Freedom from defects

With regard to their internal defects, plates with a thickness exceeding 16 mm shall as a minimum requirement satisfy the conditions for Class 2, Table 1, of Stahl - Eisen -Lieferbedingungen 072 or equivalent standards.

4. Proof of Characteristics

4.1 Proof of the characteristics of materials used

for pressure hulls is to be supplied in the form of materials test Certificates according to EN 10204. The type of Certificate required for the product concerned is indicated in Table 4.3. Unless otherwise specified, the testing authority for acceptance tests to Certificate 3.2 is **TL.**

4.2 The evidence to be supplied in respect of the characteristics of products not included in Table 4.3 shall be agreed with **TL.**

D. Principles of Manufacture and Construction

1. Treatment

1.1 Treatments applied to materials shall be properly carried out. Materials whose characteristics have been impaired by hot or cold forming have to be suitably heat-treated, see **TL** Material Rules.

1.2 Materials shall be so marked as to enable them to be identified and correlated with their respective test certificates even during and after the fabrication of the pressure hull.

2. Welding

2.1 Companies wishing to undertake the fabrication of pressure hulls for submarines shall be approved by **TL** with regard to their facilities, welding personel and professional supervision.

2.2 Before welding work is commenced, the properties of the joints to be welded have to be proved by welding procedure tests at the manufacturer's works.

2.3 All butt welds in the pressure hull shall be performed as full-penetration, multi-pass welds executed from both sides. In addition, the work is to be performed in such a way that it can be assigned a weld factor v of 1,0 in accordance with **TL** Welding Rules

3. Penetrations

3.1 Penetrations causing a weakening of the pressure hull are to be suitably strengthened, see Annex A, C.8. The reinforcement has to form an integral part of the pressure hull or connecting piece. Set-on reinforcing rings are not permitted.

The edge of openings and cutouts, e.g. pipe, cable and mechanical linkage penetrations in bulkheads and web frames, are to be rounded.

Table 4.2 Approved materials for pressure hulls

Product type	Grade of material	TL Material Rules, Standards or Specifications
Plate	Special fine-grained steel and shipbuilding steel of grades TL-D 32/36 or TL-E 32/36	Section 3, B, DIN EN 10028-3 Manufacturer's specification
Profiles and bars	General-purpose shipbuilding and structure steels, provided these are killed, also fine-grained structural steels	Section 3, B., 3,C., DIN EN 10025, DIN EN 10028-1
Pipes	Seamless and welded ferritic steel pipes	Section 4, B., 4,C. DIN 1629/30, DIN 1626/28, DIN EN 10216-2, DIN EN 10217-2
Forgings	Forgings for boilers, pressure vessels and piping	Section 5, E., DIN EN 10025, DIN EN 10083-1
Castings	Steel castings for boilers, pressure vessels and piping	Section 6, D., DIN 1681, DIN EN 10213
Bolts and nuts	Unalloyed or alloy steel bar	Section 8, C., DIN/ISO 898

Table 4.3 Proof of characteristics

Product type	Type of certificate according to EN 10204
Plates for the pressure hull Ultrasonic test	3.1.C 3.1.B
Steel profiles and bars (load-bearing elements)	3.1.C
Pipes and sockets > DN 32 ≤ DN 32	 3.1.C 3.1.B
Forgings, forged flanges > DN 250 ≤ DN 250	 3.1.C 3.1.B
Bolts ≥ M 30 < M 30 Nuts	 3.1.C 3.1.B 2.2
Small parts such as mountings, brackets and welding lugs	2.2

4. Dished Ends

The movement of the rims of dished ends shall not be inadmissibly restricted by mechanical restraints of any kind, e.g. retaining plates, stiffeners etc.

5. Pipe Connections and Flanges

5.1 The wall thickness of pipe connections shall be so dimensioned that they are fully able to withstand additional external loads. The wall thickness of socket-welded pipe connections shall be compatible with the wall thickness of the part into which they are welded. Pipe connections and flanges are to be socketwelded in such a way that the weld configuration includes the whole wall thickness of the pressure hull.

5.2 Pipe connections in accordance with the **TL** Rules, Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 8 are to be provided for the connection of pipes.

E. Calculations

1. General

1.1 Pressure hulls, pressure bulkheads, hatches, windows, suspensions etc. are to be calculated in accordance with the relevant **TL** Rules or other code of engineering practice, agreed with **TL.** For pressure hulls and pressure vessels subjected to external overpressure see Annex A.

1.2 The calculations on which the design is based are to be submitted to **TL.** If a computer programs is used for the calculations, proof of suitability of the program is to be submitted to **TL**.

1.3 Allowance is to be made for the loads due to nominal diving pressure, test diving pressure, collapse pressure, internal overpressure and any dynamic loads, reaction forces and additional local stresses caused by fastening attachments and supports as defined in Section 5.
The calculations are also to take account of the environmental conditions stated in Section 3, B.

1.4 The load factors for dynamic loads are to be agreed with **TL**. Account is to be taken of the fatigue strength of the material. Pressure hulls are to be designed for a number of operating cycles to be agreed with the Naval Authority, but at least 10000 operating cycles.

The calculations for the proof of fatigue strength shall be done according to the requirements defined in Chapter 102 – Hull Structures and Ship Equipment; Section 17 unless otherwise agreed by **TL.**

1.5 For the weld factor of welds see D.2.3.

1.6 The wall thickness of the shells and ends of seamless or welded pressure hulls shall generally not be less than 6 mm.

2. Design Criteria

The following design criteria are to be applied to the calculation of components subjected to external overpressure:

- Tensile, compressive and bending stresses at nominal diving pressures shall not exceed the permissible values stated in 3.

- Components critical to stability shall be designed with a sufficient margin to withstand buckling, bulging and lateral buckling at collapse diving pressures.

- The possibilities of failure critical to stability and of plastic failure are to be analyzed.

  Allowance is to be made for the reduction in the modulus of elasticity between the limit of proportionality and the yield point or 0,2 % proof stress. Generally, the material shall be assumed to behave elastically and plastically without strain hardening.
  Where the compressive load/ deformation curve for the material has been determined in the presence of **TL**'s representative, this curve may be used as the basis for calculations.

3. Permissible Stresses

The maximum permissible stress to be used in the stress calculation is the smaller of the following two values:

$\frac{R_{m,20^\circ}}{A}$, where $R_{m,20^\circ}$ = guaranteed minimum tensile strength [N/mm^2] at room temperasture (may be disregarded in the case of established fine - grained steels with $R_{eH} \leq 360$ N/mm^2 or where external overpressure exerts a compressive load).

$\frac{R_{eH,t}}{B}$, where $R_{eH,t}$= guaranteed yield point or minimum value of 0,2 % prof stres at design temperature.

The safety factors A and B are shown in Table 4.4.

4. Allowance for Manufacturing Tolerances

4.1 In design calculations relating to pressure hulls, allowance is to be made for deviations from the ideal shape, e.g. with regard to the circularity of the shell configuration or the positioning of the stiffening rings, see Annex B.

4.2 If the manufacturing tolerances on which calculations have been based are exceeded, the deviations observed shall be used to carry out a calculated verification of the maximum permissible pressure.

Table 4.4 Safety factors

Material	Nominal diving pressure		Test diving pressure		Collapse pressure	
	A	B	A’	B’	A”	B”
Ferritic materials	2,7	1,7	-	1,1	-	1
Austenitic materials	2,7	1,7	-	1,1	-	1
Titanium	2,7	1,7	-	1,1	-	1

SECTION 5

DESIGN LOADS

A. General

1. Scope

This Section summarizes all loads to be considered for the design of a naval submarine.

2. Use of Actual Loads

The following Rules for the loads do not release the designer and the shipyard from the proof of the actual loads in the special case. If it becomes known during the design procedure that the actual loads are higher than in these rules, the effective loads have to be considered in the calculation and the causes for it are to be defined.

3. Load Plan

All relevant loads for a naval submarine shall be summarised in a load plan.

B. Pressure Heads

1. General

1.1 Pressure head plan

As part of the load plan a plan has to be established which contains all pressure heads to be considered for the different parts of the construction. It has to be defined in which way the pressure tests have to be carried out.

It has to be defined for which components (e.g. diving/ ballasting tanks, battery spaces, pressure hull, acoustic insulation bulkheads) underpressure tests respectively overpressure tests have to be carried out.

2. Pressures for the Pressure Hull

Reference points for the pressure heads are the water surface and the lower edge of the pressure hull respectively of a constructional element. The following pressure heads are to be considered.

2.1 Pressure for nominal diving depth

The nominal diving depth NDD is the diving depth for unrestricted operation of the submarine. The nominal diving pressure NDP for this depth follows by dividing the NDD value by 10, if not otherwise agreed with **TL** for special operations.

For the fatigue life it has to be defined how often the NDD can be reached. The minimum number to be assumed for the calculation is 10 000 load cycles.

2.2 Pressure for Test Diving Depth

2.2.1 The test diving depth TDD is the diving depth to be reached during sea trials of the new building or after main overhauls under test conditions. The test diving pressure TDP, which has also to be included in the pressure head plan, is the pressure used for testing the pressure hull and equipment for its tightness and function. The test diving pressure TDP for the pressure hull is defined in Table 5.1.

Table 5.1 Coefficients S for test diving pressure and collapse diving pressure in relation to nominal diving pressure

Nominal diving pressure NDP [bar]	**5 (1)**	**10**	**20**	**30**	**40**	**50**	**≥60**
Test diving pressure / nominal diving pressure S_1 = TDP/NDP **(3)**	1,70	1,40	1,25	1,20	1,20	1,20	1,20
Collapse diving pressure / nominal diving pressure S_2 = CDP/NDP **(4)**	3,20	2,40	2,00	1,87 **(2)**	1,80 **(2)**	1,76 **(2)**	1,73 **(2)**

(1) *Minimum nominal diving pressure 5 bar*
(2) *Minimum value S2 = for operations at depths > nominal diving depths*
(3) *In the range NDP = 5....30 bar: S1 = 3 / NDP + 1,1*
(4) *In the range NDP = 5....60 bar: S2 = 8 / NDP + 1,6*

2.2.2 For all pressure tight hatch covers including closures of the torpedo tubes an additional pressure test shall be carried out. The test shall ensure the tightness up to the collapse diving pressure CDP according to 2.3. This test pressure is the pressure to be endured by the hatch cover.

This pressure test has to be applied with a suitable device.

2.3 Pressure for collapse diving depth

The collapse diving depth CDD is the absolute maximum diving depth of the submarine. The collapse diving pressure CDP is the pressure for which the pressure hull may collapse at the earliest under a load endured for 1 minute. In general the coefficient for the collapse diving pressure is chosen according to Table 5.1

2.4 Safety factor

The safety factor S_2 of the pressure hull is gained by dividing the collapse diving pressure CDP according to 2.3. by the nominal diving pressure NDP according to 2.1.

The safety factor S_2 shall cover the following uncertainties:

- Influences not covered by the calculation procedure
- Influences as consequence of fabrication mistakes (material failures, manufacturing inaccuracies, welding mistakes, residual stress)
- Negative influences during operation (corrosion deficiencies, unobserved buckling, alternating stressing)
- Time dependent strength characteristics of the material

3. Pressures for Pressure Vessels and Tanks

3.1 Nominal pressure

3.1.1 For pressure vessels and tanks which are not exposed to the diving pressure, the nominal pressure is equal to the maximum allowable working pressure.

3.1.2 The nominal pressure for pressure vessels and tanks exposed to the diving pressure is the test pressure according to 3.2 times 1,1 and divided by 1,5.

3.1.3 The nominal pressure is not decisive for the proof of fatigue strength, decisive is the maximum pressure occurring during operation.

3.2 Test pressure

3.2.1 The test pressure is the pressure for the prof of strength. The functional test shall be executed after the tightness test.

3.2.2 For pressure vessels and tanks exposed to diving pressure, the test pressure is equivalent to the collapse pressure of the pressure hull times 1,1.

3.2.3 For all other pressure vessels and tanks the test pressure is equivalent to the nominal pressure times 1,5.

C. Other External Loads

1. Wind Loads

1.1 General

Wind loads are to be considered for strength analysis of extremely exposed parts of the surfaced submarine, such as masts, as well as for the stability of the submarine only if requested by Naval Authority.

Maximum wind speeds, air density, etc. have to be agreed on with the Naval Authority according to the area of operation of the submarine. In the following Sections standard values are provided.

1.2 Wind force

$F_W = q_W \cdot c_f \cdot A_W$ [kN]

q_W = Wind pressure

= $0{,}5 \cdot \rho_L \cdot v_W^2$ [kN/m²]

ρ_L = Density of air [t/m³]

v_W = Wind speed [m/s]

c_f = Form coefficient

A_W = Projected area exposed to wind forces [m²]

Note:
For plane areas the form coefficient may be assumed to be $c_f = 1{,}0$; for rounded areas, the coefficient may be assumed to be $c_f = 0{,}6$.

The water content in the air may increase the air density ρ_L by about 30 percent.

2. Accelerations

2.1 Seastate

The accelerations from the movement of the submarine in the sea depend very much on the type of task and the mode of operation of the submarine. They have to be defined by the Naval Authority and agreed with **TL.**

At least allowance shall be made for accelerations of 2 g rms downwards and 1 g rms upwards in the vertical and 1 g rms each in the longitudinal and transverse directions (g = 9,81 m/s²).

D. Loads on Internal Structures

1. Loads on watertight and non-watertight partitions

1.1 Watertight partitions

1.1.1 Static load

The static load is:

$p_{WTstat} = g \cdot \rho \cdot CDD$ [kN/m²]

CDD = Collapse diving depth of the submarine according to B.2.3 [m]

In special cases design depth for bulkheads to be agreed between Naval Authority and **TL.**

1.2 Non-watertight partitions

The static load p_{NWT} is to be defined by the Naval Authority or the Shipyard, but shall not be less than:

$p_{NWT} = 2$ kN/m²

1.3 Additional loads

In addition, static and dynamic loads from equipment mounted on bulkheads and walls have to be considered.

2. Loads on Internal Decks

2.1 Single point loads

P_E [kN] is to be taken as a part of the total load of the device, system, etc. according to the type of foundation.

2.2 Loads on accommodation and service decks

The following loads are minimum values. These loads may be higher, depending on the definitions in the load plan.

The static uniform deck load is:

$p_{Lstat} = 3$ kN/m²

The minimum static point load is:

$P_{Estat} = 1{,}5$ kN

2.3 Loads on machinery decks

The following loads are minimum values. These loads may be higher, depending on the definitions in the load plan.

The uniform static deck load is:

$p_L = 4 \quad kN/m^2$

The minimum static point load is:

$P_E = 3 \quad kN$

3. Loads on Tank Structures Not Subjected to Additional Internal Pressure

3.1 Design pressure p_{T1}

3.1.1 Static pressure

The static pressure is:

$p_{T1} = g \cdot h_1 \cdot \rho + 100 \cdot \Delta p \quad [kN/m^2]$

h1 = Distance of load centre from tank top [m]

ρ = Density of tank liquid [t/m³]

Δp = Additional pressure component created by overflow systems

For fuel tanks, diving/ballast tanks, regulating / compensating tanks and trimming tanks connected to an overflow system, the dynamic pressure increases due to overflowing has to be taken into account in addition to the static pressure. The static pressure corresponds to a pressure height extending up to the highest point of the overflow system.

E. Load Cases

1. Load case I

Load case I characterizes the operational loads.

1.1 Nominal loads

The operational pressures defined in the pressure head plan according to B.1.1 are to be used as nominal loads. Exceptions are made for components exposed to the diving pressure according to B.3.1.2.

For the proof of the fatigue strength of the pressure hull at least 10^4 load cycles and a rectangular spectrum has to be used if not otherwise agreed by **TL**.

1.2 Internal loads

To be considered as defined in D.

1.3 Loads at emerging

During the surfacing phase of the submarine the water enclosed in the superstructure of the tower and the upper deck leads to a loading of these spaces by internal pressure. A nominal (operational) pressure of at least 0,3 bar has to be assumed.

1.4 Flow resistance

As far as not the local hydrodynamic pressure is decisive but the resultant of the hydrodynamic forces (e.g. liftable devices), the maximum resistance has to be calculated for possible speeds using form resistance coefficients or has to be found by tests.

At all areas of the outer surface the local hydrodynamic pressure at maximum speed has to be considered.

1.5 Sea slab

The loads from sea slab have to be considered for all parts of the outer surface which are emerging from the water with a static substitutive pressure of:

$p = 50\,000 \ N/m^2 = 0{,}05 \ MN/m^2$

For the tower, the upperdeck and the lifting devices this load shall only be assumed for a 1 m high strip at the most unfavourable location.

For convex curvatures of the contour the substitutive pressure may be multiplied with cos α. Herewith the angle α is the angle between the normal line to the area and the assumed direction of the sea slab. It has to be proven that the sea slab will be endured locally, always assuming normal impact. In addition it has to be proven that the resulting forces can be endured by the relevant elements of the structure. This has to be proven for the most unfavourable direction of the sea slab. If a more detailed investigation shows different loads, these loads may be used.

1.6 Loads from towing, anchoring and manoeuvring

The breaking load of the chosen anchor chains and wire ropes has to be used as limit load for the relevant parts of the structure.

As local load the maximum load of the windlass has to be used during landing operations.

1.7 Propeller thrust

The maximum propeller thrust results from calculations or from model tests. To this thrust the diving pressure acting on the propeller shaft at CDD has to be added to evaluate the total axial forces on the shaft.

1.8 Forces at rudders and hydro planes

The forces acting on rudders and hydro planes have to be calculated according to Chapter 102 - Hull Structures and Ship Equipment, Section 12.

1.9 Shock loads

The limit loads in case of shock have to be defined by the Naval Authority and agreed with **TL.**

The operational loads according to 1.1 have to be superposed.

2. Load Case II

Load case II characterizes the ultimate loads at the collapse diving depth CDD where the pressure hull has to endure the collapse diving pressure CDP.

2.1 Loads for collapse diving pressure

For the elements exposed to outside pressure the collapse diving pressure CDP according to the pressure head plan has to be used as ultimate load without considering other loads.

3. Load Case III

Load case III characterizes the test loads.

3.1 The load case III covers the loads occurring during the pressure testing for strength, tightness and functionality at the different elements or at the submarine as a whole.

As pressure load the loads for the different elements which are defined in the pressure head plan are decisive.

3.2 In addition the loads of load case I which might occur during the pressure tests have to be superposed.

SECTION 6

EXOSTRUCTURE

Page

A. General

1. Scope

The following requirements apply to the entire free flooding exostructure of the submarine including cladding, supporting structures and pressure hull fixtures.

2. Documents for Approval

The documents to be submitted to **TL** for approval are stated in Section 2, C.

B. Design Principles

1. The exostructure has to be designed in a streamlined form. Such a streamlined form has to achieve a low hydrodynamic resistance, a good steerability as well a reduced noise creation and sound radiation.

2. All free-flooding parts of submarines are to be designed and provided with openings in such a way that the spaces concerned can be fully flooded and vented. It shall be secured that constructional elements which are not pressure-proof cannot get remarkable loads from the diving pressure and that no air bubbles remain in the construction after preparing the diving procedure.

3. When welding pressure hull fixtures such as diving tank mountings, operating equipment, stabilizing fins, rudders, etc., care is to be taken to minimize the resulting internal stresses in the pressure hull. It shall be possible to inspect and preserve even those areas of the pressure hull adjoining fixtures.

4. The exostructure of a submarine is to be so designed that parts of it can be crushed by collisions, etc. without damaging the pressure hull, and in addition steps shall be taken to exclude any likelihood of the boat being caught up by parts of its exostructure.

5. Wherever possible, pressure hull penetrations for pipes, hoses and cables are to be protected against mechanical damage by pressure hull fixtures or cladding.

6. Buoyancy appliances mounted externally on the submarine are to be properly secured and protected.

7. All spaces of the exostructure shall be accessible with the possibility to walk in. The access is to be established by manholes which shall be gastight if they are located above the openings for flooding the diving/ballasting tanks. The manholes are to be situated in recesses to protect their closing devices from mechanical damage. The manholes shall have plane sealing areas. If the access by manholes cannot be achieved, in free-flooding areas removable plates fixed with screws may be installed.

C. Materials

1. Materials shall be suitable for the intended application and manufacturing process and shall have been approved by **TL.** Suitable proof is to be furnished of the characteristics of materials, e.g. by a manufacturer's Certificate.

2. The manufacture, processing and testing of steels are subject to the **TL** Material Rules.

3. The manufacture and processing of glass fibre reinforced plastic (GRP) materials are required to comply with Section 3, B. and to the **TL** Material Rules.

4. All other materials are to be manufactured and processed in accordance with recognized standards or to material manufacturer's specifications which have been examined and approved by **TL**.

5. Materials for rigid regulating/compensating tanks shall be suitable for the proposed pressure and temperature ranges, shall have a low absorption factor and shall not suffer appreciable crushing under pressure.

6. The material for the exostructure shall be compatible with the material for the pressure hull, but the strength parameters may be different. If the materials and their electro-mechanical characteristics are different, corrosion protection may become necessary.

D. Calculations

1. Recognized calculation procedures are to be followed in performing calculations relating to components of the exostructure. The dimensional design of the exostructure shall be such that, at the anticipated loads, the calculated stress is not greater than 0,6 times the yield strength.

2. For safety under collision conditions, an acceleration of 3 g should be applied in the longitudinal direction (g = 9,81 m/s^2) unless otherwise agreed by the Naval Authority. In these circumstances, the exostructure should be capable of deforming to absorb the impact energy without damage to the pressure hull.

E. Elements of the Exostructure

The following requirements have to be considered for the design of the different elements of the exostructure.

1. After Body

The after body of the exostructure is the part behind the tower which is attached at the rear end of the pressure hull.

2. Shaft Tube

The shaft tube in which the propeller shaft is situated shall be free flooding and has to be designed according to the requirements for the bearings of the propeller shaft. The shaft bearings shall be accessible in dry dock. It has to be avoided that forces from elastic deformation and vibrations of the after body are transferred into the after end of the pressure hull.

3. Wire Protector

If wire protectors are necessary for certain types of torpedoes, they have to be situated near the propeller and an easy mounting and dismounting shall be possible. Their design and location has to keep hydrodynamic and acoustic influence as low as possible.

4. Fore Body

The fore body of the exostructure is the part in front of the tower which is situated before the pressure hull. If a surfaced navigation in ice is intended, the requirements of Chapter 102 – Hull Structures and Ship Equipment, Section 13 have to be considered.

5. Keel

If a keel is arranged, it has to be designed to support the fixed ballast and to transmit the docking forces. Checking and corrosion protection of the pressure hull shall be guaranteed also in these areas.

6. Shell

The shell of the exostructure has to be carried out with a smooth surface. Connections of construction elements with steps in the shell have to be equalized if the course of flow will be influenced in negative way.

Because of safety reasons the shell has to be reinforced in the area of the diving/ballasting tanks. Screwed connections of shell elements are not permissible in the range of these tanks.

At openings for penetrations and at locations with additional loads the shell has also to be reinforced.

7. Frames and Stiffeners

The exostructure has to be supported according to the design and strength requirements by transverse and longitudinal framing and as far as necessary by web frames, stringers, middle and side girders, etc.

8. Bulkheads

According to the design requirements transverse and longitudinal bulkheads for the subdivision of the spaces of the exostructure and ballast, trim and fuel tanks have to be provided. They have to be stiffened as far as necessary.

Non watertight bulkheads may have lightening holes. For penetrations through watertight or gastight bulkheads the sealings have to be designed to enable the possibility of checking and, if necessary, of maintenance works or even replacement.

If a bulkhead serves as boundary of ballast and trim tanks as well as support for torpedo tubes, the penetrations have to guarantee the two functions as tube bearing and tightening of the ballast and trim tanks. The connection between torpedo tube and supporting bulkhead has to consider the influence of manufacturing circumstances, like welding shrinkage, etc.

9. Fixed Fins

According to the arrangement of depth control and side rudders fixed fore fins may be provided. They have to be dimensioned according to the requirements of manoeuvrability and dynamic stability of the steering characteristic of the boat, compare Section 10.

If the fins are designed as free-flooding elements sufficient flooding and venting openings have to be provided.

10. Decks and Platforms

As far as decks and platforms are needed for separation of the different spaces of the exostructure or for foundations of the various devices and equipment they may be used for stiffening of the exostructure at the same time.

11. Upper Deck

If an upper deck is situated before and after the tower it has to be arranged in a streamlined form with sufficient flooding and venting openings. Where necessary, it has to be fitted with gratings or other measures to facilitate a safe, skidproof access to the boat. All flaps have to be provided flush in the deck and shall be fastened in a shakeproof way. Bollards, belaying cleats and hawses have to be arranged in a way not to disturb the streamlined form.

Further on the upper deck has to protect all devices and equipment situated in free spaces below, like containers with rescue equipment, rescue spheres and boatsman's equipment as fenders, ropes, etc. Anchors are to be so arranged that, when stowed, they are flush with the upper deck, compare also Section 11.

12. Towing Point

The towing point is to be so designed and located that the submarine can be towed at the maximum towing speed defined by the Naval Authority even under the most adverse operating conditions.

13. Cladding

Cladding for e.g. detection and locating equipment and other extensions has to be designed according to the technical requirements. As far as not the equipment demands special measures the covers have to be dimensioned for the loads defined in Section 4.

14. Tower

In addition to the loads according to Section 5 the exostructure forming the tower has to transmit the forces from the bearing of the periscopes, electronic masts, etc. and of the detection and location devices situated in the tower. Special requirements for the permissible dislocation of the bearings to guarantee the correct functioning of the liftable equipment have to be considered.

The supporting structural members have to be situated in line with bulkheads, web frames and frames of the pressure hull.

Accessibility to the spaces of the tower has to be enabled and sufficient flooding and venting openings are to be provided to guarantee free vertical flooding. A low horizontal hydrodynamic resistance of the tower will also be an essential requirement.

SECTION 7

DIVING/BALLASTING, REGULATING/COMPENSATING and TRIMMING SYSTEMS

Page

A. General

1. The following requirements apply to the diving/ballasting, regulating/compensating and trimming systems of submarines and their associated components.

2. The documents to be submitted to **TL** for approval are stated in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Principles of Design and Construction

1. General Principles

Diving/ballasting, regulating/compensating and trimming systems are to be so designed and arranged that the following conditions are satisfied:

- The submarine shall be stable in every phase of operation
- It shall be possible to operate the submarine safely on the surface under the maximum permissible seaway conditions
- When submerged, it shall be possible to balance and trim the submarine at any depth up to or equal to its nominal diving depth
- The submarine shall at all times be capable of returning safely to the surface
- In the event of failure of the regulating / compensating system the submarine shall be capable of surfacing by jettisoning of ballast and/or emergency blowing of the diving/ballasting tanks and shall float on the surface in an upright stable position

2. Diving/Ballasting System

2.1 Diving/ballasting tanks are to be designed and constructed to withstand the impact of waves and their own internal static pressure.

2.2 Diving / ballasting tanks are to be provided with vents / valves enabling them to be completely flooded with water. The venting system shall be provided with a separate shut-off device for each individual tank. The vent valves are to be designed such as to prevent unintentional opening.

2.3 Where diving/ballasting tanks have flooding holes without means of closure, double shut-off devices may be stipulated for the vent pipe.

2.4 Where diving/ballasting tanks are blown-out by compressed air, it is necessary to ensure that blowing the tanks cannot cause an excessive overpressure.

2.5 Where the diving/ballasting tanks are to be pumped out, the flooding holes are to be fitted with means of closure and measures are to be taken to ensure that the freeing of the tanks cannot cause an excessive underpressure.

3. Regulating/Compensating System

3.1 Regulating/compensating tanks are to be designed for a working pressure corresponding to 1,2 times the nominal diving pressure subject to a minimum of PN + 2 bar. The regulating / compensating tanks are to be safeguarded against excessive overand underpressures.

3.2 Regulating/compensating tanks located within the pressure hull may be designed as gravity tanks provided that freeing is effected by pumps only.

3.3 The capacity of regulating/compensating tanks shall be sufficient to compensate for all the changes in regulating/compensating expected to arise during the planned diving duties plus a reserve capacity of at least 10 %.

3.4 Regulating /compensating tanks may be freed by compressed air or by pumping. The quantity of water admitted during flooding and expelled during freeing shall be indicated. For that purpose regulating/ compensating tanks are to be fitted with contents gauges giving a continuous reading.

3.5 The vent pipes of regulating / compensating tanks are to be designed and arranged in such a way that water cannot ingress unnoticed.

4. Trimming System

4.1 To achieve maximum leverage, trimming tanks are to be located as far forward and aft on the vessel as possible.

4.2 The transfer of water may be effected by pumping or by compressed air. The quantities of water used for trimming shall be indicated.

4.3 Trimming tanks which are located inside the pressure hull and which are freed by pumping may be designed as gravity tanks. If the trimming tanks are freed by compressed air, they are to be designed as pressure vessels according to the pressure of the compressed air system.

Pressure proof trimming tanks located on the outside of the submarine shall be designed to withstand an external pressure equivalent to 1,1 times the collapse diving depth.

C. Materials, Manufacture and Calculations

1. Diving/Ballasting Tanks

Wherever applicable, the materials, manufacture, design and calculation of diving/ballasting tanks are to comply with the requirements set out in Section 4, C., D. and E.

2. Regulating/Compensating and Trimming Tanks

The materials, manufacture, design and calculation of regulating/compensating and trimming tanks are to comply with the **TL** Rules, Chapter 107- Ship Operation Installations and Auxiliary Systems, Section 16.

SECTION 8

PRESSURE VESSELS, HEAT EXCHANGERS and FILTERS

Page

A. General

1. The documents to be submitted to **TL** for approval are stated in Section 2, C.

2. The necessary tests and markings are as stated in Section 2, D. and E.

B. Compression Chambers

Compression chambers in submarines, if applicable, are to be built and equipped in accordance with the **TL** Rules, Chapter 52 – Diving Systems, Section 2.

C. Pressure Vessels, Heat Exchangers, Filters and Pressure Gas Cylinders

Pressure vessels, heat exchangers, filters and pressure gas cylinders are to comply with the requirements set out in the **TL** Rules, Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 16.

SECTION 9

PIPING SYSTEMS, PUMPS and COMPRESSORS

Page

A. General

1. The following requirements apply to all piping systems, including valves, fittings, pumps and compressors, which are needed to operate the submarine. In addition, the **TL** Rules, Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 8 are to be observed, wherever applicable.

2. The documents to be submitted to **TL** for approval are stated in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Principles of Design and Construction

1. Pipes, Valves, Fittings and Pumps

1.1 All pipes, valves, fittings and pumps liable to be loaded with the diving pressure are to be designed for the test depth of the submarine.

1.2 Pipes which are led through the pressure hull shall be fitted with two shutoff devices, one of which is to be located immediately next to the pressure hull.

1.3 Oxygen pipes are not to be routed close to oil pipes.

1.4 Gas pipes and electric cable conduits are to be routed separately wherever possible.

1.5 Shutoff devices shall conform to a recognized standard. Valves and fittings with screw-down covers or spindles are to be safeguarded against unintentional unscrewing.

1.6 Safety relevant valves are to be operated manually also. Manual shutoff devices are to be closed by turning in the clockwise direction. Means have to be provided, that the valves can be operated in an unmistakeable way, even in insufficient lighting condition.

1.7 The open and closed positions of all sea valves and essential shut-off valves shall be clearly indicated.

1.8 All valves acting as sea connections shall be so designed that the tapered plug opens against the external pressure.

1.9 Only screw-down valves are permitted in pipes carrying oxygen. Ball valves may, however, be used as emergency shut-off devices.

2. Bilge Pumping and Ballast Water Equipment

2.1 Submarines are to be equipped with a bilge system capable of freeing all the spaces inside the vessel from water due to condensation and leakage. Provisions of MARPOL 73/78 have to be observed, if not otherwise defined by the Naval Authority.

2.2 To prevent ballast water and seawater from penetrating inside the vessel through the bilge system, two non-return valves are to be mounted in front of the freeing connections. One of these non-return valves is to be placed in the pipe in front of each suction.

2.3 Where the bilge, seawater and ballast water systems are interconnected, the connecting pipes are to be fitted with valves in such a way that seawater is reliably prevented from penetrating inside the vessel through the bilge system even in the event of faulty switching of the valves or when the valves are in intermediate positions.

2.4 Bilge pumps are to be of the self-priming type.

2.5 The bilge and ballast water system shall be provided with at least one standby pump.

2.6 Where ballast and trim tanks are freed only by pumps, the standby pump is to be connected to the emergency power supply.

3. Compressed Air Systems

3.1 Where air is used to blow diving/ballasting, regulating/compensating and trimming tanks, the supply of air carried on board shall be sufficient to blow the diving/ballasting tanks at least 4 times on surface and the regulating/compensating tanks at least 3 times at the nominal diving depth. In normal operation, the compressed air receivers providing this supply may not be used for other purposes.

3.2 A compressor should be provided for charging the compressed air receivers.

3.3 The compressed air supply is to be carried in at least 2 separate units of receivers.

3.4 The compressed air systems are to be fitted with valves in such a way that no unintentional pressure equalization can occur between different systems.

3.5 Where pressure-reducing valves are fitted, provision is to be made for bypassing and disconnecting these in the event of a fault. In addition, a safety valve is to be fitted downstream the pressure-reducing valve.

3.6 Compressed air systems are to be equipped with a sufficient number of pressure indicators.

3.7 Compressed air systems which come into contact with seawater are to be designed accordingly and are to be separated from other systems. In addition, measures are to be taken which as far as possible rule out the possibility of seawater penetrating into the compressed air system.

4. Hydraulic Systems

4.1 All piping belonging to hydraulic systems which are led through the pressure hull and which are necessary to the safety of the submarine shall be designed for the maximum allowable working pressure of the system. Wherever necessary, allowance is to be made for the possibility of a pressure rise due to the penetration of seawater into the system.

4.2 Hydraulic systems essential to the safety of the unit are to be equipped with at least two powerdriven pumps and one hand-operated emergency pump.

4.3 In individual cases, hydraulic systems not designed for continuous operation may also be equipped with hand-operated pumps.

4.4 All valves and fittings, including hydraulic accumulators, which are fitted in submarines, are to be designed in accordance with 4.1. Valves and fittings are to be placed in easily accessible positions.

4.5 Hydraulic systems are to be fitted with filters to keep hydraulic fluid clean. In addition, provision is to be made for venting and dewatering the system. Hydraulic fluid tanks are to be fitted with level indicators.

Wherever necessary, hydraulic systems are to be equipped with means of cooling the hydraulic fluid.

4.6 Hydraulic lines should not be routed close to oxygen systems.

4.7 When selecting the hydraulic oil, allowance is to be made not only for the service conditions but also for the temperatures occurring during the commissioning or repair of the submarine.

4.8 Hydraulic systems are to be equipped with all the indicating devices necessary to the operation of the system.

C. Materials, Manufacture and Calculations

1. With regard to materials, manufacture and calculations:

1.1 For pipes, valves, fittings and pumps see **TL** Rules, Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 8.

1.2 For compressors see **TL** Rules, Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 6.

1.3 For hydraulic systems see **TL** Rules, Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 14.

SECTION 10

CONTROL SYSTEMS FOR DEPTH, POSITIVE and NEGATIVE BOUYANCY and TRIM

A. General

1. The following requirements apply to all equipment for the static control of the depth, positive and negative buoyancy and trim of submarines.

2. The documents to be submitted to **TL** for approval are stated in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Principles of Design and Construction

1. General Principles

1.1 Submarines are to be fitted with systems for controlling depth, positive and negative buoyancy and trim. It is necessary to ensure that this equipment functions properly under all the specified conditions of heeling and trim.

1.2 All the remote operating units for controlling depth, positive and negative buoyancy and trim are to be grouped together on the control station and clearly marked.

1.3 The control station is to be equipped with indicating instruments which show continuously the position of the submarine and the filling level of the diving/ballasting, regulating/compensating and trimming tanks.

2. Systems and Components

2.1 The design and construction of systems and components for the control of depth, positive and negative buoyancy and trim are to comply with Section 7 and Section 9.

2.2 Control and operating units and indicating instruments are subject to the Rules set out in Section 13.

2.3 For dynamic depth control equipment see Section 11.

SECTION 11

PROPULSION and MANOEUVRING EQUIPMENT

A. General

1. The following requirements apply to all equipment for the propulsion, manoeuvring and dynamic positioning of submarines and to all steering gears, including dynamic depth control. In addition, propulsion units are subject to the **TL** Rules, Chapter 104 – Propulsion Plants, and steering gears to Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 2.

2. The documents to be submitted to **TL** for approval are stated in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Principles of Design and Construction

1. Propulsion Units

1.1 With regard to their type, number, size and arrangement, propulsion units are to be designed in accordance with the intended duties of the submarine.

1.2 Externally mounted propulsion units are either to be designed for the maximum allowable diving pressure of the submarine or they are to be pressure equalized.

1.3 Propulsion engines for submarines are to be designed for intermittent and continuous service.

1.4 When travelling on the surface, the air supply to internal combustion engines shall pass through an air/snorkel mast. For the requirements to be met by the air/snorkel mast, see Section 14. Exhaust lines are to be led out through the pressure hull via a double, pressure- tight shut-off device.

The requirements to be met by closed-circuit propulsion systems are to be agreed with **TL** in each individual case. For air independent power systems see Chapter 113 – Air Independent Power Systems for Underwater Use.

1.5 Electric propulsion motors are to be designed in accordance with the requirements stated in Section 12.

1.6 If the propulsion engine is located inside the pressure hull, the thrust block should also be located in the same space.

1.7 Shaft penetrations through pressure hull walls should be fitted with a gland of proven type designed to withstand the collapse diving pressure.

1.8 Devices for controlling the engine speed and/or the direction of rotation are to be so designed that the propulsion engine can be stopped should they fail. The propulsion engines shall also be capable to be controlled manually.

1.9 The propulsion equipment is to be fitted with a sufficient number of indicators and alarms to guarantee safe operation.

2. Rudder / Manoeuvring Equipment

2.1 Submarines are to be equipped with suitable Devices to ensure that the vessel has the necessary manoeuvrability both on the surface and when submerged.

2.2 Horizontal and vertical rudders are to be designed to withstand the maximum loads generated by the pitching motions of the submarine and the wash of the sea when surfaced and by the steering forces experienced when submerged. The effective stress in the rudder stock shall not exceed 0,5 times the yield stress.

2.3 With the vessel travelling at full speed, the steering gear shall be capable of putting the vertical rudder from 35° on one side to 35° on the other within the specified time values for surface and submerged condition. An emergency steering device shall be provided.

Note:

The time should not be more than 28 seconds.

2.4 Horizontal rudders are to be so designed that, over the whole speed range and under all loading conditions, the desired depth can be maintained.

2.5 Vertical and horizontal rudder systems are to be equipped with an alternative power supply which meets the requirements of 2.3 and 2.4. It shall be possible to switch from the main to the alternative power supply from the control station.

2.6 The main and emergency control stations are to be fitted with indicators showing the positions of vertical and horizontal rudders. In addition, suitable indicators are to be fitted which signal any malfunction or failure of the steering gear.

SECTION 12

ELECTRICAL EQUIPMENT

A. General

1. The following requirements are applicable to all electrical equipment on board submarines as well as to equipment for the handling and retrieval of submarines, where appropriate. If not otherwise stated, the **TL** Rules, Chapter 105 - Electrical Installations may be used as guidance.

In submarines with a diver's lockout, the electrical equipment in the area of the diver's lockout is also required to comply with the provisions of the **TL** Rules, Chapter 52 - Diving Systems, Section 2, H.

2. The documents to be submitted to **TL** for approval are listed in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Design Principles

1. General Principles

1.1 All electrical systems and equipment are to be constructed and installed in such a way that they are serviceable and perform satisfactorily under the design conditions specified for the submarine. The operating conditions of electrical equipment are to conform to the requirements stated in the **TL** Rules, Chapter 105 - Electrical Installations, Section 1, F.

1.2 Besides the essential consumers listed in the **TL** Rules, Chapter 105 - Electrical Installations, Section 1, B. the following items of electrical equipment on submarines also are to be considered essential consumers:

- Battery charging equipment
- Battery room ventilators
- Acid circulation and cooling system
- Equipment for monitoring and treating breathing air

2. Materials and Insulation

2.1 The materials used in the construction of electrical machines, cables and appliances shall be resistant to moist and salty sea air, seawater and oil vapours. They may not be hygroscopic and shall be flame-retardant and self-extinguishing. The requirement that they should be flame-retardant does not apply to winding insulations.

2.2 Materials with high tracking resistance are to be used for the supports of live parts.

2.3 The creepage- and air distances are to be dimensioned as appropriate for the appliance in accordance with IEC. Generator circuit-breakers, pressure hull wall penetrations, under water plug connectors and appliances directly connected to the busbars are to be designed for the next higher nominal insulation rating.

2.4 Materials and insulations for electrical equipment used in water are to be agreed with **TL** in each instance.

3. Supply Systems

3.1 Approved supply systems are:

- Direct current and single-phase alternating current:
  2 conductors insulated from the vessel's hull (2/PE)
- Three-phase alternating current:
  3 conductors insulated from the vessel's hull (3/PE)

3.2 Networks with an earthed neutral are not permitted in submarines.

4. Voltages and frequencies

The use of the following standard voltages and frequencies is recommended. The maximum permissible voltages except for propulsion purpose are:

500 V:

- For permanently installed power systems

- For power systems connected by socket outlets, provided they do not need to be handled

- For heating and galley equipment

250 V:

- For lighting systems and sockets for direct current and single-phase alternating current

- Mobile appliances with double insulation and/or protective isolating transformers

- Machinery control and monitoring systems, unit control systems and unit safety systems

50 V (protective low voltage):

- For mobile appliances used in confined conditions in damp spaces, upper decks, stores, machinery spaces and similar service spaces, where these appliances are not double insulated and/or fitted with protective isolating transformers

5. Protective Measures

5.1 All electrical equipment is to be protected in accordance with the **TL** Rules, Chapter 105 - Electrical nstallations, Section 1, J. unless otherwise stated below or agreed with **TL**.

5.2 The minimum classes of protection stated in Table 12.1 are to be applied in submarines. The class of protection shall be maintained for the equipment as installed, even when in operation (heeling position). In this context, the provision of shielding at the point of installation is deemed to be a protective measure.

5.3 Protective conductors

The following points are to be observed in relation to the use of protective conductors:

- The protective conductors shall take the form of an additional cable, additional conductor or additional core in the connecting cable; cable shields or sheaths may not be used as protective conductors

- A conductor which is live in normal operation may not at the same time be used as a protective conductor and may not be connected with the latter to the hull.

  The core marked green/yellow shall not be used as live conductor.

- The cross-section of the protective conductor shall be equal to at least half that of the principal conductors. However, with cross-sections of 16 mm^2 and less, its cross-section shall be equal to that of the outer conductors. The minimum cross-section of separately laid protective conductors is 4 mm^2.

  The cross-section of the protective conductor shall at least comply with the factors shown in Table 12.2.

  In the unit's propulsion network, the dimensional design of the protective conductors is to be based on the maximum short-circuit currents of the equipment concerned, the maximum break times of the relevant protective elements and a maximum temperature rise of the protective conductor of 90 °C.

- Machines and appliances mounted on insulated vibration dampers are to be earthed with mobile cables or conductors or braided copper leads.

- The protective conductor shall be connected to the hull in a position where it can easily be checked.

- The superstructure or the hull of the unit, as the case may be, is to be provided in an easily accessible position with means of connection in the form of a connecting plate with M 12 stud bolts to which protective conductors can be connected without the use of tools when the Unit is in harbour or in dock. The connection described also serves as a protective lightning conductor when in dock.

Table 12.1 Minimum degrees of protection against foreign bodies and water (in conformity with IEC 529)

Type of equipment / Where installed	Generators Motors Transformers	Switchgear Electronic units Recording equipment	Telecommunications equipment Input units Signalling equipment Switches Sockets Junction boxes Actuators	Heating equipment Heaters Cooking equipment	Lighting fittings
Service spaces, control rooms, accommodation spaces, day rooms, radio room	IP 23	IP 23	IP 23	IP 44	IP 23
Sanitary spaces, commissary spaces, machinery spaces, separator and pump rooms	IP 44	IP 44	IP 55	IP 44	IP 34
Pipe tunnels, bilges	IP 56	-	IP 56	IP 56	IP 56
Outside pressure hull	Watertightness under pressure in accordance with the submarine design criteria				

Table 12.2 Cross-section for earthing conductors

Cross-section of outer conductor	Minimum cross-section of earthing conductor	
[mm^2]	in insulated cables [mm^2]	separately laid [mm^2]
0,5 - 4	equal to cross-section of outer conductor	4
> 4 ≤ 16	equal to cross-section of outer conductor	equal to cross-section of outer conductor
> 16 ≤ 35	16	16
> 35 < 120	equal to half the cross-section of outer conductor	equal to half the cross-section of outer conductor
≥ 120	70	70

C. Primary Systems

1. Electrical power required

1.1 Proof of adequate rating of the units for generation and storage of electrical power has to be furnished by a power balance.

1.2 The power required is to be determined for the following operating conditions:

- Normal operation (surface, snorking and diving operation)
- Emergency operation

1.3 In the power balance all consumers installed, including their power inputs, are to be considered.

2. Power Supply

All electrical equipment essential for the safety of the submarine and its crew is to be connected to an independent main and emergency power supply system.

Other solutions that achieve equivalent safety may be accepted, they have to be agreed with **TL**.

Note:

It is recommended to provide facilities to operate the submarine in surface mode only with diesel gensets without any battery back up.

2.1 Main electrical power supply

2.1.1 Each submarine is to be equipped with a main power source of sufficient capacity, such as to ensure

- That normal operation and the conditions of life as intended to prevail on board can be maintained, without having to take recourse to the emergency power supply
- A sufficient supply of electric power for the envisaged periods of service when operation is both independent of and dependent on an outside air supply

2.1.2 The main power source shall consist of at least two mutually independent, power supply systems, such as

- generator sets
- batteries
- fuel cell (fc) systems

Exceptions may be permitted for vessels with restricted range of service and/or accompanied by supply vessels.

2.1.3 If started electrically, generator sets shall be equipped with a starting device as per **TL** Rules, Chapter 105 - Electrical Installations, Section 3.

2.2 Emergency power supply

2.2.1 The emergency power source shall be capable of supplying the submarine with the energy required in emergencies.

All electrical equipment required for surfacing the vessel shall be adequately supplied with power. Apart from this, simultaneous supply of electrical power to at least the equipment listed below is to be ensured for a period of 168 hours.

- Emergency lighting inside the unit
- Emergency communications equipment
- Equipment for maintaining a breathable atmosphere
- Important monitoring and alarm equipment, e.g. leakage monitoring system, fire alarm system, O_2-monitor and H_2-monitor
- Solenoid valves for blowing diving and reserve buoyancy tanks
- Locating equipment, signal lamps

2.2.2 In addition, it shall be possible to supply electricity to the wireless equipment and important navigating equipment as defined by the Naval Authority but at least for 18 hours of operation.

2.3 Alternative Solution

The electrical system might be designed without a special emergency power supply, if the source of electrical power fulfils the following design criteria:

- The source of electrical power consists of two mutually independent power supplies (generator-sets)
- The batteries necessary for diving operation can be separated into minimum two independent parts
- Power supply for propulsion in surfacing or snorking mode consists out of two independent sources of electrical power e. g. two diesel genset
- Consumers that are usually supplied via the emergency power supply as per 2.2.1 and 2.2.2. shall be supplied from two sources in diving as well as in surface mode (supply via a part battery is accepted one independent source) .For these consumers a supply time of at least 168 hour equivalent to the design with an emergency source of power should be provided.

3. Charging and Shore Connection

3.1 Where socket connections are provided for charging and shore connection with a nominal current more than 16 A these are to be blocked such as to preclude both insertion and withdrawal of the plug, with the contact sleeves of the sockets being alive.

3.2 On the main switchboard and/or ship mains switchboard an indicator is to be fitted showing whether the shore connection line is alive.

4. Batteries and Battery Charging Facilities

4.1 Batteries

4.1.1 Batteries are to be rated such as to be capable of supplying the consumers during the period specified in accordance with the power balance, when charged to 80 % of their rated capacity.

4.1.2 At the end of the supply period the voltage in the storage battery and/or in the consumers shall at least reach the values quoted in the **TL** Rules, Chapter 105 - Electrical Installations, Section 1, F. and 3, C.

4.1.3 Accepted batteries are lead-acid batteries with diluted sulphuric acid as electrolyte and steel storage batteries with nickel-cadmium cells and diluted potassium hydroxide as electrolyte.

Other types of batteries, may be accepted, if suitability for submarine use is proven.

4.1.4 If not otherwise stated, batteries shall be designed such as to retain their rated capacity at inclinations of up to 22,5° and such that inclinations of up to 45° electrolyte will not leak. Cells should be covered as far as possible

4.1.5 The casing shall be resistant to electrolytes, mineral oils and cleaning agents, as well as to corrosion due to salt mist. Glass and readily flammable materials are not approved as materials for casings.

4.1.6 In the case of batteries containing liquid electrolyte it shall be possible to check the electrolyte level. The maximum admissible electrolyte level has to be marked.

4.1.7 Lead and alkaline batteries should not be installed on the same submarine.

4.1.8 Where the installed battery capacity is 1000 Ah or more, the battery is to be divided into battery units so that restricted operation of the submarine is still possible in the event of a fault.

4.1.9 It shall be possible to bridge damaged cells.

4.1.10 The maximum weight of transportable units has to be agreed with the Naval Authority.

4.1.11 The rating data of the storage batteries are to be indicated on rating plates. Storage batteries are to be serviced and operated in accordance with manufacturers' instructions.

4.2 Batteries, installation, ventilation and monitoring

4.2.1 Batteries providing the source of electrical energy for electric propeller drives and/or the unit's power network should be located in special battery spaces. It is necessary to ensure that the batteries are accessible for cell replacement, for repairs and maintenance.

4.2.2 Battery spaces shall be arranged and ventilated to prevent the accumulation of ignitable gas mixtures.

4.2.3 The quantity of air to be aspirated and exhausted during charging shall be so calculated, as to exclude any possibility of exceeding the lower explosion limit for a hydrogen air mixture. H_2-monitors permanently mounted at suitable points shall measure the gas concentration in the battery space, the exhaust system and, where necessary, in other spaces within the unit. If the gas concentration reaches and exceeds a level equivalent to 35 % of the lower explosion limit (LEL), this shall automatically release a visual and audible alarm at a central monitoring station. Equipment for monitoring the H_2 - concentration shall be type tested.

4.2.4 Battery spaces shall contain no other electrical appliances apart from the batteries themselves. Lighting fixtures as well as monitoring equipment for H_2 concentration may be installed, if they are in compliance with the hazardous area requirements for H_2 atmosphere (see IEC 60079 recommendation).

4.2.5 Measures are to be taken to ensure that neither the crew nor the operational equipment can be endangered by emissions of electrolyte fumes.

4.2.6 A sign is to be mounted at the entrance of battery spaces pointing out that only insulated tools shall be used inside and conductive objects like keys, ballpoint pens, watches with conductive watch straps have to be taken off.

Attention is to be drawn to the explosion hazard.

4.2.7 Storage batteries are to be installed in such a way that mechanical damage is as far as possible

excluded. Safe operation under the environmental conditions stated in Section 3, B. is to be ensured and the discharge of electrolyte is to be prevented.

Suitable measures, e.g. provision of plastic trays or flexible rubber bags, are to be taken to prevent, wherever possible, electrolyte from entering the battery space bilges in the event of mechanical damage to individual battery cells.

4.3 Charging facilities

4.3.1 The charging facilities, usually the diesel gensets, including the control device have to meet the requirements of the batteries. The maximum admissible charging currents shall not be exceeded.

4.3.2 If during charging simultaneously consumers are fed, the maximum charging voltage shall not exceed 120 % of the rated voltage.

4.3.3 The battery chargers are to be rated such that the tolerances of the limited characteristics and constant characteristics respectively are adhered to irrespective of external disturbance effects. Preferably chargers with IU or IUW characteristics should be employed.

4.3.4 The charging process shall cut out automatically in case of

- Failure of the battery space ventilation
- Excessive temperature of charging generator
- Excessive H_2 - concentration

5. Power Distribution

5.1 Distribution and switchgear

5.1.1 Electrical distribution systems are to be so designed that a fault or failure in one circuit cannot impair the operation of other circuits or the power supply.

Redundant supplies have to be provided in minimum for all essential consumers e. g. supply from each part battery.

In surface operation supply of all essential consumers should be possible without any battery.

5.1.2 If emergency power supply is provided the emergency power distribution system may be supplied via a transfer line from the main power distribution system in normal operation.

5.1.3 The cable length between switchboards and batteries has to be minimized. The unprotected cables are to be laid on separate cable runs up to the circuit breaker. They are to be protected against mechanical damage.

5.1.4 Circuits at protective low voltage shall not be routed with circuits at higher voltage in a joint conductor bundle or cable duct.

Terminals for different voltage levels are to be arranged separately and are to be clearly identified.

5.1.5 Switches and fuses for different voltage systems are to be spatially separated inside the switchboard.

5.2 Switching and protective devices

5.2.1 Each circuit is to be protected against overload and short-circuit.

5.2.2 All consumer circuits are to be fitted with switches. The switching action shall be on all poles.

5.2.3 Fuses in distribution panels may be used for overload protection to a rated current of 63 A. The use of greater fuses, e.g. in the main switchboard has to be agreed with **TL.**

5.2.4 A continuously operating insulation monitoring system is to be installed.

An alarm has to be available at a continues manned operation station if the insulation value drops below a preset limit.

5.3 Enclosures for electrical equipment

5.3.1 The enclosures of electrical equipment installed outside the pressure hull or operated in water has to be approved by **TL**.

5.3.2 Enclosures mounted on the outside of the pressure hull are to be tested at the test diving pressure, subject to a minimum of 1,1 times the collapse diving pressure.

5.4 Earthing

The earthing of electrical systems and equipment on submarines is subject to the requirements stated in the **TL** Rules, Chapter 105 - Electrical Installations.

5.5 Cables and lines

5.5.1 Cables and lines for submarines shall be suitable for the proposed application. Their use is subject to approval by **TL**.

5.5.2 The selection, dimensions and installation of cables and lines has to be based on the **TL** Rules, Chapter 105 - Electrical Installations, Section 11 and Section 15, G.

5.5.3 Only halogen-free materials should be used as insulating sleeves, protective coverings, sheaths and fillers of cables used in submarines.

5.5.4 Cables outside the pressure hull shall be radially watertight and designed for 1,3 time the collapse diving pressure.

The pressure resistance is to be verified by pressuretesting for each cable (connectors fitted).

5.5.5 In cables for winding on drums, no mechanical forces may be transmitted via conductors of the cable and their insulation

5.6 Busbars

5.6.1 Where busbars are used for connecting equipment, only sealed or insulated systems may be used.

Exceptions to this Rule are switchboards and enclosed electrical service spaces.

5.6.2 The permissible load of busbars has to comply with the **TL** Rules, Chapter 105 - Electrical Installations, Section 5, F.

5.6.3 The busbar system is to be so constructed that neither the connected equipment nor the busbar system itself can be damaged by movement of the busbars, temperature rises or external mechanical influences.

It is recommended that expansion links should be fitted.

Prior to the installation of busbar systems, proof is required of mechanical strength under short-circuit conditions considering the effects of the electrical heating produced by the short-circuit current.

5.6.4 For busbars, only copper with a conductivity of 56 m/(Ω mm^2) may be used.

If other conducting materials are used, the loading capacity of the system is to be reduced accordingly

5.7 Electrical penetrations in pressure hull walls, underwater plug connections

5.7.1 Pressure hull penetrations shall be gas and watertight. Their tightness shall be guaranteed even should the connected cables be damaged.

Electrical penetrations may not be used for the passage of other systems.

5.7.2 Electrical pressure hull penetrations and underwater plug connections shall be type tested.

Type-testing is performed, on application, at the manufacturer's works and comprises at least the following individual tests:

- Hydraulic pressure test, in which the test pressure has to be equal 1,1 time the collapse diving pressure. The test is to be conducted in accordance with the test pressure/time curve shown in Fig. 12.1, the changes in pressure being applied as quickly as possible.

- Gastightness test with open cable ends. If compressed air is used, the test pressure shall be equal to 1,1 time the collapse diving pressure .

  In all pressure and tightness tests on pressure hull wall penetrations, the pressure shall in each case be applied from the pressure side of the wall penetration.

  During the pressure and tightness test, the penetration is to be loaded with the rated current in all conductors.

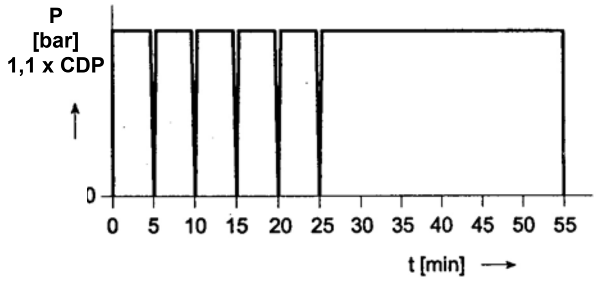


Figure 12.1 Test pressure / time curve

- High voltage test at an AC voltage of 1000 V plus twice the rated voltage. This test is performed at the rated frequency and is to be carried out for 1 minute in each case between all the conductors mutually and between the conductors and the casing. The test is performed in the disconnected state. The sealing of the connector shells and the like is permitted where this is stipulated by the manufacturer in the relevant data sheet.

- Measurement of insulation resistance

  The minimum value of the insulation resistance between the conductors mutually and between the conductors and the casing shall be 5 MOhm.

  The insulation resistance is to be measured with an instrument using 500 V DC.

  With wet plug connections, the minimum insulation resistance is also to be measured after the connection has been made once in saltwater.

- Visual check against manufacturer's documentation

5.7.3 All electrical pressure hull wall penetrations and all plug connections are to be subjected to individual inspection by the manufacturer.

This inspection comprises the following tests:

- Hydraulic pressure test in accordance with Fig. 12.2 at 1,1 times the collapse diving pressure

- High-voltage test

- Measurement of insulation resistance

A manufacturer's test certificate is to be issued covering the inspection.

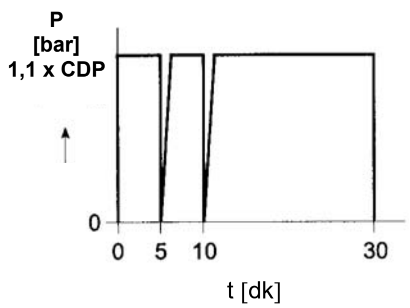


Figure 12.2 Test pressure / time curve

6. Electrical machines

6.1 Electrical machines shall comply to the **TL** Rules, Chapter 105 - Electrical nstallations, Section 14.

6.2 Generators with an output of ≥ 100 kVA and all electric propeller motors rated at over 100 kW are to be equipped with a standstill heating system.

6.3 Machines for electric propeller drives rated at more than 100 kW are to be equipped with monitoring devices in accordance with the **TL** Rules, Chapter 105 - Electrical Installations, Section 12.

6.4 Insulation classes A and E are not permitted for the windings of electrical machines in submarines.

6.5 In addition to the tests stipulated in **TL** Rules, Chapter 5 - Electrical, Section 20, A.4., the following electrical machines are to be tested in the presence of a **TL** Surveyor:

- Generators and motors for electric propeller drives

- Motors for steering gear drives and windlasses

- All other motors driving machines and equipment necessary to the safety and manoeuvrability of the submarine

7. Lighting

7.1 Service and work spaces, safety and control stations, accommodation spaces and day rooms are to be equipped in minimum with normal and emergency lighting.

The emergency lighting has to be independent from the normal lighting. This applies to the power supply as well as to the cable/ distribution network.

If an emergency power supply is provided, the emergency lighting shall be supplied from the emergency source of power.

7.2 The lighting is to be so designed and arranged that all important instruments and markings can be read and any necessary operations can be safely performed.

8. Spare Parts

The amount of spare parts has to be agreed with the Naval Authority.

SECTION 13

CONTROL and MONITORING, COMMUNICATION and NAVIGATION EQUIPMENT

Page

A. General

1. The following requirements supplement the **TL** Rules, Chapter 105 - Electrical Installations and Chapter 106 - Automation as far as applicable and are to be applied to the construction and use of control, monitoring and communication equipment in submarines as well as to that of navigating equipment in submarines built under the survey and in accordance with the **TL** Rules.

2. The documents to be submitted to **TL** are listed in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Control and Monitoring Equipment

1. Design Principles

1.1 General principles

1.1.1 All control and monitoring equipment is to be designed and constructed so that it works properly under the design and environmental conditions specified for the submarine.

1.1.2 Computer-aided operating systems for the navigation and/or for the control and monitoring of the submarine will be accepted.

Details of the scope and redundancy requirements of these systems are to be agreed with **TL.**

The systems are subject to **TL**-type-approval.
Such type-approval relates both to the hardware and to the software.

Other approval may be accepted by **TL**.

1.1.3 The automation equipment on board submarines is to be constructed in accordance with **TL** Rules, Chapter 106 - Automation as far as applicable. Apart from this, the following is to be observed.

1.1.4 All items of control and monitoring equipment are to be clearly inscribed and identified.

1.1.5 Indicating instruments and synoptic displays are to be designed and inscribed in such a way that they can be read quickly and clearly.

1.1.6 Probable faults or failures which may ocur in the control and monitoring system shall not provoke a critical operating condition.

1.1.7 As far as possible, control and monitoring equipment is to be safeguarded against faulty operation.

1.1.8 Control and monitoring equipment shall be capable of maintaining the submarine's assigned operating parameters.

1.1.9 Any specified inadmissible variations in the operating parameters/conditions shall actuate an (visual and audible) alarm at the control station. The same shall also occur in the event of automatic switching operations in the gas and power supply systems or faults in the control and monitoring system.

1.1.10 In addition to electronic control and monitoring equipment, independent safety devices shall be fitted which prevent a fault in one system from provoking an improper response in another system.

1.1.11 Automatic control equipment shall be capable of being switched to manual operation.

1.1.12 The response values of control and monitoring equipment shall be so coordinated with each other that, when a threshold is reached, a warning is initiated, followed, after a certain warning period or if the process variable continues to change at a preset speed, by the actuation of safety devices.

1.1.13 The integral operation of control and monitoring systems shall be designed to take account of the lags and time constants of the units and elements making up the system (e.g. by allowing for the length and cross-section of piping systems and the response time of gas analyzers).

1.2 Construction

1.2.1 Control and monitoring systems should comprise easily replaceable assemblies, of the plug-in type wherever possible. Standardization of units is recommended and the number of assembly types is to be kept small in order to minimize the spare parts inventory.

1.2.2 Plug-in cards shall be clearly marked or coded to prevent inadvertent exchange.

1.2.3 Measures are to be taken to prevent condensation inside electronic units, even when switched off. Standstill heating is recommended.

1.2.4 Wherever possible, control and monitoring equipment should be capable of operation without forced ventilation. Any cooling system used is to be monitored.

1.2.5 Components shall be effectively secured. Any mechanical loading of wires and soldered connections due to vibration or jolting is to be reduced to a minimum.

1.2.6 The construction of systems and units is to be common and well arranged. Good accessibility is to be ensured to facilitate measurements and repairs.

1.2.7 Input equipment such as limit switches, transducers, transformers and reading-in machines, as well as control elements, fire alarm systems, remote control devices for propulsion systems, engine alarm systems as well as combined equipment for the recording of measurement data and interferences requires to be type-approved in line with Guidelines for the Performance of Type Tests.

1.3 Circuitry

1.3.1 Control and monitoring equipment with a safety function shall be designed on the fail-safe principle, i.e. faults due to short-circuit, earthing or circuit breaks shall not be capable of provoking situations hazardous to personnel and/or the system. In this respect, it is to be assumed that faults occur singly. The failure of one unit, e.g. due to short-circuit, shall not result in damage to other units.

1.3.2 Alarm systems shall be designed on the closed-circuit or the monitored open-circuit principle. Equivalent monitoring principles are permitted.

1.3.3 Instruction and control units for safety functions, e.g. emergency stop buttons, shall be independent of stored-program control systems and shall act directly on the output unit, e.g. the STOP solenoid.

1.3.4 Stored-program control systems should be reactionless and, in case of fault, should cause no malfunctions in program-independent safety interlocks or stepped safety circuits for fixed subroutines.

1.3.5 Freely accessible potentiometers and other units for equipment trimming or operating point settings shall be capable of being locked in the operating position.

1.3.6 Interfaces with mechanical switchgear shall be so designed that the operation of the system is not adversely affected by contact chatter.

1.3.7 The equipment shall not be damaged by brief overvoltages in the unit's power supply, due for example to switching operations.

1.4 Power supply

Regarding the power supply to control, monitoring and ship safety equipment the requirements as per Chapter 105 - Electrical Installations, Section 9 are to be observed, as is the following:

1.4.1 The equipment is to be supplied via separate power circuits. Selective circuit opening of each of these in the event of short-circuit is to be ensured.

1.4.2 For power supply to systems which require to remain operational in the event of failure of the main power supply system common mains backed up by storage battery may be provided. For this mains, two power supply alternatives shall be available, compare

TL Rules, Chapter 105 - Electrical Installations, Section 4.

1.4.3 The control and monitoring equipment shall be capable of being safely operated in the event of voltage and frequency variations referred to in the **TL** Rules, Chapter 105 - Electrical Installations, Section 1, F.

2. Navigation and Manoeuvring

2.1 Control station

2.1.1 For the control and monitoring of the submarine a control station is to be provided which shall be equipped with indicators displaying all essential information about the submarine, its internal conditions and the operating states of the auxiliary systems and with all the control devices needed to operate the submarine including its communication equipment.

2.1.2 The grouping and arrangement at the control station of the instruments for the control, monitoring and operation of the submarine shall conform to the principles of safety technology and ergonomics.

2.1.3 No units or equipment liable to impair the control or monitoring of the submarine may be installed in the area of the control station.

2.2 Control station equipment

2.2.1 For each of the functions to be performed on the control station of the submarine the following monitoring equipment is to be provided

2.2.2 Navigation:

- Navigational radarscope
- Position indication system (e.g. GPS)
- Obstruction signalling device (if fitted)
- Optical surveillance (e.g. TV, periscope)
- External communication system (e.g.VHF)
- Internal communication system
- Navigation and signal lamp monitor
- Chronometer

2.2.3 Steering:

- Gyro compass
- Depth indicators
  2 depth indicators which work independently of each other and are not connected to the same pressure hull penetration.
- Heeling and trim angle indicator
- Speed and distance indicator
- Rudder angle indicators (vertical and horizontal rudders)
- Indicator showing speed and direction of rotation of main driving propeller
- Thrust direction indicator for other propulsion units (if fitted)
- Level indicators for regulating/compensating and trimming tanks

2.2.4 Submarine atmosphere

- The indicators and alarms specified in Section 14 for monitoring the submarine atmosphere.

2.2.5 Electrical equipment

- Generator current and voltage indicators
- Battery capacity, current and voltage indicators
- Current consumption indicators of propeller motors and essential electric drives
- Power supply/distribution indicators

- Insulation monitor displays

2.2.6 Alarm equipment and indicators

- Machinery alarm systems
- Fire detection and fire alarm system
- Leakage indicator(s)
- General alarm system
- Pressure gauge for all compressed-air receivers
- Pressure gauge for all oxygen storage tanks
- Pressure gauges for hydraulic system(s)

2.3 Control equipment

2.3.1 The control station or another suitable place of the submarine is to be equipped to control at least the following:

- Propulsion plant
- Autopilot
- Vertical and horizontal steering gears
- Diving/ballasting systems
- Trimming system
- Regulating/compensating systems
- Freeing systems
- Power distribution
- Auxiliary systems
- Emergency stopping devices (e.g. combustion engines, shut-off hull valves)

C. Communication Equipment

1. General

1.1 Regardless of their type, size and function or range of service, submarines are to be equipped with various means of internal and external communication.

1.2 For submarines with a diver's lockout suitable means and procedures of communication shall be provided.

2. Internal communications equipment

2.1 Compartments, rooms and control stations are to be equipped with a two-way communications system.

2.2 A telephone link independent of the submarines power supply system is to be provided between the control station and the steering gear compartment and between the control station and the propulsion machinery space.

3. Surface Communications

3.1 Submarines are to be equipped with at least one two-channel transmitter/receiver, one of the channels of which shall operate on safety channel 16-VHF, while the other is used as a "working channel" for communication.

3.2 Submarines are also to be equipped with an additional radiotelephone.

4. Underwater Communications

Submarines are to be equipped with a two-channel side-band UT system, if not otherwise defined by the Naval Authority. The UT system should have a minimum range equivalent to twice the nominal diving depth of the submarine, but at least 1 nautical mile.

5. Emergency Communications Equipment

5.1 Submarines are to be equipped with radiotelephones connected to the emergency or alternative power supply and capable of both surface and snorkelling operation. The emergency radiotelephone equipment should include at least one VHF transmitter / receiveroperating on safety channel 16.

D. Navigation Equipment

1. All electrically operated items of navigation equipment necessary to the safety of the submarine and its crew are to be connected to the submarine's emergency or alternative power supply. The availability of the equipment for service and its current operating status are to be indicated at the control station.

2. Wherever necessary, the official regulations of the Naval Authority are to be observed when fitting out the submarine with navigation equipment. The minimum equipment to be provided should include the relevant items specified in Sections 3, E. and 16, B.

SECTION 14

LIFE SUPPORT SYSTEMS

A. General

1. The following requirements apply to all those plant components and parts which are needed to ensure life support and a safe environment for the crew of the submarine.

2. The documents to be submitted to **TL** for approval are stated in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E.

4. For breathing gas systems the **TL** Rules, Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 18 have to be observed as far as applicable.

B. Design Principles

1. Submarines are to be fitted with equipment for providing, maintaining and monitoring life support conditions. The equipment is to be so designed that the necessary conditions can be maintained as defined by the Naval Authority, but at least for 168 h in excess of the maximum intended duty period of the submarine.

For submarines equipped with a diver's lockout, the space of the lockout is to comply with the requirements set out in the **TL** Rules, Chapter 52 – Diving Systems.

2. Equipment is to be installed for the circulation and treatment of the atmosphere in the submarine such that the oxygen partial pressure can be maintained within the range 0,19 - 0,24 bar and the CO_2 partial pressure can be kept below 0,01 bar in the various spaces. In addition, air purifying and conditioning units are to be installed. The limit values for the permissible atmospheric impurities are to be agreed with **TL** in each case.

3. Facilities are to be provided for supplying the whole crew with food and water and for disposing of waste and effluent during the period stated in 1.

4. An emergency respirator or a breathing mask which can be connected to the emergency breathing air system is to be provided for each crew member plus 20 %.

5. Suitable equipment is to be fitted for monitoring the environmental conditions inside the vessel. The crew is to be warned by an automatic alarm in the event of inadmissible deviations from the O_2 and CO_2 partial pressures stated in 2.

C. Air Supply

1. Air Supply and Gas Exhaust System

1.1 When travelling on the surface or at snorkel depth, it shall be possible to ventilate the vessel via an air/snorkel mast which is to be designed and arranged to prevent the penetration of spray and swell water.

1.2 For spaces where air can be contaminated, gas exhaust systems have to be provided. The venting of battery spaces is to be separated from other ventilation systems as far as applicable.

2. Air Renewal

2.1 Oxygen system

2.1.1 An oxygen system is to be installed to replace the oxygen consumed from the atmosphere in the submarine.

2.1.2 The oxygen supply system is to be designed on the basis of a consumption rate of at least 25 ℓ/h per person.

2.1.3 The oxygen is to be stored in at least two separate units/groups of bottles, if possible outside the pressure hull.

2.1.4 Each unit/group of oxygen bottles is to be connected to the inside of the submarine by a separate line.

2.1.5 All pipes and components used in oxygen systems shall be carefully cleaned and degreased before being put into service.

2.1.6 Manually operated oxygen dosing units are to be equipped with a pressure gas cylinder shut-off valve and a device for controlling the flow-rate. A flow-rate indicator has to be fitted.

2.1.7 Dosing units are to be equipped with a manually operated bypass.

3. CO_2 absorption

3.1 For regenerating the breathing air a CO_2 absorption unit is to be provided which shall be capable of keeping the CO_2 partial pressure in the range 0,005 - 0,010 bar. In addition, it shall be possible to maintain a CO_2 partial pressure within the submarine of not more than 0,020 bar at the end of the survival time stated in B.1.

3.2 The design of the CO_2 absorption unit is to be based on a CO_2 production of 20 ℓ/h per person at 20 °C and 1 bar.

3.3 The CO_2 absorption unit is to be fitted with a dust filter of non-combustible material.

4. Emergency breathing air supply

4.1 Emergency breathing air systems/appliances are to be designed to ensure that in an emergency all crew members have sufficient breathing air while the submarine is rising, or being brought, to the surface, subject to a minimum time of 30 minutes.

4.2 The emergency breathing air appliances are to be so designed and arranged that in an emergency each crew member can very quickly reach a breathing appliance and can reach the exit from the submarine without first having to remove the breathing mask.

5. H_2 monitoring

5.1 The hydrogen content is to be monitored continuously in the battery spaces, the exhaust system and if applicable in other spaces. The position of the measuring points is to be fixed considering the local conditions.

5.2 If a gas concentration of 35 % of the lower explosion limit is exceeded, it is to be signalled optically and acoustically to the control station.

If a value of 50 % of the lower explosion limit is reached, all charging or discharging processes of the batteries have to be interrupted.

If the H_2 concentration is still rising after the switchoff, e.g. from finish gassing of the batteries, immediately surfacing is to be initiated and forced ventilation is to be applied.

5.3 The request for immediate surfacing is to be signalled optically and acoustically at the control station. Reset of the optical signal shall be possible only after surfacing and after sufficient fresh air has been supplied.

5.4 The measuring and assessing equipment for monitoring of the H_2 concentration shall be approved by **TL.**

5.5 The hydrogen measuring system is also to be supplied by an emergency power supply.

D. Monitoring Equipment

1. The control station of the submarine is to befitted with indicating instruments for monitoring at least the following environmental conditions inside the submarine:

- Pressure
- Temperature
- Humidity
- Oxygen partial pressure
- CO_2 partial pressure
- Pressure of connected breathing gas cylinders
- Downstream pressure of pressure-reducing valves

2. The readings of the pressure gauges shall be accurate to at least 1 % of the complete indicating range. The use of mercury pressure gauges and thermometers is not permitted.

3. Each section of the submarine which can be separated should be provided with facilities for measuring the room temperature and the O_2 and CO_2 partial pressures.

4. A permanent gauge and a standby indicator are to be provided for monitoring both the O_2 and CO_2 partial pressure. Test tubes may be recognized as standby indicators.

5. The system for the analysis of oxygen shall have a minimum indicating accuracy of ± 0,015 bar oxygen partial pressure.

6. The CO_2 analysis system shall have a minimum indicating accuracy of ± 0,001 bar CO_2 partial pressure.

7. A system of analysis is to be provided for determining atmospheric impurities such as CO, NO, NO_x and hydrocarbons. Test tubes may be accepted for this purpose.

E. Emergency Thermal Protection

For each crew member Submarines are to be equipped with sufficient thermal protection even in an emergency of the duration stated in B.1.

SECTION 15

FIRE PROTECTION and FIRE EXTINGUISHING

Page

A. General

1. The requirements of this Section apply to the fire protection and fire extinguishing systems of submarines and are to be applied in conjunction with the **TL** Rules, Chapter 102 – Hull Structures and Ship Equipment, Section 20 and Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 9, where applicable.

2. The documents to be submitted to **TL** for approval are stated in Section 2, C.

3. The necessary tests and markings are as stated in Section 2, D. and E

B. Structural Fire Protection

1. As far as possible, only non-combustible materials or materials which are at least flame-retardant are to be used inside submarines. All loadbearing components and insulations are to be made of non-combustible materials.

2. Sources of ignition are to be avoided wherever possible. Electrical heating appliances and heaters are to be fitted with protection against overheating.

3. Components and materials are to be selected with a view to minimize the accumulation of electrostatic charges.

4. Where combustible materials are installed in closed cabinets, the latter are to be so designed that effective extinguishing action can be taken from outside.

C. Fire Detection and Alarm Systems

1. Fire Detection Systems

1.1 Fire detection systems including central fire detection stations, fire detectors and the wiring of the detection loops require the approval of **TL.**

1.2 Fire detection systems shall be so constructed that any fault, e.g. supply failure, short-circuit or wire breakage in the detection loops, or the removal of a detector from its base triggers a visual and audible signal at the central fire detection station.

1.3 The design and arrangement of fire detection and alarm systems are to conform to the **TL** Rules, Chapter 105 – Electrical Installations, Section 9, C.3. and Chapter 106 – Automation, Section 11, H, as applicable.

2. Fire Alarm Systems

2.1 Submarines have to be equipped with an automatic fire alarm system.

2.2 The fire alarm system should be located at least at the submarine's control station. Fire alarms should be mounted in the individual spaces of the submarine.

2.3 The fire alarm may be actuated manually from the control station (and other suitable places) or automatically by the fire detection system.

D. Fire Extinguishing Systems

1. Each compartment of the pressure hull is to be equipped with suitable means for extinguishing a fire in the interior by providing for the rapid and efficient distribution of the extinguishing agent to any part of the space.

2. The fire extinguishing systems are to be designed and constructed in such a way that they can safely deal with every conceivable outbreak of fire under the environmental conditions stated in Section 3. Actuation of a fire extinguishing system may not cause any unacceptable pressure change in the space concerned.

3. Extinguishing systems include manual extinguishers or permanently installed extinguishing appliances.

4. Wherever possible, manual extinguishers are to be mounted where they are easily accessible. Permanently installed extinguishing systems should only be capable of manual actuation and should, as far as possible, be safeguarded against improper and accidental operation. The systems should be actuated from outside the space to be protected and only after an alarm has been given in the space which has then been evacuated by all present crew members.

5. Extinguishing agents with a toxic, stifling or narcotic effect are not permitted. Other solutions should be agreed with **TL.**

In case that for separated compartments carbon dioxide may only be used as extinguishing agent with acceptance of the Naval Authority special procedures are to be defined and trained to guarantee the safety of the personal on board.

6. Suitable means are to be provided to ensure that in any space the quantity of extinguishing agent ejected does not exceed that required to extinguish the fire.

SECTION 16

RESCUE SYSTEM

Page

A. General

1. The following Rules apply to all the systems for emergency surfacing the submarine and rescuing the crew.

The personal protective equipment (e.g. life buoys, life jackets, immersion suits for thermal protection) provided for the crew of the submarine are to be defined by the Naval Authority.

2. The documents as stated in Section 2, C. and the rescue procedures are to be submitted to **TL.**

3. The necessary tests and markings are as stated in Section 2, D. and E.

B. Design Principles

1. For the purposes of these Rules, rescue appliances include all systems and equipment for recovering the submarine and rescuing its crew, including in particular:

- Emergency gas supply for blowing the diving tanks by e.g. additional supply of compressed air or hydrazine generators.

- Marker buoy and signal ejector

- Mating flange for external submarine rescue systems if installed

- Rescue sphere if installed

2. If hard ballast is used for emergency surfacing calculated proof is to be furnished that, after release of the hard ballast, the submarine rises safely to the surface and floats there in a stable position.

The devices for jettison of ballast are to be so designed that two mutually independent actions have to be performed to initiate the release operation.

3. For the marker buoy of a submarine, see Section 3, E.

4. Where the submarine is provided with a mating flange for an external submarine rescue system or a rescue sphere, the relevant design parameters and calculations are to be agreed with **TL** in each case.

5. An emergency system for the blowing of the diving/ballasting tanks has to be provided. A calculation which shows the required volume and blow pressure for safe emergency surfacing of the submarine is to be submitted to **TL**. The requirements have to be based on the Safety Envelope Calculation and have to be agreed with the Naval Authority and **TL.**

ANNEX A

DESIGN of the PRESSURE HULL

Page

Note:

*For the design of pressure hulls, also Annex A of **TL** Rules for Submersibles, Edition 2016 is to be applied as a supplementary document.*

A. General

1. Introduction

A method of calculation for designing the pressure hulls of submarines is described in the following, which can be used for the two loading conditions as defined in Section 5:

- Nominal diving pressure NDP

- Collapse diving pressure CDP

to investigate the stresses in the pressure hull and the corresponding states of stability.

The method of calculation presented takes account of fabrication relevant deviations from the ideal shape of the shell (e.g. out-of-roundness). The fabrication tolerances as defined in Annex B have to be applied for the calculation.

Conical shells are calculated in sections, each of which is treated as a cylindrical shell.

Overall collapse of the design is regarded as buckling of the hull structure between bulkheads, deep frames or dished ends.

For the states of stability described, proof is required of sufficient safety in respect of the particular form of damage concerned.

When using the method of calculation it is to be remembered that both elastic and elastic-plastic behaviour can occur in the materials of the shell structure.

It is generally the case that:

- At nominal diving pressure, the stress is within the purely elastic range of the material

- At test pressure, the stress may lie at the commencement of the elastic-plastic range of the material

  However, calculations relating to the permissible stress being exceeded can be based on the assumption that the behaviour of the material is elastic.

- At the collapse pressure, the stress may lie in the elastic or the elastic-plastic range of the material

When calculating a pressure hull, use is to be made of design data corresponding to the proposed service conditions of the submarine in accordance with Section 4, E.

Pressure hulls subjected to internal overpressure are in addition to be designed in accordance with Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 16.

2. Longitudinal Strength

The longitudinal strength of the hull structure is based on the longitudinal bending moments and shear forces.

It has to be checked only on request of **TL.**

3. Vessels Similar to the Pressure Hull

For vessels which are partly or totally arranged like pressure hulls and from which the safety of the submarine depends in the same way, like entrance trunk, torpedo tubes, containers for survival devices, etc., the same proofs have to be carried out as for the pressure hull.

4. Acrylic Plastic Windows

For design of acrylic plastic windows see **TL** Rules, Chapter 53 – Submersibles, Appendix B.

B. Fatigue

1. Proof of fatigue has to be carried out according to load case I characterized by operational loads with nominal diving depth NDD according to Section 5, B.2.1.

2. The proof of stresses is to be based on the nominal geometry.

3. For the calculation of the stresses in the pressure hull, the following influences have to be considered with sufficient accuracy:

- Increase of stress at frames, deep frames, bulkheads and buckling rings
- Increase of stress at penetrations
- Disturbances of the state of stress because of connection with pressure-proof extensions.

C. Strength at Nominal Diving Depth

1. Proof of strength has to be carried out for load case I characterized by loads at nominal diving depth NDD according to Section 5, B.2.1.

2. For the calculation of the stresses in the pressure hull the stress limits as defined in Section 4. E.3. apply.

D. Ultimate strength at Collapse Depth

1. Scope

Proof of ultimate strength has to be carried out for load case II characterized by loads with collapse diving depth CDD according to Section 5, B.2.3.

For the following types of failure it has to be proven that the pressures for a failure are greater or equal to the calculation pressure:

- Symmetric buckling between the frames
- Asymmetric buckling between the frames
- General instability under consideration of the partial effect of the deep frames
- Tilting of the frames
- Buckling of the dished ends and spheres
- Yielding at discontinuities

2. Calculation of Stresses in a Uniformly Stiffened Cylinder or Cone as Basis For The Calculation of The Collapse Pressure

2.1 The geometrical situation is defined in Fig. A.1.

Designations in Fig. A.1:

R_m = Mean radius of a cylindrical shell

h = Actual thickness of the shell after deduction of corrosion allowance

h_{St} = Web height of the frame

t_{St} = Web thickness of the frame

b_G = Flange width

t_G = Flange thickness

L_{Sp} = Frame spacing

A_{Sp} = Cross-sectional area of the frame

R_{Sp} = Radius to the centroid of the frame cross section

2.2 Calculation of factors and basic formulas

$$F_1 = \frac{4}{\theta}\left\{\frac{\cosh^2\eta_1\theta - \cos^2\eta_2\theta}{\frac{\cosh\eta_1\theta\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\sin\eta_2\theta}{\eta_2}}\right\} \quad (1)$$

$$F_2 = \frac{\frac{\cosh\eta_1\theta\sin\eta_2\theta}{\eta_2} + \frac{\sinh\eta_1\theta\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\sin\eta_2\theta}{\eta_2}} \quad (2)$$

$$F_3 = \sqrt{\frac{3}{1-\nu^2}}\left\{\frac{-\frac{\cosh\eta_1\theta\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\sin\eta_2\theta}{\eta_2}}{\frac{\cosh\eta_1\theta\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\sin\eta_2\theta}{\eta_2}}\right\} \quad (3)$$

$$F_4 = \sqrt{\frac{3}{1-\nu^2}}\left\{\frac{\frac{\cosh\eta_1\theta\sin\eta_2\theta}{\eta_2} - \frac{\sinh\eta_1\theta\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\sin\eta_2\theta}{\eta_2}}\right\} \quad (4)$$

$$p^* = \frac{2Eh^2}{R_m^2\sqrt{3\left(1-\nu^2\right)}} \quad (5)$$

E = Young's modulus

= $2{,}06 \cdot 10^5$ N/mm² for ferritic steel

v = Poisson's ratio

= 0,3 (typically)

$$\gamma = \frac{p}{p^*} \quad (6)$$

p = Calculation pressure

= CDP (in general)

$$\eta_1 = \frac{1}{2}\sqrt{1-\gamma} \quad (7)$$

$$\eta_2 = \frac{1}{2}\sqrt{1+\gamma} \quad (8)$$

$$L = L_{Sp} - t_{St} \quad (9)$$

$$L_{eff} = \frac{2}{\sqrt[4]{3\left(1-\upsilon^2\right)}}\sqrt{R_m h} \quad (10)$$

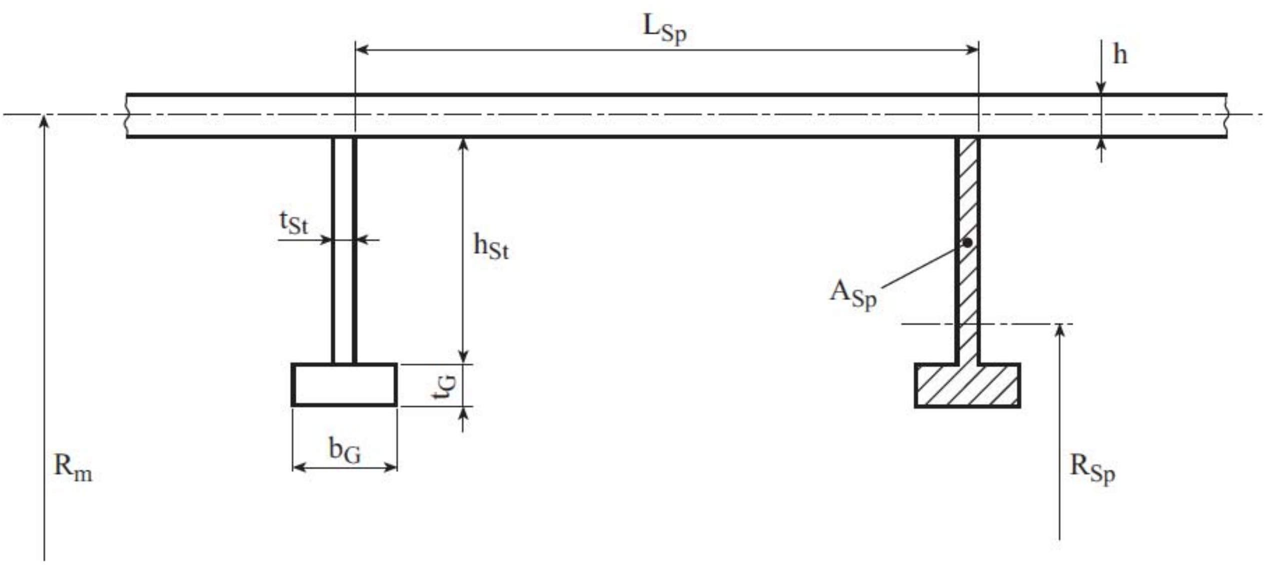


Figure A.1 Geometrical situation of frames stiffening the pressure hull

$$A_{eff} = A_{Sp} \frac{R_m}{R_{Sp}} \qquad \textbf{(11)}$$

$$\theta = \frac{2L}{L_{eff}} \qquad \textbf{(12)}$$

Circumferential stress of the unstiffened pressure hull σ_u:

$$\sigma_u = -\frac{pR_m}{h} \qquad \textbf{(13)}$$

Radial displacement midway between the frames w_m:

$$w_m = -\frac{pR_m^2}{Eh}\left(1-\frac{\nu}{2}\right)\left\{1-\frac{A_{eff}F_2}{A_{eff}+t_{St}h+LhF_1}\right\} \qquad \textbf{(14)}$$

Radial displacement at the frames:

$$w_{Sp} = -\frac{pR_m^2}{Eh}\left(1-\frac{\nu}{2}\right)\left\{1-\frac{A_{eff}F_2}{A_{eff}+t_{St}h+LhF_1}\cdot\left[\cosh\eta_1\theta\cos\eta_2\theta+\frac{\sqrt{\frac{1-\nu^2}{3}\frac{F_4}{F_2}+\gamma}}{4\eta_1\eta_2}\sinh\eta_1\theta\sin\eta_2\theta\right]\right\} \qquad \textbf{(15)}$$

Mean membrane stress in longitudinal direction (independent from the longitudinal coordinate x):

$$\sigma_x^M = -\frac{pR_m}{2h} \qquad \textbf{(16)}$$

Membrane stress in circumferential direction midway between the frames:

$$\sigma_{\varphi,m}^M = E\frac{w_m}{R_m} + \nu\sigma_x^M \qquad \textbf{(17)}$$

and at the frames:

$$\sigma_{\varphi,Sp}^M = E\frac{w_{Sp}}{R_m} + \nu\sigma_x^M \qquad \textbf{(18)}$$

Bending stresses in longitudinal direction midway between the frames:

$$\sigma_{x,m}^b = \pm\sigma_u\left(1-\frac{\nu}{2}\right)F_4\frac{A_{eff}}{A_{eff}+t_{St}h+LhF_1} \qquad \textbf{(19)}$$

and at the frames:

$$\sigma_{x,Sp}^b = \pm\left(\sigma_u - \sigma_{\varphi,Sp}^M\right)F_3 \qquad \textbf{(20)}$$

The positive sign is valid for the outside of the cylindrical shell.

Bending stresses in circumferential direction midway between the frames:

$$\sigma_{\varphi,m}^b = \nu\sigma_{x,m}^b \qquad \textbf{(21)}$$

and at the frames:

$$\sigma_{\varphi,Sp}^b = \nu\sigma_{x,Sp}^b \qquad \textbf{(22)}$$

The circumferential stress in the frame σ_{Sp} follows from the radial deflection to:

$$\sigma_{Sp} = E\frac{w_{Sp}}{R} \qquad \textbf{(23)}$$

This stress depends on the radius R.

2.3 Calculation of the stresses in a conical hull

The formulas given above are also applicable to stiffened conical shells.

The relevant formulas have to be modified using the half apex angle α. For this, the equivalent mean radius yields to:

$$R_{m,ers} = R_m / \cos\alpha \qquad \textbf{(24)}$$

and the equivalent frame spacing turns to:

$L_{Sp,ers} = L_{Sp}$ / cos α, respectively

$L_{ers} = L$ / cos α **(25)**

R_m = Radius midway between the frames of the bay under consideration..

The calculation has to be carried out for both frames of the bay under evaluation. The dimensions of the frames have to be multiplied by the radius ratio $R_m/R_{m,Sp.}$ For the following calculation of the collapse pressures the (absolutely) greatest value is decisive.

3. Calculation of the Collapse Pressure For The Asymmetric İnterstiffener Buckling of the Shell in Uniformly Stiffened Sections of the Pressure Hull

3.1 For conical pressure hulls the equivalent values as defined for the stress calculation above have to be used.

For calculation of the minimum buckling pressure which depends on the number of the circumferential lobes, the following approximation may be used:

3.2 Elastic buckling pressure:

$$p_{cr}^{el} = \frac{2 \cdot \pi^2 \cdot E \cdot f}{3 \cdot \Phi \cdot \left(1 - \nu^2\right)} \cdot \left(\frac{h}{R_m}\right)^2 \cdot \frac{\frac{R_m \cdot h}{L^2}}{3 - 2 \cdot \Phi \cdot (1 - f)} \qquad \textbf{(26)}$$

Theoretical inelastic buckling pressure:

$$p_{cr}^{i} = p_{cr}^{el} \cdot \frac{1 - \nu^2}{1 - \nu_p^2} \cdot \left\{ \frac{E_t}{E} \cdot \left(1 - \frac{3\Phi}{4}\right) + \frac{E_s}{E} \cdot \frac{3\Phi}{4} \right\} \qquad \textbf{(27)}$$

with:

$$\Phi = 1.23 \frac{\sqrt{R_m \cdot h}}{L} \qquad \textbf{(28)}$$

$$f = \frac{\sigma_x^M}{\sigma_{\varphi,m}^M} \qquad \textbf{(29)}$$

$$\sigma_v = \sqrt{\sigma_{\varphi,m}^{M^2} + \sigma_x^{M^2} - \sigma_{\varphi,m}^M \sigma_x^M} \qquad \textbf{(30)}$$

For secant module:

$$E_s = \frac{\sigma_v}{\varepsilon_v} \qquad \textbf{(31)}$$

For tangential module:

$$E_t = \frac{d\sigma_v}{d\varepsilon_v} \qquad \textbf{(32)}$$

For inelastic Poisson's ratio:

$$\nu_p = 0,5 - (0,5 - \nu)\frac{E_s}{E} \qquad \textbf{(32)}$$

f, σ_v, E_s, E_t are functions of the inelastic buckling pressure p_{cr}^{i} to be determined. For the iterative evaluation of p_{cr}^{i} the value f can be computed for the calculation pressure CDP and be assumed as constant in the following calculation. σ_v can be determined by linear extrapolation starting from the value of the calculation pressure CDP.

3.3 Secant module and tangential module of ferritic steel can be calculated according to the following formulas:

For $\sigma_v > 0,8\ \sigma_{0,2}$:

$$E_t = E \cdot \left\{ 1 - \left(\frac{\sigma_v - 0,8\ \sigma_{0,2}}{0,2\ \sigma_{0,2}} \right)^2 \right\} \qquad \textbf{(33)}$$

$$E_s = E \cdot \frac{\sigma_v}{\sigma_{0,2}\left(0,8 + 0,2\ \text{arc tanh}\frac{\sigma_v - 0,8\ \sigma_{0,2}}{0,2\ \sigma_{0,2}}\right)} \qquad \textbf{(34)}$$

For $\sigma_v < 0,8\ \sigma_{0,2}$:

$E_s = E_t = E$ **(36)**

$\sigma_{0,2}$ = 0,2 % yield strength, R_{eH}

3.4 The secant module and tangential module for austenitic steels are:

For $\sigma_v > 0,6\ \sigma_{0,2}$:

$$E_t = E \cdot \left\{ 1 - k \left(\frac{\sigma_v - 0,6\,\sigma_{0,2}}{0,4\,\sigma_{0,2}} \right) \right\} \qquad \textbf{(37)}$$

$$E_s = E \cdot \frac{\sigma_v}{0,6\sigma_{0,2} - \frac{1}{k} 0,4\sigma_{0,2} \ln\left(1 - k \frac{\sigma_v - 0,6\sigma_{0,2}}{0,4\sigma_{0,2}}\right)} \qquad \textbf{(38)}$$

k has to be calculated from the condition:

$$\sigma_{0,2} + 0,002 \cdot E = 0,6\sigma_{0,2} - \frac{1}{k} 0,4\sigma_{0,2} \ln(1-k) \qquad \textbf{(39)}$$

at least with the accuracy of two decimals.

For $\sigma_v < 0,6\ \sigma 0_{,2}$:

$$E_s = E_t = E \qquad \textbf{(40)}$$

3.5 It has to be proven, that the collapse pressure, which is the theoretical inelastic buckling pressure p_{cr}^{i} multiplied by the reduction factor r, is at least equal to the calculation pressure CDP of the pressure hull.

With a reduction factor:

$$r = 1 - 0,25\, e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1\right)} \qquad \textbf{(41)}$$

4. Calculation of the Collapse Pressure For The Symmetric İnterstiffener Buckling of the Shell in Uniformly Stiffened Sections of the Pressure Hull

4.1 For conical pressure hulls the equivalent values as defined for the stress calculation above have to be used.

4.2 Elastic buckling pressure:

$$p_{cr}^{el} = \frac{2}{\sqrt{3(1-\nu^2)}} \cdot E \cdot \frac{h^2}{R_m^2} \left\{ \left[\frac{2L}{\pi L_{eff}} \right]^2 + \frac{1}{4} \left[\frac{\pi L_{eff}}{2L} \right]^2 \right\} \qquad \textbf{(42)}$$

Theoretical inelastic buckling pressure:

$$p_{cr}^{i} = \frac{2}{\sqrt{3(1-\nu^2)}} \cdot E_s \cdot \frac{h^2}{R_m^2} \cdot C \cdot \left\{ \left[\frac{\alpha L}{\pi} \right]^2 + \frac{1}{4} \left[\frac{\pi}{\alpha L} \right]^2 \right\} \qquad \textbf{(43)}$$

with:

$$\alpha = \sqrt[4]{\frac{3\left(\frac{A_2}{A_1} - \nu_p^2 \frac{A_{12}^2}{A_1^2}\right)}{R_m^2 \cdot h^2}} \qquad \textbf{(44)}$$

$$C = \sqrt{\frac{A_1 A_2 - \nu_p^2 A_{12}^2}{1 - \nu_p^2}} \qquad \textbf{(45)}$$

$$\nu_p = \frac{1}{2} - \frac{E_s}{E}\left(\frac{1}{2} - \nu\right) \qquad \textbf{(46)}$$

$$A_1 = 1 - \frac{1 - E_t/E_s}{4(1-\nu_p^2) K^2 H} \left[(2-\nu_p) - (1-2\nu_p) k \right]^2 \qquad \textbf{(47)}$$

$$A_2 = 1 - \frac{1 - E_t/E_s}{4(1-\nu_p^2) K^2 H} \left[(1-2\nu_p) - (2-\nu_p) k \right]^2 \qquad \textbf{(48)}$$

$$A_{12} = 1 + \frac{1 - E_t/E_s}{4\nu_p (1-\nu_p^2) K^2 H} \left[(2-\nu_p) - (1-2\nu_p) k \right] \cdot \left[(1-2\nu_p) - (2-\nu_p) k \right] \qquad \textbf{(49)}$$

$$H = 1 + \frac{1 - E_t/E_s}{4(1-\nu_p^2) K^2} \left\{ \left[(2-\nu_p) - (1-2\nu_p) k \right]^2 - 3(1-\nu_p^2) \right\} \qquad \textbf{(50)}$$

$$k = \frac{\sigma_{\varphi,m}^{M}}{\sigma_x^{M}} \qquad \textbf{(51)}$$

$$K^2 = 1 - k + k^2 \qquad \textbf{(52)}$$

The procedure for the evaluation of the theoretical inelastic buckling pressure is analogous to that described above for asymmetric buckling.

4.3 It has to be proven, that the collapse pressure, which is the theoretical inelastic buckling pressure p_{cr}^{i} multiplied by the reduction factor r, is at least equal to the calculation pressure of the pressure hull.

With a reduction factor:

$$r = 1 - 0,25\, e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1\right)} \qquad \textbf{(53)}$$

5. Proof of the collapse pressure for the general instability under consideration of the deep frames

5.1 The proof of the general instability (global collapse) has to be done on the basis of a stress calculation which meets the equilibrium criteria in a deformed state. As pre-deformations, the out-of-roundness of the frames has to be considered. It has to be proven, that the out-of-roundness permissible according to Annex B. can not lead to a global collapse.

5.2 Consideration of the stress-strain behaviour

For austenitic steels and other materials, for which $\sigma_{0,01} < 0{,}8\ \sigma_{0,2}$ is valid, the actual stress-strain behaviour has to be considered by adequate calculation. The pressure hull, pre-deformed to the permissible out-ofroundness, has to be incrementally pressure loaded. For the calculation of the increasing elastic displacement and stresses, the deformations in equilibrium condition and the actual, local material behaviour have to be considered.

For materials with $\sigma_{0,01} \geq 0{,}8\ \sigma_{0,2}$ a linear elastic behaviour can be assumed for a stress calculation according to a theory of 2nd order. In this case the following stress limits (without consideration of local weaknesses) have to be met:

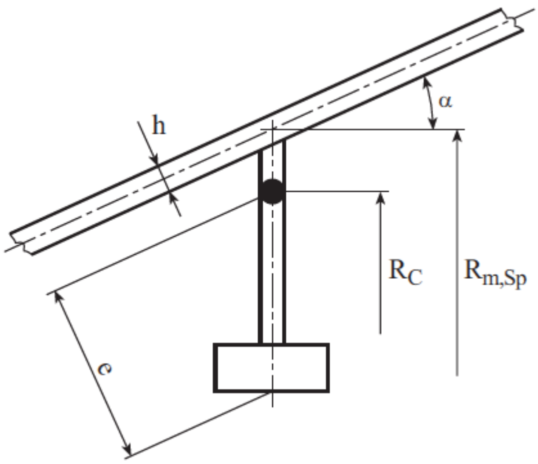


Figure A.2 Situation at a frame or deep frame

- The sum of basic stress and stress due to out-of-roundness in the frame flange shall not exceed $\sigma_{0,2}$.

- The sum of basic stress and stress due to out-of-roundness in the deep frame flange shall not exceed 80 % of $\sigma 0_{,2}$.

5.3 The calculation procedure is described in the following:

Definitions:

P	=	Calculation pressure of the pressure hull CDP
$n \geq 2$	=	Number of circumferential lobes of out-of-roundness
w_0	=	Maximum permissible out-of-roundness of the pressure hull according to Annex B.
R_m	=	Mean radius of the pressure hull in the considered bay
$R_{m,Sp}$	=	Mean radius of the pressure hull at particular frame or deep frame
e	=	Distance from the centroid of the frame or web frame plus the effective length of shell to the furthest surface of the flange (see Fig. A.2)
R_C	=	Radius to the centroid of the frame or deep frame cross section. (see Fig. A.2)
L_R	=	Length of the generating shell line of the considered bay (see Fig. A.3)
L'	=	Length of the generating shell line of the left hand or the right hand adjacent bay, depending on the field boundary for which the proof is made (see Fig. A.3)
L_S	=	Distance between bulkheads

$$\beta = \frac{\pi R_m}{L_R}; \quad \beta_S = \frac{\pi R_m}{L_S} \qquad \textbf{(54) (55)}$$

α = Half apex angle (see Fig. A.2)

Generally the cone angle is not constant, neither in the actual deep frame bay nor in the adjacent bay. Which angle is decisive will be described in the following for each particular case.

I, I_R = Area moment of inertia of frame respectively deep frame including effective length of pressure hull shell, to be assumed always paralel to the axis of the pressure hull.

The effective length is:

$$L_{eff} = \frac{2}{\sqrt[4]{3(1-\nu^2)}}\sqrt{R_{m,Sp} h / \cos\alpha} \qquad \textbf{(56)}$$

But not greater than the average value of both adjacent frame distances

α_1, α_2 = The local half apex angle at the deep frame

The area moments of inertia have to be converted to the radius R_m of the actual field by multiplying them by the ratio $(R_m/R_{m,Sp})^4$.

The proof has to be done for each section bounded by deep frames, bulkheads or end bottoms. End bottoms are to be considered as bulkheads.

A pressure hull section relevant for general instability may be limited by two deep frames, followed by two adjacent deep frame (or bulkhead) bays at each end, compare Fig. A.3. The calculation has to be performed for both adjacent bays in question. The most unfavourable case is decisive.

5.4 Basic stress in the frames and in the deep frames

The basic stress in a frame flange has to be calculated according to 2.1, eq. (23) for $R=R_{Flange}$.

The effect of the half apex angle α is explicitly considered in the following formulas.

The basic stress in a deep frame can be conservatively evaluated according to the following formula:

$$\sigma_{Rsp} = -\frac{p R_m L_{eff}(1-\nu/2)\dfrac{R_m}{R_{Flange}}}{A_{Rsp}\dfrac{R_m}{R_{Rsp}} + L_{eff} h}\,\frac{1}{\cos\alpha} \qquad \textbf{(57)}$$

$$L_{eff} = \frac{2}{\sqrt[4]{3(1-\nu^2)}}\sqrt{R_m h / \cos\alpha} \qquad \textbf{(58)}$$

R_{Flange} = radius of the flange

It has to be observed that A_{Rsp} is the sole section area of the deep frame and R_{Rsp} the corresponding radius. For the thickness of the shell the locally reinforced shell thickness at the deep frame has to be used, if applicable.

The bending stress in the frame respectively deep frame is:

$$\sigma_b = \pm w_{el}\, Ee \frac{n^2-1}{R_C{}^2} \qquad \textbf{(59)}$$

R_C = See Fig. A.2

The elastic bending deflection w_{el} for the frames reads:

$$w_{el} = w_0 \frac{p}{p_g^n - p} \qquad \textbf{(60)}$$

and for the deep frames:

$$w_{el} = w_0 \frac{p}{p_g^n - p}\,\frac{p_M}{p_M + p_R} \qquad \textbf{(61)}$$

With the membrane part :

$$p_M = \frac{Eh}{R_m}\cos^3\alpha \frac{\beta^4}{(n^2-1+\beta^2/2)(n^2+\beta^2)^2} \qquad \textbf{(62)}$$

α is the average half apex angle and h the average shell thickness in the considered bay.

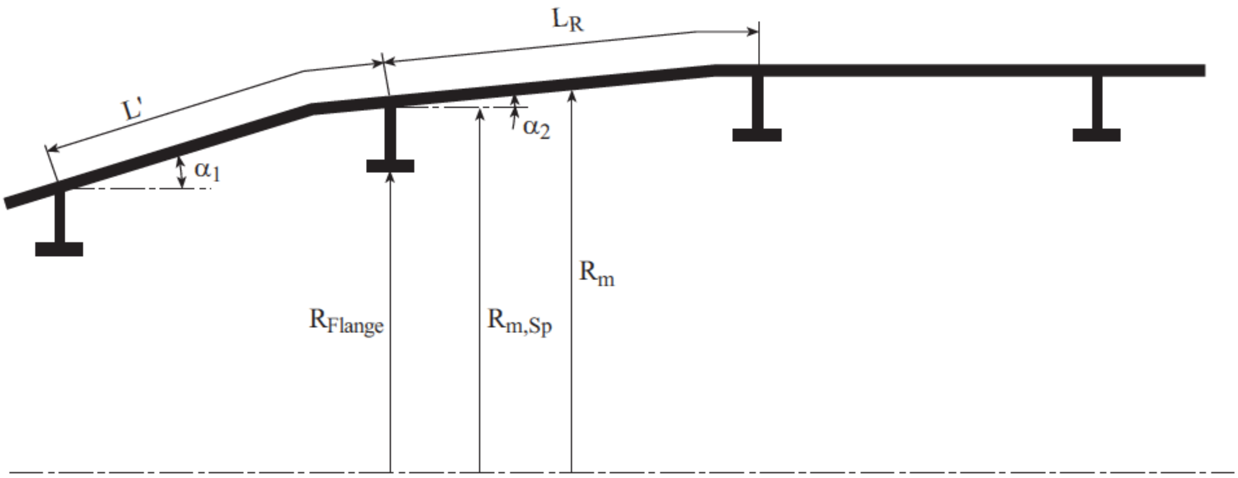


Figure A.3 Example for conical pressure hull

And with the deep frame part p_R:

$$p_R = \frac{2\left(n^2-1\right)EI_R\cos^3\alpha}{R_{C,R}^2\left[R_m-4\left(R_m-R_{C,R}\right)\right]\left(L_R+L'\right)} \cdot \frac{n^2-1}{n^2-1+\beta_S^2/2} \qquad \textbf{(63)}$$

α is the maximum half apex angle along the pressure hull section starting at the midbay of the bay under consideration and ending at the midbay of the adjacent bay.

$R_{C,R}$ applies to deep frames.

The total instability pressure p_g^n has to be evaluated as follows:

$$p_g^n = p_{Sp} + \frac{p_M p_R}{p_M + p_R} + p_{Sch} \qquad \textbf{(64)}$$

using p_M and p_R as described above, and the frame part p_{Sp} as well as the bulkhead part p_{Sch} below:

$$p_{Sp} = \frac{\left(n^2-1\right)EI_{Sp}}{R_{C,Sp}^3 L_{Sp}}\cos^4\alpha\frac{n^2-1}{n^2-1+\beta^2\frac{1}{2}\frac{p_R}{p_R+p_M}} \qquad \textbf{(65)}$$

$R_{C,Sp}$ applies to frames.

$$p_{Sch} = \frac{Eh}{R_m}\cos^3\alpha\frac{{\beta_S}^4}{\left(n^2-1+{\beta_S}^2/2\right)\left(n^2+{\beta_S}^2\right)^2} \qquad \textbf{(66)}$$

α is here to be understood as the average half apex angle in the bay considered.

The frame part has to be calculated with the dimensions of an equivalent frame including equivalent frame spacing. Generally these are the dimensions of the frame closest to the midway point of the bay under evaluation, which have to be converted to the average bay radius in a manner described in 2.3 above.

The following condition has to be met:

For each frame of the considered bay the permissible out-of-roundness has to be calculated for n = 5, assuming for p_g^5 an infinitive bay length. The average of the out-of-roundness values evaluated in this way for three adjacent frames divided by the related frame radius shall not be less than the out-of-roundness for the equivalent frame evaluated in analogue way.

6. Proof of the collapse pressure for tripping of frames

6.1 The proof of the tripping stability has to be done for frames and deep frames on the basis of a stress calculation, which fulfils the status of equilibrium in deformed condition. As pre-deformations the imperfections of the frames as defined in Annex B have to be considered.

Concerning the consideration of the stress-strain behaviour the rules defined in 5.2 are valid.

For materials with $\sigma_{0,01} \geq 0{,}8\ \sigma_{0,2}$ linear elastic behaviour can be assumed for a stress calculation according to 2nd order theory. The following stress limits have to be observed (disregarding local material weakening):

- The equivalent stress in frame web shall not exceed $\sigma_{0,2}$.
- The circumferential stress in frame flange shall not exceed $\sigma_{0,2}$.

The effects to be considered in this procedure are defined further on.

6.2 Additional stresses caused by frame imperfections

The additional stresses caused by imperfections of the frame cross section have to be evaluated for internal frames according to the following formulas.

The imperfections "inclination of web to plane of frame θ", "eccentricity of flange to web u_{ex}" and "misalignment of frame heel to frame plane d" are defined in Annex B.

$$h'_{St} = h_{St} + \frac{t_G}{2} \quad (67)$$

$$\beta = \frac{h'_{St}}{R} \quad (68)$$

$$\beta_G = \frac{h'_{St}}{R_G} \quad (69)$$

$$A'_G = b_G\, t_G - \frac{t_G\, t_{St}}{2} \quad (70)$$

$$I_G = \frac{b_G^3\, t_G}{12} \quad (71)$$

$$J_G = \frac{b_G\, t_G^3}{6\,(1+\nu)} \quad (72)$$

$$A'_{St} = h'_{St}\, t_{St} \quad (73)$$

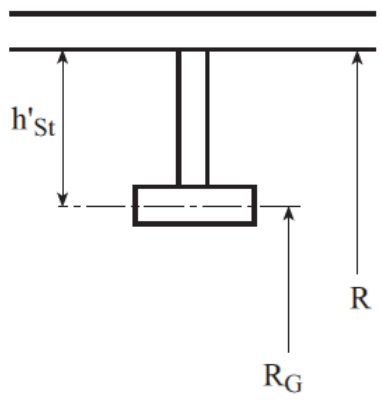


Figure A.4 Local situation at the frame

$$D = \frac{E\, t_{St}^3}{12\left(1-\nu^2\right)} \quad (74)$$

$$L_0 = \frac{\sigma_0\, A_{Sp}}{R} \quad (75)$$

$$F_G = \sigma_0\, A'_G \quad (76)$$

σ_0 = Basic stress in flange acc. to 6.3 / 6.4.

$$\lambda = \frac{A'_{St}}{A_{Sp}} \quad (77)$$

n = Number of circumferential lobes of imperfections; the calculation has to be performed for n = 3

$$e = \frac{h'^2_{St}\, L_0}{D} - 2n^2\, \beta^2 \quad (78)$$

$$\varepsilon = \lambda\, \frac{h'^2_{St}\, L_0}{D} \quad (79)$$

$$g = n^2\, \beta \left(\lambda\, \frac{h'^2_{St}\, L_0}{D} - n^2\, \beta^3 \right) \quad (80)$$

$$k_{11} = 12 - 1{,}2\, e + 0{,}6\, \varepsilon - \frac{13}{35}\, g \quad (81)$$

$$k_{12} = 6 - 0{,}1\,e - \frac{11}{210}\,g + \nu\,n^2\,\beta^2 \quad (82)$$

$$k_{22} = 4 - \frac{2}{15}\,e + 0{,}1\,\varepsilon - \frac{g}{105} \quad (83)$$

$$k_{31} = 6 - 0{,}1\,e + 0{,}1\,\varepsilon + \frac{13}{420}\,g \quad (84)$$

$$k_{32} = 2 + \frac{e}{30} - \frac{\varepsilon}{60} + \frac{g}{140} \quad (85)$$

$$A_{11} = \frac{n^2\,E}{R_G^4}\left(n^2\,I_G + J_G\right) + \frac{D}{h_{St}^{'3}}\,k_{11} - n^2\,\frac{F_G}{R_G^2} \quad (86)$$

$$A_{12} = \frac{n^2\,E}{R_G^3}\left(I_G + J_G\right) - \frac{D}{h_{St}^{'2}}\,k_{12} \quad (87)$$

$$A_{22} = \frac{E}{R_G^2}\left(I_G + n^2\,J_G\right) + \frac{D}{h_{St}^{'}}\,k_{22} \quad (88)$$

Amplitudes of the elastic displacement u and twist ω of the connection web-flange:

$$u = \frac{1}{Det}\left(B_1\,A_{22} - B_2\,A_{12}\right) \quad (89)$$

$$\omega = \frac{1}{Det}\left(B_2\,A_{11} - B_1\,A_{12}\right) \quad (90)$$

with

$$Det = A_{11}\,A_{22} - A_{12}^2 \quad (91)$$

$$B_1 = \theta\left[\frac{F_G}{R_G}\left(1 + n^2\beta_G\right) - L_0\,\lambda\,k_{1,\theta}\right] + u_{ex}\,\frac{F_G}{R_G\,h_{St}^{'}} \cdot n^2\,\beta_G + d\,\frac{L_0\,n^2\beta_G}{h_{St}^{'}}\left[\left(1-\lambda\right)\frac{R}{R_G} - \lambda\,k_{1,d}\right] \quad (92)$$

$$B_2 = -\theta L_0\,\lambda\,h_{St}^{'}\,k_{2,\theta} + u_{ex}\,\frac{F_G}{R_G} - d L_0\,\lambda\,n^2\,\beta_G\,k_{2,d} \quad (93)$$

where :

$$k_{1,\theta} = \frac{1}{2}\left(-1 - \frac{\varepsilon}{420} + 0{,}013g + 0{,}015e^2 - 0{,}025e\varepsilon - 0{,}7n^2\beta\right) \quad (94)$$

$$k_{1,d} = \frac{1}{2}\left(-1 - \frac{\varepsilon}{420} + 0{,}013g + 0{,}015e^2 - 0{,}025e\varepsilon\right) \quad (95)$$

$$k_{2,\theta} = \frac{1}{12}\left[1 + \frac{e}{60} - \frac{\varepsilon}{105} - \frac{g}{140} - 0{,}008\,e^2 + 0{,}013e\varepsilon + 0{,}6\,n^2\beta\left(1 + \frac{19e}{1260} + \frac{25\varepsilon}{336}\right)\right] \quad (96)$$

$$k_{2,d} = \frac{1}{12}\left(1 + \frac{e}{60} - \frac{\varepsilon}{105} - \frac{g}{140} - 0{,}008e^2 + 0{,}013e\varepsilon\right) \quad (97)$$

Stresses in the flange are as follows:

$$\sigma_{b,G} = \pm\frac{E\,b_G}{2\,R_G^2}\left(n^2\,u + R_G\,\omega\right) \quad (98)$$

bending stress around radial axis, and

$$\tau_G = \frac{n\,E\,t_G}{2\left(1+\nu\right)R_G^2}\left(u + R_G\,\omega\right) \quad (99)$$

torsional stress around the tangential axis, which is phase-shifted against $\sigma_{b,G}$ by a quarter period.

The bending stress at the toe of the web is:

$$\sigma_{b,St} = \pm\frac{6}{t_{St}^2}\left[\frac{D}{h_{St}^{'2}}\left(k_{31}\,u - k_{32}\,h_{St}^{'}\,\omega\right) + \lambda\,L_0\left(k_{3,\theta}\,h_{St}^{'}\,\theta + k_{3,d}\,n^2\,\beta\,d\right)\right] \quad (100)$$

with

$$k_{3,\theta} = \frac{1}{12}\left(1 + \frac{e}{60} - \frac{\varepsilon}{140} + 0{,}4\,n^2\,\beta \cdot \left(1 + 0{,}019\,e - 0{,}009\,\varepsilon\right)\right) \quad (101)$$

and

$$k_{3,d} = \frac{1}{12}\left(1 + \frac{e}{60} - \frac{\varepsilon}{140}\right) \qquad \textbf{(102)}$$

The stresses resulting from imperfections of the frames are to be checked for frames and deep frames, using different procedures.

6.3 Frames

For the stress σ_0 always $\sigma_{0,2}$ of the frame material has to be used.

The bending rigidity of the flange has to be neglected, i.e. set to zero ($I_G = 0$).

The equivalent stress at the web toe has to be evaluated with the calculation pressure for both signs of the bending stress $\sigma_{b,St}$.

Circumferential stress:

$$\sigma_\varphi = \sigma_{Sp} + \frac{e_B}{e_A}\,\sigma_{unr} \pm \nu\,\sigma_{b,St} \qquad \textbf{(103)}$$

with σ_{Sp} according to 2.2, eq. (23) for $R = R_B$, compare Figure A.5 and

$$\sigma_{unr} = \sigma_{0,2} + \sigma_{Sp}\,\frac{R_B}{R_A}\,. \qquad \textbf{(104)}$$

Radial stress:

$$\sigma_r = -\frac{L_0}{t_{St}} \pm \sigma_{b,St} \qquad \textbf{(105)}$$

The equivalent stress:

$$\sigma_v = \sqrt{\sigma_\varphi^2 + \sigma_r^2 - \sigma_\varphi\,\sigma_r} \qquad \textbf{(106)}$$

Must not exceed $\sigma_{0,2}$.

6.4 Deep frames

For σ_0 the absolute value of the flange stress has to be taken, as obtained for the half value of the permissible out-of-roundness resulting from the general instability proof performed for n = 2 circumferential lobes according to the procedure described in 5. above.

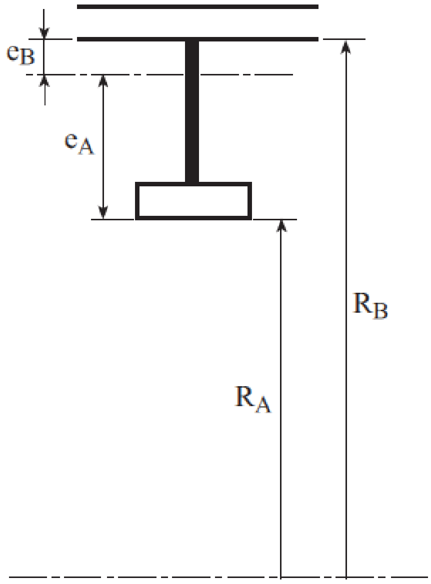


Figure A.5 Situation of the frame in relation to the axis of the pressure hull

a) $$\sigma_0 + \left|\sigma_{b,G}\right| \le \sigma_{0,2} \qquad \textbf{(107)}$$

b) $$\sqrt{\sigma_0^2 + 3\tau_G^2} \le \sigma_{0,2} \qquad \textbf{(108)}$$

the equivalent stress at the web toe:

c) $$\sigma_v = \sqrt{\sigma_\varphi^2 + \sigma_r^2 - \sigma_\varphi\sigma_r} \le \sigma_{0,2} \qquad \textbf{(109)}$$

The circumferential stress σ_φ is the sum of the basic stress σ_{Rsp} obtained with the formula (57) in 5.4 and v-times the web bending stress $\sigma_{b,St}$ according to formula (100):

$$\sigma_\varphi = \sigma_{Rsp} + \nu\sigma_{b,St} \qquad \textbf{(110)}$$

The radial stress is:

$$\sigma_r = \frac{-A_G\,\sigma_0 + A_{St}\,\sigma_{Rsp}}{R_B\,t_{St}} \pm \sigma_{b,St} \qquad \textbf{(111)}$$

Optionally, for simplified calculations, the formula:

$$\sigma_0 = \frac{1}{2}\left|\sigma_{Rsp}\right| + 0,4\sigma_{0,2} \qquad \textbf{(112)}$$

can be used.

6.5 Modifications for outside frames

For outside frames all radii (R, R_G, R_A, R_B) have to be applied as negative values.

7. Calculation of the collapse pressure for spherical ends

7.1 The calculation is based on the local thickness and curvature.

7.2 Definitions

The following definitions are valid:

$R_{m,l}$ = Maximum local mean radius of curvature of the sphere at shell half thickness

$R_{a,l}$ = Maximum local mean outside radius of curvature of the sphere

h_l = Local average shell thickness

Critical arc length or diameter of the measuring circle to be used for averaging:

$$L_k = 2,4\sqrt{R_{a,l}\,h_l} \qquad \textbf{(113)}$$

Elastic buckling pressure of the sphere:

$$p_{cr}^{el} = 0,84\,E\,\frac{{h_l}^2}{{R_{a,l}}^2} \qquad \textbf{(114)}$$

Theoretical inelastic buckling pressure of the sphere:

$$p_{cr}^{i} = p_{cr}^{el}\,\frac{\sqrt{E_t\,E_s}}{E} \qquad \textbf{(115)}$$

$$p_{0,2} = \frac{2\,\sigma_{0,2}\,h_l\,R_{m,l}}{R_{a,l}^2} \qquad \textbf{(116)}$$

The local radius has to be evaluated with a bridge gauge as defined in Annex B. For the design, a local radius of 1,4 times the nominal radius and the nominal shell thickness has to be assumed.

7.3 Spherical ends made of ferritic steel

For spherical ends made of ferritic steel grade TL-M550 or similar material p_{cr} can be calculated as follows:

7.3.1 For spherical ends in "as welded" condition the following is valid:

$$p_{cr} = p_{cr}^{el} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} \le 0,47 \qquad \textbf{(117)}$$

$$p_{cr} = p_{0,2}\left(0,38 + 0,195\frac{p_{cr}^{el}}{p_{0,2}}\right) \quad \text{if} \quad 0,47 < \frac{p_{cr}^{el}}{p_{0,2}} \le 3,18 \qquad \textbf{(118)}$$

$$p_{cr} = p_{0,2} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} > 3,18 \qquad \textbf{(119)}$$

7.3.2 For stress relieved spherical ends the following is valid:

$$p_{cr} = p_{cr}^{el} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} \le 0,595 \qquad \textbf{(120)}$$

$$p_{cr} = p_{0,2}\left(0,475 + 0,195\frac{p_{cr}^{el}}{p_{0,2}}\right) \quad \text{if} \quad 0,595 < \frac{p_{cr}^{el}}{p_{0,2}} \le 2,7 \qquad \textbf{(121)}$$

$$p_{cr} = p_{0,2} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} > 2,7 \qquad \textbf{(122)}$$

The fabrication of ends by welding of stress relieved segments and the welding of the penetrations into the shell after stress relieving is permitted.

The calculated collapse pressure p_{cr} shall be at least equal to the calculation pressure of the pressure hull.

7.4 Spherical ends of other materials

For spherical ends made of other materials the inelastic buckling pressure p_{cr}^{i} which has been evaluated according to the formulas described above has to be multiplied by the reduction factor k defined in Fig. A.6.

8. Penetrations of the pressure hull

The following rules for dimensioning are valid under the assumption that the material strength is the same for the shell of the pressure hull and for the reinforcement of the penetration boundary.

The rules are based on the replacement area principle .

For different material strength the rules have to be modified in an effective way.

8.1 Penetrations in the cylindrical or conical part of the pressure hull

8.1.1 Small penetrations which do not interrupt frames

8.1.1.1 Circular penetrations in radial direction

The situation is characterised by Fig. A.7.

Designations:

h = Thickness of the shell after deduction of corrosion allowance

h_v = Thickness of the shell of the pressure hull in the reinforcement vicinity

R_i = Internal radius of the pressure hull

d = External diameter of the penetration

ℓ_1, ℓ_2 = Excess lengths of connecting piece

ℓ_{min} = Min (ℓ_1, ℓ_2)

= Smaller excess length of connecting piece

ℓ_{max} = Max (ℓ_1, ℓ_2)

= Bigger excess length of connecting piece

t = Wall thickness of nozzle

A = Sectional area to be substituted

A_w = Effective substitutive sectional area

ℓ_w = Effective length of the connecting piece

$$\ell^* = \frac{\sqrt{0,5(d-t)\cdot t}}{\sqrt[4]{3\left(1-\nu^2\right)}} \qquad \textbf{(123)}$$

$$R_m = 0,5\cdot(d-t) \qquad \textbf{(124)}$$

It has to be proven that the effective sectional area of the boundary enforcement A_W of the penetration is at least equal to the cut out sectional area A of the shell.

The area to be substituted is

$$A = 0.5 \cdot d \cdot h \qquad \textbf{(125)}$$

For penetrations, which are designed in the form shown in Fig. A.7 the effective sectional area can be calculated according to the following formula:

$$A_w = 0,78\cdot\sqrt{R_i\cdot h_v}\cdot(h_v - h) + t\cdot\ell_w \qquad \textbf{(126)}$$

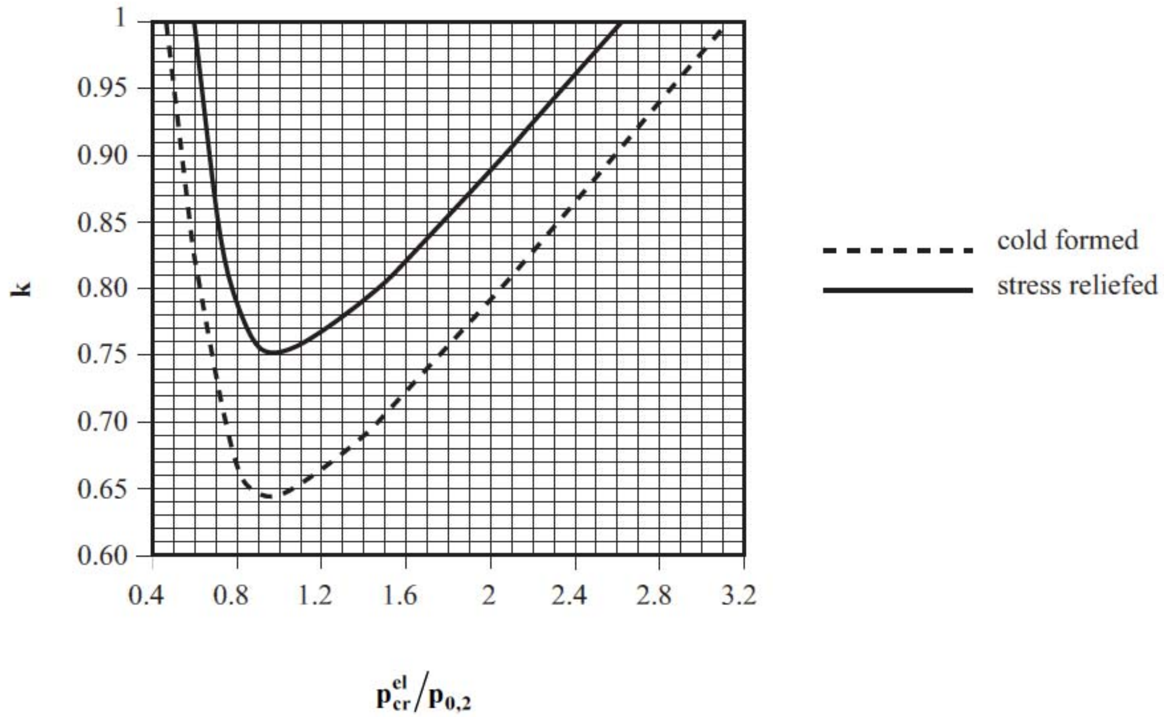


Figure A.6 Reduction factor for different types of steel.

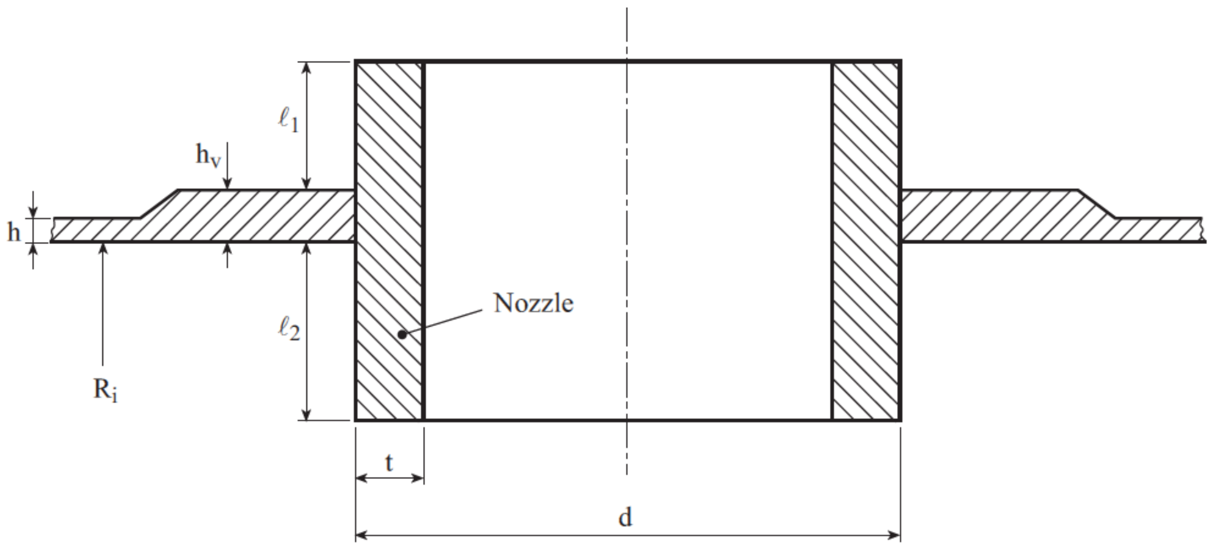


Figure A.7 Penetration of a connectiong piece through the enforced shell.

Effective length of the connecting piece:

Case 1:

$\ell_w = 2.\ \ell^* + h_v$ for **(127)**

$\ell_1 \geq \ell^*$; $\ell_2 \geq \ell^*$ **(128)**

Case 2:

$\ell_w = 2\ .\ \ell_{min} + h_v$ for **(129)**

$\ell^* / 2 \leq \ell_{min} \leq \ell^*$ **(130)**

Case 3:

$\ell_w = \ell_{min} + \min(a, \ell^* / 2) + h_v$ for **(131)**

$\ell_{min} < \ell^* / 2$; $\ell_{max} > \ell^* / 2$ **(132)**

$a = \ell_{max}\ (0{,}4 + 0{,}6\ \ell_{min}^2 /;\ \ \ell_{max}^2)$ **(133)**

8.1.1.2 Flush form of circular penetrations in radial direction

Penetrations in flush form of the pressure hull ($\ell_1 = 0$), may have in the penetration area a cut out to include a zinc ring , see Fig. A.8.

In this case ℓ_w can be evaluated with the formulas given above. In addition the strength of the section A-A has to be proven.

In the case that the pressure hull is not enforced, the following condition has to be met:

$$c_\tau = \sqrt{3} \cdot \frac{h \cdot d - 2 \cdot c \cdot b}{d - c} \qquad \textbf{(134)}$$

$$d = \max\left(L_a, L_u \cdot \frac{\sigma_a}{\sigma_u}\right) \qquad \textbf{(135)}$$

8.1.1.3 Non-circular penetrations or penetrations not in radial direction

If the penetration is not circular or does not cut the shell of the pressure hull in radial direction the diameter d has to be replaced by

$$d = \max\left(L_a, L_u \cdot \frac{\sigma_a}{\sigma_u}\right) \qquad \textbf{(136)}$$

L_a = Width of the penetration line in direction of the cover line

L_u = Width of the penetration line in circumferential direction

σ_a = Membrane stress in the pressure hull in direction of the cover line

σ_u = Membrane stress in the pressure hull in circumferential direction

In special cases, if the Rules can only be utilized in limited way, the strength has to be proven by numerical computation.

8.1.2 Big penetrations interrupting frames

For preliminary dimensioning the following procedure is can be used:

The effective enforcement for the penetration has, in a similar way as for the small penetrations, to substitute the area cut out. The sections of the interrupted frame webs are to be considered additionally. The effective substitutive sectional area has to be evaluated in analogues way as for small penetrations. Compact enforcement rings are fully load carrying if they are located directly in the penetration line.

The construction in the flange plane of the frame has to be designed in such a way that the maximal permissible forces in the flange ($A_{Flange}\ .\ \sigma_{0,2}$) can be transmitted.

Big penetrations have to be proven by numerical computation.

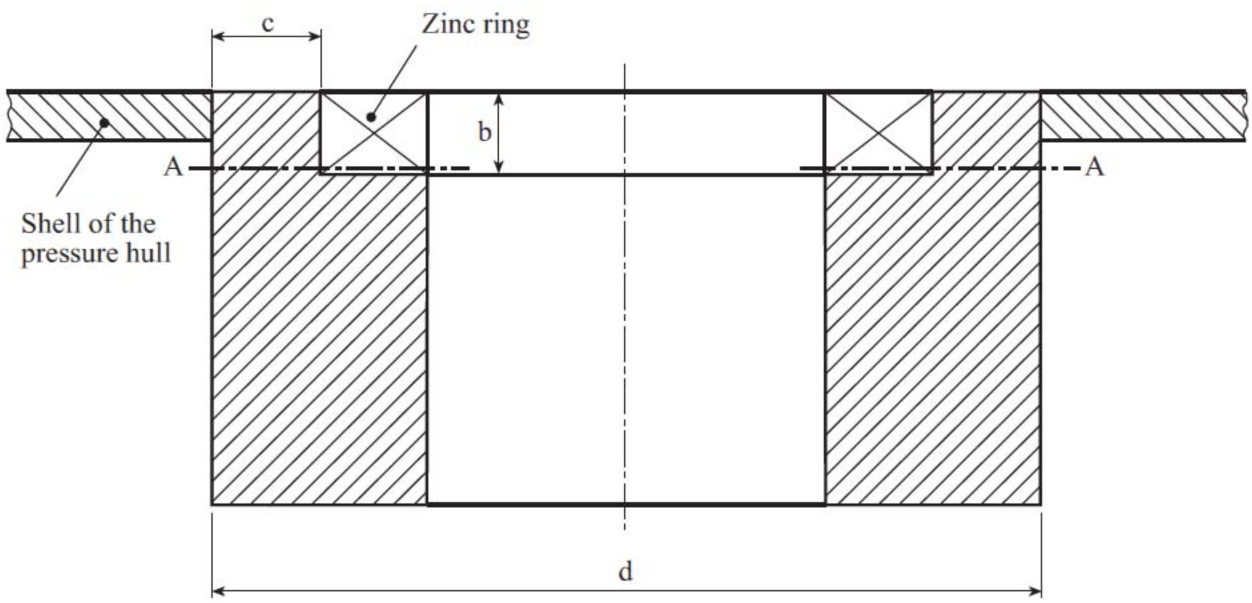


Fig. A.8 Penetration of flush form

8.2 Penetrations of spherical shells

For penetrations of spherical shells 8.1.1 is valid in analogous way. Here h is the thickness, hv the increased thickness and Ri the internal radius of the sphere.

In cases where the rule of substitutive areas is not fulfilled, the ultimate strength has to be numerically proven. Then the radius of the spherical shell in the area of the penetration has to be chosen according to 1,4 times the nominal radius. The achieved failure pressure is then to be reduced like the partial plastic buckling pressure evaluated for the undisturbed end dish, see Fig. A.6.

E. Proofs using numerical methods (Finite Elements Methods)

1. For areas for which a numerical stress proof is required the ultimate limit state has to be numerically proven. Should in exceptional cases a numerical prof for convex end dishes be required, than the critical area has to be modelled with the actually measured or the maximum permissible radius of curvature.

2. The computation has to consider the deformations in the balance and the partially plastic material behaviour defined in D.3.

3. The suitability of the method and the choice of the element type have to be demonstrated with a computation model evaluating the failure pressures for the symmetrical and asymmetrical buckling in the area with regular stiffening cylinder. The numerically evaluated values should be 2 % to 4 % lower than the values analytically evaluated in D.4.

4. The numerically evaluated failure pressure shall be 7 % higher than the calculation pressure in areas where a numerical proof has to be carried out.

F. Creep Rupture Strength

For pressure hulls made of creeping material it has to be proven by model tests or by computation that the pressure hull can withstand for 104 minutes 0,8 times of the calculation pressure. It has to be defined by **TL** how such a proof has to be carried out or, depending on the rescue concept, this time period may be reduced.

ANNEX B

FABRICATION TOLERANCES FOR THE PRESSURE HULL

Page

Note:

*For the tolerances of pressure hulls, also Annex B of **TL** Rules for Submersibles, Edition 2016 is to be applied as a supplementary document.*

A. General

1. This Annex describes the allowable fabrication tolerances for the pressure hull.

2. All tests should be carried out under the presence of a Surveyor and a measurement report is to be send to **TL.**

B. Pressure Hull Frames

1. The following measurements shall be carried out on every frame of the pressure hull at eight measuring points uniformly distributed around the circumference.

- Flange width
- Flange thickness
- Web thickness
- Frame spacing (measured at frame heel)
- Frame height at frame moulding edge
- Eccentricity flange to web
- Web tilt to plane of frame

Spacing "k" of the frame heel from a reference plane shall be determined by direct measurement. The location of the frame heel is shown as detail "A" in Fig. B.1. For cylindrical pressure hull parts this measurement shall be carried out on a minimum of one frame per ring (with a ring length of up to a maximum of 8 pressure hull frames) and for conical pressure hull parts on every frame at 16 measuring points uniformly distributed around the circumference.

2. The following tolerances are maximum values and shall be adhered to. These tolerances calculated from percentages may be rounded up to half of a millimetre.

Flange width : 0 % to +4,5 %

Flange thickness : 0 mm to +3 mm

Web thickness : 0 mm to +3 mm

With regard to the flange width resp. flange thickness the nominal cross-sectional area of the flange is considered to be a permissible acceptance criteria. Depth tolerances of 0,2 + 0,04 . t ≤ 1 mm (t = material thickness in mm) due to flat grinding of nicks may be exceeded locally, however, the nominal cross-section of the flange or web must not be reduced to more than 90 %.

Frame spacing : generally ± 1 % at circumferential seams + 1 % to – 3 %

Frame height at frame moulding edge : 0 % to + 5 %

Tolerances up to –2 % are allowed locally if the mean value of the 8 measuring points reaches nominal value.

Eccentricity flange to web : 2 % of frame height

Web tilt to plane of frame : ± 2°

Position of frame heel to reference plane : + 4 mm for frames
± 6 mm for web frame

If the maximum difference of determined spacings (k_{max} - k_{min}) is larger than 8 mm for frames resp. 12 mm for web frames, the real deviations of h shall be determined by evaluation according to the following formula:

$$h_i = k_i - A - B \sin\varphi_i - C \cos \varphi_i$$

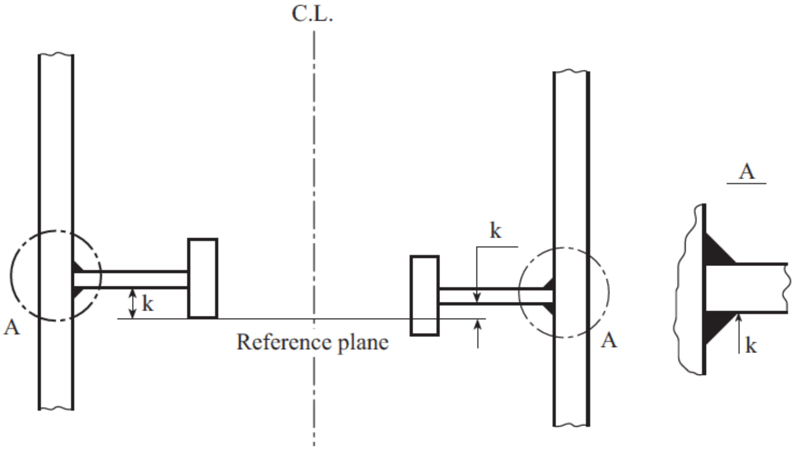


Figure B.1 Definition of reference plane

$A = 1/n\ (k_1 + k_2 + k_3 + \ldots + k_n)$

$B = 2/n\ (k_1 \sin \varphi_1 + k_2 \sin \varphi_2 + k_3 \sin \varphi_3 + \ldots + k_n \sin \varphi_n)$

$C = 2/n\ (k_1 \cos \varphi_1 + k_2 \cos \varphi_2 + k_3 \cos \varphi_3 + \ldots + k_{n\ \cos}\ \varphi_n)$

$\varphi_i = 360° \cdot i / n$

h_i = Deviation of frame heel from the actual plane of frame at measurement point i

k_i = Measured spacing of frame heel from the reference plane of measuring point i

n = Number of measuring points.

C. Roundness of the Pressure Hull

1. The roundness of each frame including the transition rings shall be measured.

2. The following requirements must be met prior to conducting roundness measurements:

- The required tests mentioned above shall only be carried out when no subsequent changes of measured values are to be expected.

- The section must be cooled down to ambient temperature and relieved from any tension by means of appropriate aids in order to prevent falsification of measurements results.

3. The measurement of the pressure hull can be carried out from outside or from inside. In principle the roundness measurement shall be carried out at 24 points distributed as uniformly as possible around the circumference. It can be conducted with the help of a circular template, calipers, a three-point bridge gage, photogrammetry or theodolite methods, in which case access must be provided by appropriate means. If the measuring of individual values is not possible due to constructional reasons (e. g. in the area of larger openings), they shall be supplemented practically (in general by linear addition) as far as the method allows. The details of the measuring method must be approved by **TL.**

4. The results of the evaluations shall be presented to **TL** as tables and as graphs.

5. The maximum permissible out-of-roundness is ± 0,2 % of the nominal pressure hull diameter unless otherwise agreed by **TL.**

The following formulas apply to 24 measuring points distributed uniformly around the circumference:

$u_i = w_i - A - B \sin \varphi_i - C \cos \varphi_i$

$A = 1/24\ (w_1 + w_2 + w_3 + \ldots + w_n)$

$B = 1/12\ (w_1 \sin \varphi_1 + w_2 \sin \varphi_2 + w_3 \sin \varphi_3 + \ldots + w_n \sin \varphi_n)$

$C = 1/12\ (w_1 \cos \varphi_1 + w_2 \cos \varphi_2 + w_3 \cos \varphi_3 + \ldots + w_n \cos \varphi_n)$

In this case

i = Measuring points 1 to n (for this formula n = 24)

w_i = Measured value of the curve shape at measuring point i

u_i = Calculated out-of-roundness of the pressure hull at measuring point i

φ_i = Angle at measuring point (see B.2.)

6. In the case of non-uniformly distributed measuring points angular separation of measuring points ≤ 18° the following formulas apply:

$$u_i = w_i - E - F \sin \varphi_i - G \cos \varphi_i$$

$$E = 1/2\,\pi D\,[w_1\,x_2 + w_2\,(x_3 - x_1) + w_3\,(x_4 - x_2) + \ldots + w_n\,(x_1 - x_{n-1} + \pi D)]$$

$$F = 1/\pi D\,[w_1 \sin \varphi_1\ x_2 + w_2 \sin \varphi_2\ (x_3 - x_1) + w_3 \sin \varphi_3\ (x_4 - x_2) + \ldots + w_n \sin \varphi_n\ (x_1 - x_{n-1} + \pi D)]$$

$$G = 1/\pi D\,[w_1 \cos \varphi_1\ x_2 + w_2 \cos \varphi_2\ (x_3 - x_1) + w_3 \cos \varphi_3\ (x_4 - x_2) + \ldots + w_n \cos \varphi_n\ (x_1 - x_{n-1} + \pi D)]$$

In this case

i = Measuring points 1 to n

n = Actual number of measuring points

w_i = See definition in 5.

u_i = See definition in 5.

D = Diameter of measuring circuit

x_i = Circumferential coordinate at measuring point i (measuring distance from starting point, $x_n = x_0 = 0$)

φ_i = Angle at measuring point i

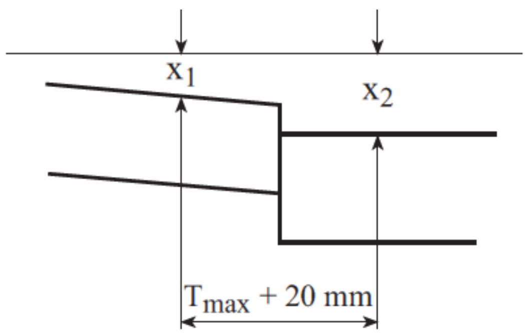
$= 360 \cdot x_i / \pi D$

D. Pressure Hull Plating

1. All longitudinal and circumferential seams in the pressure hull plating shall be inspected for edge offset, weld sinkage, undercuts and hollow grinding. This shall also be carried out for the welded connections of the plating with a transition ring. The inner and outer surfaces of the plates shall be inspected for damage.

2. The required tests mentioned above shall only be carried out when no subsequent changes of measured values are to be expected. Weld seam sections that have been reworked in the meantime because of inadmissible defects shall be measured again.

3. The radial deviations x_1 and x_2 are the basis for the determination of weld sinkage and edge offset of sheet metal surfaces with regard to their nominal positions next to a welding seam.



The overlapping of both plates that is to be determined using the measuring values x_1 and x_2 must be at least 87 % of the nominal thickness of the thinner plate for circumferential seams and 92 % of the nominal thickness of the thinner plate for longitudinal seams. It is only necessary to measure the actual thickness of both plates in those borderline cases where the overlapping determined on the basis of the nominal thickness exceeds the tolerance value.

4. The tolerances for the course of the theoretical mid-plane line at the transition ring shall be laid down separately in the production documents and shall be checked.

5. The symmetric portion of the deviations

$$\frac{x_1 + x_2}{2}$$

is defined as weld sinkage. It may not be larger than 5 mm for circumferential and not larger than 3 mm for longitudinal seams unless otherwise agreed by **TL.**

6. Damage to plate surfaces, such as scores, scratches, arc strikes, indentation pits, etc. shall be thoroughly smoothed and inspected for surface cracks. The flaws treated in this way may have a depth of

$$0{,}2 + 0{,}04 \cdot t \leq 1 \text{ mm}$$

t = Sheet metal thickness [mm]

even if this exceeds the tolerance for the nominal thickness. Deeper flaws shall be carefully welded out, ground level to the sheet metal surface and inspected for surface cracks.

E. Three-Dimensional End-Closures

1. The following measurements shall be carried out for three dimensional end-closures:

- Plate thickness
- Edge offset at weld seams between elements of the domed end closure and between the end closure and the transition ring
- Course of the theoretical lines at the transition ring joint
- Sinkage of weld seams within the domed end closure
- Weld undercuts, damage to plate surface
- Spherical shape of the end closure

2. The measurements shall only be carried out when no subsequent changes of measured values are to be expected. Weld seam sections that have been reworked in the meantime because of inadmissible defects shall be checked again.

3. The permissible edge offset on butt welds within the domed end closure shall be in accordance with the specifications in D.3. for circumferential seams.

4. Weld sinkage of butt welds within the domed end closure shall be less than 3 mm. In some places weld sinkage may be up to a maximum of 5 mm under the condition that this area must not be longer than:

$$L = \sqrt{R \cdot t}$$

L = Length of weld sinkage [mm]

R = Radius of calotte [mm]

t = Nominal calotte thickness [mm]

The distance between individual areas must be at least 100 mm or 5 times the thickness of the plate. The smaller value shall be valid.

5. The maximum permissible flattening U_{max} of the domed end closure from the theoretical spherical shape is 32 % of the plate thickness t (mean value of measured thickness values in measuring area). The maximum permissible vaulting of the domed end closure from the theoretical spherical shape is 2 U_{max} The measuring is to be conducted with a three-point bridge gauge (dial gage in the centre of the measuring circuit); the diameter of the measuring circuit D_{max} being calculated using the following formula:

$$D_{max} = 2{,}9 \cdot \sqrt{R \cdot t} \qquad [\text{mm}]$$

(only up to 32 % permissible flattening)

Using a measuring bridge with a small measuring circuit diameter D means an aggravation of the measuring method and is therefore permitted. In this case, however, the permissible flattening U_{perm} shall be calculated using the following formula:

$$U_{perm} = U_{max} \cdot \left(\frac{D}{D_{max}} \right)^2 \quad [mm]$$

If the value U_{perm} is exceeded when using a measuring bridge with a smaller measuring circuit diameter, this area must be measured again using a larger measuring bridge.

6. Measuring should be conducted as continuous as possible on the accessible side. Areas that cannot be measuring should not be larger than 1/3 D_{max}. Any weld seam areas with cambers, hollow grinding and weld sinkage shall be considered corrected in the measuring results.