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THE REGULATIONS FOR THE ASSURANCE OF THE RELIABILITY OF PRESSURE VESSELS

PREDPISI ZA ZAGOTOVITEV ZANESLJIVOSTI TLAČNIH POSOD

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In this article the most important differences in the regulations for the assurance of the reliability of pressure vessels in some developed countries of the world (USA, Germany, Britain and France) are considered. Using a comparison of these regulations a common basis is given regarding the possible severe consequences in the case of failures. Establishing quality assurance is necessary for the high reliability of pressure vessels.

Key words: pressure vessels, regulations, assurance of reliability

V članku so predstavljene najvažnejše razlike v predpisih razvitih držav (ZDA, Nemčija, Anglija in Francija) o zagotavljanju zanesljivosti tlačnih posod. Na osnovi primerjave predpisov je v primeru napak pripravljena ocena posledic. Za zagotovitev zanesljivosti posod je potreben stalen nadzor.

Ključne besede: tlačne posode, predpisi, zagotovitev zanesljivotsi

1 UVOD

Pressure vessels play a very important role in power plants and process plants because of their complexity. Examples of pressure vessels include: reactor vessels, heat exchangers, large heat boilers etc.

The construction of pressure vessels must be adapted to suit the conditions. In general, pressure vessels are cylindrical or spherical.

According to the generally accepted regulations and recommendations, pressure vessels are divided into four classes:

- **I – The first (highest) class** consists of the main vessels in nuclear plants, vessels with highly poisonous fluids, and large vessels with poisonous, explosive or flamable fluids;
- **II – The second class** consists of very important large vessels in industrial and energy plants, exchangers, large heat boilers and similar steel constructions;
- **III – The third class** consists of vessels containg small quantities of the fluid products mentioned in the second class, which in the case of a rupture or a break would cause less problems than the ones in the second class;
- **IV – The fourth class** consists of products which in the case of a rupture or a break could cause insignificant damage to the environment or people.

Regulations in the field of pressure vessels include obligatory actions in design, production and exploitation of pressure vessels. The problem of safe and reliable work vessels exists in countries known for the production of the highest class of pressure vessels, as well as in those countries that use these vessels. Long-term experience in the production and exploitation of pressure vessels of all classes is used as the basis for defining the rules, regulations and standards.

The problem of safe and reliable working of pressure vessels (especially high class ones) exists in countries that deal with the design of processing and other plants.

This problem is even greater in those countries that have installed vessels of the highest class. It should be noted that energy and processing plants present a very complicated group of structures, and pressure vessels play a very significant role in these situations. Tracking and testing of the vessel's integrity during production and exploitation in these countries is conducted by non-governmental organizations, using destructive and non-destructive testing.

In less developed countries, the status of pressure vessels is monitored by a combination of standards used in the majority of the more developed countries. In most cases, parts of the regulations the USA and Germany are used: less frequently, those from Britain and France.

The quality assurance system used during the construction and service life of power plants has now been implemented in compliance with the ISO 9000 standard series. The exception is obligatory national and international regulations for nuclear power plant components. Common modes and causes of failure such as creep with fatigue and cracking have been the subject of many investigations [1-7].

2 A REVIEW OF THE REGULATIONS

The main aim of the regulations relating to pressure vessels is the assurance of:
- necessary vessel quality,
- the reliability of vessels during use,
- the safety of people and property involved in the production and exploitation of vessels.

Depending on their use, pressure vessels are designed according to different Technological Regulations of the developed countries. In the oil and petro-chemical industry most of the vessels are designed according to the "ASME Boiler and Pressure Vessel Code", Section VIII Division 1, and vessels for Energy and Chemical Plants are mainly designed according to the German AD-Merkblätter.

2.1 Regulations for Pressure Vessels in the USA

American regulations for pressure vessels "ASME Boiler and Pressure Vessels Code" were founded in 1911 by the American Society of Mechanical Engineers (ASME). During the time since it was established these regulations have been developed in eleven sections:

Section I: Steam Boilers

Section II: Specification of materials (A-steel, N-non-iron, C-electrode and welding wires)

Section III: Parts 1 and 2 - Components of nuclear energy plants. Basic requirements;
Part 1, Undersection: NB-class 1. component, NC-class 2. component, ND-class 3. component, NE-class MC-component, NF-component lug, NG-construction for core lug. Appendix;
Part 2, Regulations for concrete reactor vessels and containment

Section IV: Heating Boilers

Section V: Methods of testing without destruction

Section VI: Recommendations for maintenance and usage of heating boilers

Section VII: Recommendations for maintenance and usage of steam boilers

Section VIII: Part 1. Pressure vessels, Part 2. Pressure vessels, alternative regulations

Section IX: Qualifications of welding and soldering procedures

Section X: Plastic pressure vessels reinforced with glass fiber

Section XI: Control regulations for components of nuclear plants in operation

For the design of pressure vessels, Section VIII is the mostly commonly used, and Part 1 of this section consists of introduction, basic requirements regarding methods of pressure vessel production, requirements regarding the class of materials and appendix [8].

Part 1 of Section VIII includes pressure vessels ranging from 103 kPa to 20.7 MPa. Materials used for pressure vessel production, listed in this section, are included in Section II, Parts A, B and C. These materials are closely related to those recommended by the American Society for Testing and Materials (ASTM) material standards, recommended by ASME regulations as well. The allowed stress of steels cannot be smaller than the following values: 1/4 minimum specific tensile strength at ambient temperature, 1/4 tensile strength at design temperature, 5/8 minimum specific yield stress at ambient temperature, 5/8 yield stress at design temperature. The maximum allowed stress of austenite steels and some other special alloys is given in two possible cases: lower allowed stress, determined with the help of the previous four criterias, must be applied when higher plastic deformations for construction elements, such as pipe elements, are not allowed; higher allowed stress can be applied where larger, permanent deformation is not one of the reasons for improper functioning. This higher allowed stress can exceed 2/3 of the yield stress of special alloys and 5/8 of the yield stress of austenite steels, but must not exceed 90% of the yield stress at the design temperature.

The magnitude of the maximum allowed yield stress in the area of creep rate for all materials cannot be greater than the lowest of the following values: 100% of the average stress which leads to 0.01% permanent deformation after 1000 hours, 67% of the average stress which leads to fracture after 100,000 hours, 80% of the minimum stress which leads to fracture after 100,000 hours.

In the regulations of the ASME, Section VIII, Parts 1 and 2, the method for determining the allowed stress on compression is given, this is very important for vessels with thin walls which have a small ratio of vessel thickness to vessel diameter, where the allowed stress on pressure is much smaller than the allowed tensile stress. It must be mentioned that the allowed stress on pressure can never be greater than the allowed stress on tensile. This is mentioned mostly because in many standards the way of determining the stress pressure in pressure vessels is not specified.

For all the materials which are acceptable for the production of pressure vessels according to Section II, ASME regulations provide a table listing the allowed yield stress. Since the production of vessels often requires European materials, the magnitude of the allowed stress must be determined in the way suggested by the ASME regulations. Problems occur because in European standards tensile strength at elevated temperatures is not defined for some materials. In this case, criterion regarding the increased temperatures must be left out. Alternatively, the application of ASME regulations can be possible since European standards have determined the yield stress with respect to temperature for most materials.

In the ASME regulations, methods of calculation for the common components of pressure vessels are discussed. Connecting parts and their reinforcing rings are calculated by the method of stress concentration, which has been used for several years because of its simple application and high reliability. The factor of stress concentration, proportional to the control of maximum stress, ranges from 1.5 to 3.5.

ASME regulations, Section VIII, Part 1, do not define the way the tube sheets should be calculated, so the Tubular Exchangers Manufacturers Associations (TEMA) standards are used.

For pipe elements calculations in the USA, special methods which disregard material's fatigue and thermal stress estimate are used. These methods do not define the way of stress analysis in different parts of pressure vessels.

The alternative regulations in ASME Section VIII, Part 2, are relatively new, and are based on the basics of Section III. Section VIII, Part 2, allows greater stress than Part 1. The maximum allowed yield stress in the region under the creep limit is defined as the smallest of the following values: 1/3 tensile strength at the design temperature, 2/3 yield stress at the design temperature.

In Section VIII, Part 2, the limits concerning material selection for pressure vessels are much stricter. In this part more accurate calculations are required and certain design details are not allowed. Production procedures are pointed out as well as more thorough testing control compared to that in Section VIII Part 1. Furthermore, in Section VIII, Part 2 there are no limitations concerning the pressure on vessels greater than 20.7 MPa like in Part 1. In addition, in Part 2, a simple criterion for the definition of fatigue analysis is given, and if this analysis is necessary, detailed instructions for the calculation are provided.

2.2 Regulations for Pressure Vessels in Germany

The official regulations in Germany for pressure vessels are divided into regulations for stationary pressure vessels and regulations for portable pressure vessels. Stationary pressure vessels, steam boilers and heaters are included in the "Druckbeh V-Verordnung über Druckbehälter, Druckgasbehälter und Füllanlagen" regulations, and portable pressure vessels are included in the Druckgasverordnung (DGV) regulations. The German state inspection Technische Überwachung Verein (TÜV) is in charge of the approval and enforcement of these regulations, and it has the right to ask for additional analysis and control if it is uncertain that the quality of the vessel is satisfactory and its stability is guaranteed.

Vessels with a pressure less than 50 kPa, or a volume less than 0.01m^3 are not included in these regulations. Vessels with a product greater than the design pressure, in kPa, and the vessel's volume, in m^3, less than 0.01 are also not included in these regulations.

The AD-Merkblätter technological regulations and DIN standards include design norms, materials, production and control of pressure vessels. Technische Regelung für Dampfkesseln (TRD) includes standards for steam boilers.

The AD-Merkblätter technological regulations for pressure vessels include the following standard groups: (G) basic principles, (A) equipment, (B) calculations, (W) material, (H) production, (N) non-metal pressure vessels, (HP) production and testing, (BP) drive and testing, (RB) calculations for nuclear plant reactors, (RH) production of nuclear plant reactors, (RW) materials for nuclear plant reactors [9].

In the previous comparison of different regulations and standards, one of the basic criteria is the way of defining the allowed stress on materials.

First, the allowed rolled and forged-steel stress at the temperature lower than the creep limit is calculated by division of the yield stress value or conventional yield limit of 0.2% at the design temperature with a safety factor of 1.5.

Second, the allowed rolled and forged-steel stress in the range of creep temperature is calculated by division of the strength limit value after 100,000 hours at the design temperature, with the mentioned safety factor of 1.5.

And third, along with the two already mentioned conditions, it is necessary to check if there is at least single safety compared to the value of the permanent deformation of 1% after 100,000 hours (average value) at the design temperature and at least single safety compared to the value of the strength limit after 100,000 hours at a temperature 15 °C higher than the design temperature.

Based on the previous three conditions it is obvious that the allowed stress is generally equal to 2/3 of the yield stress at the design temperature for all the temperatures under the creep limit of the material and 2/3 of the strength limit after 100,000 hours at the design temperature, with the possibility of on influence of factors mentioned in the third condition. The tensile strength of steel is disregarded when determining the allowed stress of steel according to AD. For the level-of-safety estimate of the pressure vessel along with the stress of the material it is necessary to include other factors which have an influence on safety.

AD technical regulations of group B, define calculations for the characteristic parts of the vessel. When calculating connecting parts, the method of experimental yield stress is applied.

AD technical regulations of group W individually list those materials which can be used for the design of pressure vessels, as well as the precise limits of use. One of the basic factors is the amount of control of materials and establishments and/or individuals which conduct the control, along with the sort of certificate necessary for different materials and the person who has the authority to award that certificate. It is a rule that materials of higher quality require a certificate from financially independent organizations or authorized experts.

Generally, the total amount of control during the production has a significant effect on the quality of pressure vessels, especially in the criteria concerning the acceptability of welded joints. Good maintenance cannot increase the quality in production, but it can ensure a longer period of exploitation.

2.3 Regulations for Pressure Vessels in Britain and France

Until the end of 1977, BS 1515-Fusion Welded Pressure Vessels was applied for pressure vessels in Britain. Part one of this standard deals with vessels made out of carbon and ferrite steels, and Part 2 deals with austenite steel vessels. Since 1977, BS 5500- Unfired Fusion Welded Pressure Vessels, has been used in Britain. This standard has replaced previous standards in this area [10-12].

The French regulations for the design of appliances under pressure and calculation regulations are determined by the Syndicat National de la Chaudronnerie de la Tolerie et de la Tuyauterie Industrielle (SNCT). A large portion of pressure vessels used in process technology, plants assembly, petro-chemical and oil processing have been designed and produced according to these regulations. The French SNCT regulations give rules strictly for calculations and the design of pressure vessels. Those rules are divided, according to characteristic components of vessels, into seven parts, from C1 to C7. It is important to mention that SNCT regulations include stress in conditions of special work in calculations, as well as under conditions of hydraulic testing.

3 A SHORT COMPARISON OF THE REGULATIONS

The criteria concerning the yield stresses are closely related and there are, in general, no major differences. For example, according to the AD and DIN norm criteria, the allowed stress is 66.6% or 2/3 of the yield stress, and according to ASME, Section VIII, Part 1, it is 62.5% or 5/8 R_{eH}.

If the maximum allowed yield stress is taken into consideration in the comparison, according to ASME, Section VIII, Part 1, this stress is the smallest and for its determination the factor of safety compared to the tensile strength and yield stress is used. On the other hand, according to the AD Technological regulations this stress is the largest and for its determination, the criterion of strength is disregarded (this includes only carbon and low-alloyed steels). All the other more important regulations are between these two extreme cases (ASME and AD). Differences in the allowed stress according to ASME, Section VIII, Part 1 and AD are the highest at the temperatures close to the ambient temperature. These differences are the smallest at the temperature at which, according to ASME, for determination of allowed stress, authoritative yield stress shows.

For determination of the allowed stress according to ASME, Section VIII, Part 1 and AD in the region of creep of materials, the criterion of 100,000 hours time strength is the same, and other criteria have small and insignificant differences.

The mentioned differences show that the difference in mass (this also means in the price) of the vessel between ASME and AD is the greatest at a temperature of 300 °C. The difference in the application of the radiographic control is added to this difference as well. The volume of the radiographic control according to ASME, for partial control which uses the quality factor of the welded joint 0.85, is smaller and it is usually 10% lower than all the other butt joints, while according to AD control, for the quality factor of the welded joint (depending on the group of materials) ranging from 0.85 to 1.0 the span of these tests is 25% for transverse, 100% for longitudinal and 100% for cross-welded joints.

4 RECEIVING OF MATERIALS AND RELIABILITY MODELS

The acceptance of materials, especially high quality ones, according to DIN, should be performed by an independent inspection service and according to ASME regulations it should be performed by a qualified service. For the certification of materials, conditions and procedures the situation is more complicated, so the price of accepting a smaller amount of materials is high. Even though regulations and laws define many things, irregularities, sales of inappropriate materials (even if the certificate of required quality is different from the delivered material) have been made in practice, particularly in this area. Delivery mistakes are avoided in cases when the acceptance of the materials is made by authorized government inspectors (Lloyd Register, Bureau Veritas, TÜV and others).

Since the regulations from the USA and Germany are normally applied, the regulations of other countries were not compared, but it can be said that they are within the limits of the AD and ASME regulations. Other developed countries have their own regulations for pressure vessels, while less developed countries are working on the development of common standards for pressure vessels, and they are getting considerable help from the countries of the European Union.

The required reliability level of pressure vessels is a basis of the quality assurance system. Many different reliability models are used in practice, such as: stress-strength (mainly in these regulations), fault tree analysis, failure rate etc.

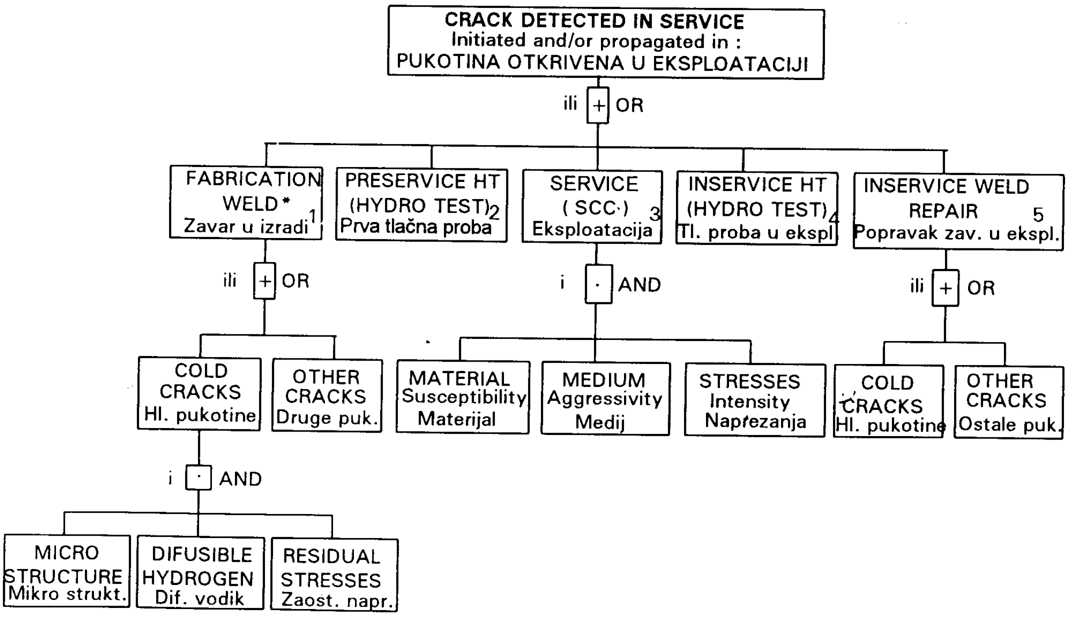

Figure 1: Model Fault Tree – Crack detected in service
Slika 1: Shema napak - razpoka, odkrita pri uporabi

Model Fault Tree Analysis (FTA) (**Figure 1**) shows crack types detected and reported at various phases of a pressure vessel's fabrication and service [5,13].

The cracks found during inservice inspection may originate at various stages of the pressure vessel's fabrication and use. In all the listed phases 1-5 the new cracks may initiate, or small previously undetected ones, may propagate and become detectable. This is the reason why non-destructive testing should be performed after each phase. Repetition of any phase should require new non-destructive testing.

5 CONCLUSION

In this article the regulations for the assurance of reliability of pressure vessels, especially in developed countries such as the USA and Germany, are considered. In these regulations two reliability models are used: stress-strength and fault-tree analysis.

For the assurance of the reliability of pressure vessels, quality assurance and quality control procedures are to be established and implemented strictly. Knowledge of the regulations and the quality assurance manual are required to ensure succesful fabrication, acceptance, service, inservice inspection, repair and the reliable operation of pressure vessels.

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