INIS-mf--7656 BR8206508

ANAIS PROCEEDINGS

COBEM 81

VI CONGRESSO BRASILEIRO DE ENGENHARIA MECANICA

RIO DE JANEIRO, 15 – 18 de dezembro de 1981

TRABALHO PAPER N.° D-16 P.P. 149 - 156 PUC/RJ

DESIGN CONCEPT FOR VESSELS AND HEAT EXCHANGERS

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SUMÁRIO

~~Neste trabalho é apresentado~~ Apresenta-se um conceito de projeto para vasos e trocadores de calor, submetidos a carregamentos externos e internos, resultantes de operação normal e acidente. Uma definição e explicação das condições de operação e níveis de tensão são fornecidos. Uma descrição do tipo de análise (tensão, fadiga, deformação, estabilidade e vibração) é apresentada em detalhe, e também, os procedimentos técnicos para os vasos, trocadores de calor e suas partes estruturais individuais. (autor)

SUMMARY

A design concept for vessels and heat exchangers against internal and external loads resulting from normal operation and accident is shown. A definition and explanation of the operating conditions and stress levels are given. A description of the type of analysis (stress, fatigue, deformation, stability, earthquake and vibration) is presented in detail, also including technical guidelines which are used for the vessels and heat exchangers and their individual structure parts. (author).

1. Introduction

Vessels and heat exchangers of nuclear plants are installed in primary systems as well as in other nuclear and conventional circuits. According to the classification of the system, the vessels and heat exchangers are designed for different operating conditions with different allowable stress levels.

For relevant technical safety systems also loads due to earthquake and, if necessary, loads due to postulated pipe rupture might be considered.

To meet these strains a proposal is done for the requirements of the design concept for vessels and heat exchangers.

2. Operating conditions and stress levels

2.1 General

For each system the operating conditions (load cases) are classified due to the postulated safety requirements.

For the vessels and heat exchangers the stress levels must be related to the load cases.

2.2 Operating conditions (load cases)

2.2.1 General

In general, load cases, can be:

- static
- dynamic
- non-steady state

2.2.2 Design load case

Usually this load cases cover the stresses which are the result of the maximum loads of normal operating conditions. Only those loadings are considered, which have components of primary stresses. Design pressure, temperature, dead weight and other design determining loads contribute to this load case.

2.2.3 Operation conditions

2.2.3.1 Normal operating conditions

This includes all those conditions which belong to the normal operational service inclusive the start up, shut down, full or partial load including the transients.

2.2.3.2 Abnormal operating conditions

These are the deviations from normal operating conditions, which occur through function, or switching effects in the system.

2.2.3.3 Test cases

The test cases cover initial as well as periodic pressure testing.

2.2.4 Failure modes

Distinction should be made between emergency conditions and faulted conditions.

Deviations with low probability from normal operational conditions are emergency conditions, but deviations with extremely low probability as well as postulated load cases, are considered as faulted conditions. The design earthquake is considered as emergency condition, the safe shutdown earthquake as faulted condition.

3. Stress levels for vessels and heat exchangers

Stress level 0 is related to the design load case. In this case the primary stresses (membrane and bending stress) are to be considered.

The stress level A for the normal operational condition includes a consideration of all primary (membrane and bending stress), secondary and peak stresses, especially because also the proof of the fatigue has to be done. The same is valid for stress level B for the abnormal operating conditions.

The stress level P is related to the testing conditions and only primary stresses are considered.

The emergency conditions are related to stress level C, the faulted conditions to stress level D. For both only the primary stresses are considered.

4. Loads on the vessels and heat exchangers

The stresses and strains created by mechanical loads should be determined and evaluated by an analysis of the component mechanical behaviour.

Mechanical loads are:
dead weight
pressure and pressure transient
temperature and temperature transient
loads from attached piping
restraint free end displacement heat expansion
vibration caused by earthquakes as well as
flow induced forces and tube vibration especially in heat exchangers

The individual loads are superimposed according to the requirements of each load case.

5. Analysis of the mechanical behaviour

5.1 General

The analysis shows that the component (vessels and heat exchangers) will withstand the loads at each stress level. The stresses and deformations of the components and their parts are determined for the given loads and the correct design has to be proved with the corresponding allowable values.

The analysis can be carried out besides others also with the aid of a calculation model; with this model,the component is transferred to an idealized model, to which the component should correspond in its characteristics.

The following methods may be used:

finite differences method

finite elements method

structural dynamic analysis

5.2 Types of analysis

In general the following analyses are made for vessels and heat exchangers; stress, fatigue, deformation, stability, earthquake and vibration analysis.

5.2.1 Stress analysis

The object of this analysis, with stress category and stress limits definition is to demonstrate that only allowable strains and by this only allowed deformations may result.

The stress categories shall be divided into primary stresses, secondary stresses and peak stresses.

Primary stresses:

Stress which is necessary for the laws of equilibrium. It is not self-limiting. Therefore a thermal stress can not be a primary stress. If the primary stress exceeds the yield strength, a global failure is the consequence. A primary stress can be of - local
- general character

Secondary stresses:

Stress which is self-limiting, that means if yield stress is exceeded, no global failure is existing usually a secondary stress is coming from constraints of adjacent material or (i.e. cladding) by self constraints of structure. A secondary stress can be

- thermal stress
- bending at a gross structural discontinuity

Peak stresses:

A peak stress is a very localized stress without noticeable distorsion. It is the increment of stress which is additive to the primary plus secondary stress and is mainly caused by local discontinuities or local thermal stress. It may be only necessary for the fatigue calculation, because it is only the source of a fatigue crack or a bittle fracture. Examples:

a) thermal stress in the austenic cladding of a carbonsteel component
b) surface stresses produced by thermal shock

For evaluating the primary stresses the reference stress is determined; for the sum of the primary and secondary or for the sum of the primary, secondary and peak stresses the alternating stress intensity is formed.

The reference stresses are calculated on the basis of the shear stress hypothesis. To avoid the failure because of large deformation the primary and secondary stresses are determined; on the other hand, to avoid failure due to fatigue the sum of all stress components has to be considered.

For any case the following procedure has to be used (when the principal stress direction does not change) to determine the alternating stress intensity:

Consider the values of the three principal stresses at the point versus time for the complete stress cycle. These are designated as σ_1, σ_2 and σ_3. Determination of the stress differences $S_{12} = \sigma_1 - \sigma_2$, $S_{23} = \sigma_2 - \sigma_3$ and $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. The symbol S_{ij} used to represent anyone of these three stress differences. Determination of the extremes of the range through which each stress difference S_{ij} fluctuates, and find the absolute magnitude of this range for each S_{ij}. Call this magnitude S_{rij} and let S_{altij} = 0,5 S_{rij}. The alternating stress intensity S_{alt} is the largest of the S_{altij} values.

The reference stress and the alternating stress intensity are dependently of the material characteristic values.

5.2.2 Fatigue analysis

This analysis type should be made to determine the usage factor of each part of the component. The usage factor must be lower than one.

A simplified fatigue analysis can be made, whereby six criteria have to be fulfilled which however will not be detailed here. Otherwise the elastic fatigue analysis will be used. If the criteria for this elastic fatigue analysis is not passed the simplified elastic - plastic fatigue analysis has to be made.

A special application is found in the heat exchangers with a crossflow of the medium for the tubes. The tubes are set vibrating, a vibration amplitude will be created by the crossflow.

However all vessels and heat exchangers with high number of load cycles must be taken into consideration.

5.2.3 Deformation analysis

This should only be carried out if for operational reasons deformation must be limited.

5.2.4 Stability analysis

In the stability analysis, structural stability with respect to inadmissible sliding and tilting of the component and its support under the superposed loads shall be examined.

In addition, sufficient strength and stability (buckling) of the component and its supports shall be proved.

Elements of components supports are points of attachment at the shell, such as lugs, joints and fastenings. This can be done with screws, bolts, welds and the foundation anchoring.

5.2.5 Seismic analysis

Vessels and heat exchangers are classified in accordance with their functions for the load case earthquake. A difference is made between Class I and Class II (A) components. Class I components are components which must be able to perform a safety-related function during and after or only after a DBE and SSE. Class II (A) components are components which are not required to perform a safety-related function during or after an SSE, but whose failure would, however, be an hazard to a Class I component. Additional to the loads due to earthquake other loads must be considered, such as dead weight, pressure, flow induced forces, etc. The protection objectives are defined of Class I components by the terms function, tightness and stability, for Class II only tightness and stability.

To determine the loads and stresses caused by earthquakes different calculation methods may be used.

Quasi dynamic as well as dynamic methods are employed. As many of the vessels and heat exchangers are low-frequency, the response spectrum method is an adequate method. For this a response spectrum will be calculated for the horizontal and vertical directions. The spectra depends from the type of buildings, from the level of installation and from the damping value. The response spectrum shows the acceleration dependently of the frequency. To determine the eigenfrequencies and mode shapes, which must be known for the response spectrum analysis, calculation models on the bases of finite element programs are developed.

The displacements and forces and moments may be superimposed according to different methods; square root of the sum of the squares, group build up method and the 10 percent combination method.

The stress results are evaluated according to stress level C (for DBE) and to stress level D (for SSE).

5.2.6 Vibration analysis

At heat exchangers tubes subject to cross flow from experience vortex shedding frequencies and liftforces are observed.

The lift coefficient is used for the determination of the acting forces at the tube. Consequently the stresses of the whole tube caused by flow-induced forces can be determined. At still higher flow velocities there appears the effect "fluid-elastic coupling"; the velocities then occuring represent an upper limit.

For the flow-induced loads of the heating tubes due to vortex shedding, the margin between forcing frequencies and natural frequencies is sufficiently wide. The forcing frequencies are much lower than the natural frequencies of the parts of the heating tube.

The danger of vibrations due to "fluid - elastic coupling", especially in the upper regions of the steam generator, does not exist, because the actual flow velocity is substantially lower than the critical one.

6. Loads on vessels and heat exchangers from attached piping

A special item are the nozzle loads for connecting piping systems. The connection loads and moments are in many cases not available at the time of the first design. Therefore, one has to define at the beginning of the calculation several maximum loads and moments, which are treated as an upper limit and which must not be exceeded at the later performed piping analysis. The formula utilized for determining loads and moments is based on experiments, calculations and assessments of other facilities and has been borne out in a modified form. These loads are also used for dimensioning nozzles.

7. Technical guidelines

Besides the already mentioned calculation methods, the finite element method is especially suitable for the more complex calculations that can not be analysed according to the technical guidelines. Its use is very efficient with corresponding experience, being however cost and time intensive.

The following technical guidelines are especially used for design dimensioning:

AD - guidelines	(Germany)
TRD	(Germany)
DIN - Standards	(Germany)
VDI - Guidelines	(Germany)
ASME Code	(USA)
Britsh Standard (BS)	(England)

For the structural parts of vessels and heat exchangers the following guidelines are mainly used:

Vessel wall	- AD, ASME, BS 1515
Tube plate	- AD, ASME, BS 1515
Nozzles - reinforcement	- AD, TRD, ASME, BS
Flanges	- AD, DIN, ASME, BS 1515
Supports	- DIN, ASME, BS 1515