DETERMINATION OF THE RESIDUAL RESOURCE OF PRESSURE VESSELS ACCORDING TO CRACK GROWTH CRITERION

Ganchev I.
Ph.D., Eng
Todor Kableshkov University of transport
1574 Sofia, 158 "Geo Milev" Str.
REPUBLIC OF BULGARIA
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Abstract

The article describes the features of predicting the residual resource of pressure vessels. The dependencies when applying this method are presented. A way to determine the probabilities of crack occurrence and the impact of their enlargement and growth on the residual life of the pressure vessel is shown..

Keywords: Pressure vessels, receivers, resource of vessels for pressure fluids, determination of residual resource

1. Introduction

Steel pressure vessels, as equipment with increased danger, are usually installed in industrial enterprises, where it is necessary to provide a resource of some fluid (water, air, etc.) for the needs of various technological.

Defining and evaluating the potential causes of disruption to the normal operation of pressure vessels that may occur during their operation is of utmost importance and requires special attention. The occurrence of cracks in weld areas and in other areas of the vessel hull can lead to serious accidents, such as explosion, implosion or damage to various elements of the facility or adjacent installation and equipment.

This article presents the dangers and risks that may arise in the process of operation of pressure vessels as a result of the appearance of cracks in various areas of the metal casing, as well as the possibilities of their calculation and determination of the residual resource of this facility with increased danger.

2. Determination of the probability of failure-free operation of a pressure vessel

The probability of failure-free operation of a pressure vessel using the maximum crack size criterion analysis method can be represented as follows:

$$R\left(\frac{\beta}{F_{cf}}\right)=R_d\left(\frac{\beta}{F_{cf}}\right).R_{nd}\left(\frac{\beta}{F_{cf}}\right).R_n\left(\frac{\beta}{F_{cf}}\right) \quad (1)$$

where,

- $R_d\left(\frac{\beta}{F_{cf}}\right)$ - determines the cracks found during operation
- $R_n\left(\frac{\beta}{F_{cf}}\right)$ - determines the cracks that have occurred since the last inspection

3. Determination of the residual resource distribution function

If we assume that the crack in the pressure vessel shell has certain conditions for independent occurrence and determine that there is some limit state, then this state will appear when at least one of the cracks reaches the limit size.

To determine the residual resource distribution function $\boldsymbol{Y(F_{cf})}$ it is necessary to use the formula (1), which in this case takes the following form:

$$S_Y\left(\frac{Y}{F_{cf}}\right)=1-R_d\left(\beta_k+\frac{Y}{Fcf}\right).R_{nd}\left(\beta_k+\frac{Y}{Fcf}\right).R_n\left(\beta_k+\frac{Y}{Fcf}\right) \quad (2)$$

Let us consider the method of calculating the probabilities involved in the formulas (1) and (2), assuming that the sizes, type and location of the appeared cracks on the shell of the steel pressure vessel are known. If the loading process on a given zone or element of the pressure vessel ($\boldsymbol{\beta_k}$, $\boldsymbol{\beta}$) is deterministic, then crack growth on that segment will also be a deterministic process

The probability of determining the detected cracks will have the following definitions:

$$R_d\left(\frac{\beta}{F_{cf}}\right)=1$$

or

$$R_d=\left(\frac{\beta}{F_{cf}}\right)=0$$

In the general case, to calculate the probability of determining the detected cracks, it is necessary to use the transition distribution functions, from which it is determined that with the increase of $\boldsymbol{\beta}$, an approximation to the normal distribution of a given mathematical expectation is asymptotically established.

If the calculated probability $R_d\left(\frac{\beta}{F_{cf}}\right)$ at the time of the next inspection is less than the limit value, one of the following actions must be taken:

- cracks found to be removed
- to take measures to stop the further growth of the cracks found
- components containing a dangerous crack to be replaced.

In these cases, the probability $R_d\left(\frac{\beta}{F_{cf}}\right)$ increases to a value of 1.

The probability $R_{nd}\left(\frac{\beta}{F_{cf}}\right)$ that the ultimate limit state as a result of the growth of missed cracks will not be reached is determined in the same way as the probability of the development of cracks from technological defects.

If detection actions are performed according to Poisson's principle for the population of missed cracks then the probability $R_{nd}\left(\frac{\beta}{F_{cf}}\right)$ depends only on the mathematical expectation of the number of missed cracks, their size distribution and the transition distribution function $S_l\left(\frac{l,\beta}{l_k,\beta_k}\right)$.

The probability $R_n\left(\frac{\beta}{F_{cf}}\right)$ is equal to the addition to one of the probabilities of reaching a limit state due to crack growth occurring in the pressure vessel after the time β_k of the last inspection.

The mathematical expectation of these cracks is determined using the following dependencies:

- $S_\psi\left(\frac{\psi,\beta}{\psi_k,\beta_k}\right)$ (3)
- - the damage size distribution function ψ
- $\mu(\beta)=\int_0^\infty \beta(\psi)dS\psi(\psi;\beta)$ (4) - for the intensity of the crack initiation flow

where

$S\psi(\psi;\beta)$ is a function of the damage size distribution ψ over a period of time β.

To calculate the probability $R_{nd}\left(\frac{\beta}{F_{cf}}\right)$ we will use the following formula

$$S_F(F)=1-\exp\left[-\sum_{i=1}^{I}\int_M \mu_i\left(li^{**};F\right)\frac{dM}{M_0}\right] \quad (5)$$

As a result of applying formula (5), we will get the following expression

$$R_{nd}\left(\frac{\beta}{F_{cf}}\right)=\exp\left[-\sum_{i=1}^{I}\int_M v_i\left(l_i^{**};\frac{\beta}{F_{cf}}\right)\frac{dM}{M_0}\right] \quad (6)$$

where

- $v_i\left(l_i^{**};\frac{\beta}{F_{cf}}\right)$ is the mathematical expectation of the number of missed cracks of the ***i***-th type in area ***M₀*** at time β provided the corresponding characteristic is known at $\beta=\beta k$.
- l_i^{**} - these are the limiting dimensions of the ***i***-th type crack

For the mathematical expectation $v_i\left(l_i;\frac{\beta}{F_{cf}}\right)$ is obtained

$$v_i\left(l_i;\frac{\beta}{F_{cf}}\right)=\mu(F_{cf})\int_0^\infty S_i\left(l,\frac{\beta}{l_k},\beta_k\right)\left[1-Ri\left(\frac{D}{l_k}\right)\right]r_i\left(\frac{l_k}{F_{cf}}\right)dl_k \quad (7)$$

$$(k=1,2.....)$$

- $\mu_i(F_{cf})$ - this is the mathematical expectation for the number of cracks detected at time $\beta=\beta k$, taking into account the appearance of new cracks
- $r_i\left(\frac{l_k}{F_{cf}}\right)$ - transition function of distribution
- $Ri\left(\frac{D}{l_k}\right)$ - probability of detecting cracks of the ***i***-th type

Determining the residual resource of pressure vessels is of particular importance to ensure their long and trouble-free life.

As a result of the assessment of the resource, the condition of the vessel is determined and an assessment is given of its operability both at the time of the inspection and the amount of the remaining period of accident-free operation.

From the calculations to determine the probability of occurrence of damage in this type of vessels, the period between two checks on its condition is also determined. The lower the probability of cracking, or at best the absence of cracks, the longer the intervals between two pressure vessel safety inspections can be.

Since these vessels are high-risk equipment, it is extremely important for their trouble-free and safe operation to carry out periodic checks on their condition. On the basis of the collected data on the deviations from their normal state and, in particular, establishing the occurrence of cracks, the necessary actions must be taken to establish their influence on the state of the pressure vessel and to assess its residual resource.

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