PNEUMOTESTS OF VESSELS USING ACOUSTIC EMISSION CONTROL

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ABSTRACT

The method of wind tunnel pneumatic tests using acoustic emission is discussed. The results of stress - strain analysis, residual strength study, safety factors determination, flaw detection are described as well as the tests themselves. Special attention is paid to the role of acoustic - emission and strain-gauging control during the tests.

KEYWORDS

Pneumatic test, acoustic emission, structure mechanis.

The main task of hydraulic tests of pressure vessels during their technical control is the detection of flaws that can affect the structure carrying capacity at the future operation, can lead to the structure removal or crash with large expenditures.

Hydraulic test can be removed by pneumatic one when controlled using acoustic emission method. It should be considered that vessel detail damage affecting its integrity is very unfavourable at the pneumotests. This condition, in turn, defines the specific approach to providing the structural strength based on impossibility of static crack growth. Acoustic emission means allow to detect the crack growth and the growth of crack-like flaws, as well as to stop the loading timely in these cases.

The idea of pneumotests of the wind tunnel shell appeared because the hydraulic tests could take the fixture out of service for more than a year.

The tunnel structure is the closed type shell (inner volume is 20000 cubic meters), reinforced by the frame and having doors (windows) of different shapes and size. The test excess pressure is 0.375 MPa. The total weld length having passed the 100% ultrasonic control exceeds 7 km. The main material is steel (Ct.20K).

While preparing for the pneumotests there should be provided:

- flaw detection control of the tunnel shell;
- structural strength analysis establishing the appropriate safety factor;
- the usage in the most critical structure locations of acoustic emission allowing to detect safely enough the near-critical state while the shell supercharging,that is defined by the moment of crack start.

As known, the crack-like flaws may initiate in the main structural material at the manufacture, assembly and operation of welded pressure vessels. The actual state of the vessel structure can be defined based on the flaw detection using nondestructive testing. In conformity with different vessel elements the maximum undetectable crack-like flaw should be defined in terms of the given nondetection probability.If the flaws aren't detected it is assumed that there is a single crack in the element having the maximum nondetectable size. One of the main tasks providing the test safety is the structural element strength evaluation assuming the abovementioned cracks.

The strength of each vessel element is considered to be provided at test pressure P, if the condition of crack arrest at the maximum nondetectable size ℓ_0 is satisfied:

$$K\ (\ell_0,\ f_1 \cdot f_2 \cdot P) < \frac{\bar{K}_c}{f_3 \cdot f_4} \qquad (1)$$

where K is stress intensity factor at the stresses acting in the element, $\bar{K}_c$ is average stress intensity factor at crack start; f_i are safety factors, considering design errors and strength characteristics scatter (f_1 is stress-strain state defining error at critical locations (zones), f_2 is stress intensity factor error; f_3 is the error of the used model in the comparison between the actual stress intensity factor and the allowed value of $\bar{K}_c$, f_4 is the scatter of allowable $\bar{K}_c$values).

Flaw detection for the many of the shell elements is carried out by optico-visual methods.Two zones of control were differentiated - welded joints zone in the frame area of the tunnel and the zone near welding the frames and their radial ribs. The size of safely detectable flaws in the shell welded joints is 120 mm,while in the welded joints of frames and radial ribs it is 60 mm.

Design investigations of the structural stress-strain state were performed using the finit element method.The types of finit elements and the relative net space were found out for each structural joint, which provided the required accuracy of results.

For turning knees N 1 and 2 the low stress level was proved by analysis and then by tests. Based on the analysis of turning knees N 3 and 4 it was found,that they need rework to decrease the pressure stresses level. Such rework included the setting of additional roads. Each turning knee analysis came down to the decision of equation system, containing about 3500 unknowns. Some other joints were also analysed to calculate their stress-strain state.

The critical zones were listed including 12 joints. The main criteria for this list were the degree of responsibility of the joint, the importance of consequences at its going out of order,stress level,the presence of manufacturing features (for instance, casting), the absence of data on joint work and the resulting large errors in the definition of stress-strain state.Besides, this list contains the typical elements, frequently used in the wind tunnel structure.

Residual strength evaluation for critical zones of the wind tunnel walls needed the crack resistance of the primary structure material.The main criterion for residual strength was crack restart criterion,i.e. the wind tunnel body looses its lift when the stress intensity factor at the foreseen crack tip reaches the value, corresponding to crack restart. This critical value equals K_{co} for plain stress state. For massive structure elements the value K_{1c} was used,that meant the critical stress intensity factor at plain strain conditions.

When the value K_{co} was used at the residual strength analysis, to avoid its dependance on the crack length the following expression similar to Parton and Morozov(1974) was used:

$$K = K_{co}\ (\sigma_{co}) = K_{co}^{T}\left[1 - \left(\frac{\sigma_{co}}{\sigma_B}\right)^2\right]^{1/2} \qquad (2)$$

were σ_{co} is crack restart stress, σ_B is ultimate strength, K^T_{co} is the parameter of material crack resistance, independent of the crack length.

To determine the parameters K^T_{co} and K_{1c} special investigation were carried out on different types of speciments and R - curves were developed. Besides the average value of K^T_{co} and K_{1c} their scatters were also determined, which were used in the analysis of K^T_{co} and K_{1c}.

In comparing test data for specimens with and wihtout welding it was found that the static crack resistance level of the welding material isn't lower than of the basic one.

Residual strength analysis of critical zones was based on the linear fracture mechanics and the predetermined safety factors were utilized. Stress intensity factors were calculated and fracture curves were developed for all critical tunnel body zones at different possible crack locations. The total of 57 locations in 12 critical zones of the tunnel body was analyzed.

Residual strength analysis based on the critical curves was carried out providing the required safety factors at test pressure and safely detectable crack length (120 mm for regular zone and 60 mm for irregular zone).

The carried analysis showed that except 5 critical zones all critical locations satisfy the strength requirements.

Strength requirements to crack restart at the choosen safety factors are not satisfied for the following five critical zones:

- the filling- unfilling box;
- the supercharge chamber door;
- the loading door throat;
- the tubes of exhausting system;
- the loading door supports.

That is why the opportunities of providing the strength in the above-mentioned critical zones were analyzed and additional activities were developed.

For the loading door throat the finite element analysis was carried out on the three - dimensional model, that allowed to choose the appropriate option of structure strengthening, decreasing the design maximum stress by 30–40 MPa.

For three structural elements : filling-unfilling box, supercharge chamber door and the tubes of exhaust system - the safely detectable crack size decreased to 46 mm, provided by the careful flaw detection before the pneumatic tests, as well as by the activities directed at the inspection of these zones during the pneumatic tests.

For 12 loading door supports the safely detectable crack size is to be decreased to 13 mm satisfying the required safety factors. It is unlike to guarrantee the provision of such size at flaw detection in this case.

That is why the finite element analysis was carried out, that allowed to find out loads redistribution between the supports when one, two or three supports are out of action. If one support is disturb the load on the next one increases 1.26 times as large, if two supports are disturb the load on the next support increases 2.26 times as large. The disturbance of three or more supports is inadmissible.

The set dependence of load distribution between the supports was used for the development of built-in stress-gauge control system and the fast analysis of its data during pneumatic tests.

In addition, acoustic emission sensors were mounted on two most loaded supports according to the analysis.

During the pneumotest of wind tunnel shell its integrity was controlled by acoustic emission sensors at four corners of loading door cutouts, two locations of loading door supports fastening and four corners of entrance door cutout. For signal acquisition and recording the devices of Physical Acoustic Corporation,USA, that is a fourchannel system 3000/3104, multi-channel system Spartan,acoustic emission sensors P15, P151, preamplifiers 1220 having built-in band filters for frequency range of 100-300 kHz, were used.The parameters of acoustic emission signal were recorded on the floppy disks and were graphically displayed at the monitor screens of computer blocks in acoustic emission system.

Sensitivity threshold of the apparatus for the safe acoustic emission recording at the crack growth moment should not exceed 55 dB.

After all preliminary investigations of wind tunnel shell it was pneumatically tested by the test pressure. After a 10-minute exposure the pressure was gradually decreased down to the working one. At the careful visual inspection no cracks in the welded joints and the basic metal as well as the untightness in the bolted joints and visible residual strains were found. Thus, the wind tunnel shell sustained the test by the test pressure.

The sensitivity threshold limit was reached in the tests only along one channel, that was not the result of the increase in acoustic emission discrete signal activity, but of the amplitude growth in continuous noise signal due to air leakage through the fitted joints. Acoustic-emission control could not find out the growing flaws in the controlled zones.

Therefore above-mentioned procedure of wind tunnel strength provision can be used for other different shells, sertified by the pneumatic tests.

REFERENCES

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