STABILITY OF CYLINDRICAL SHELLS WITH OPENINGS REINFORCED WITH BRANCH PIPES

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In the development of large vacuum chambers with openings into which branch pipes are installed there is the question of providing stability of the designs while optimizing metal content. Studies [1-3] on the stability of shells with openings have shown that openings with a profile that is not reinforced reduce the critical load of the design. The presence of an initial geometric irregularity in the zone adjoining the opening can result in the formation of localized stability loss (even for an opening of small diameter [1]). It is quite a complex task to carry out a theoretical calculation of the stress-strain state and stability of these designs. However, from experimental studies on models produced industrially it is possible to determine the effect of openings with installed branch pipes on the stress-strain state and stability of cylindrical shells.

We can examine the results of experimental studies on the stability of large welded models of cylindrical shells with diametrically positioned cylindrical branch pipes. Cylindrical models made of 12Kh18N10T austenite steel with R/H ratios of 133:1 and 200:1 (where R is the radius of the cylindrical shell, H is the wall thickness) were selected for the studies. The diameter of the main shell of the models was \( D = 2R = 800 \text{ mm} \). The shell was produced by stretch rolling followed by longitudinal seam welding. Two diametrically opposed openings of equal size were produced in the shells and cylindrical branch pipes closed at the ends with flat covers with ribbed reinforcement were installed and welded into the openings (Fig. 1). The diameter of the branch pipes was 0.6\( D \), 0.8\( D \), and 1\( D \). The thickness \( h \) of the branch pipe was taken as equal to the thickness of the main shell. A rigid flange was fixed at one end of the main shell in order to support the model on a stand during the tests (Fig. 2). The main shell was closed at the other end by a flat cover with ribbing.

The stresses close to the branch pipes were recorded using KF 5P-3-100-A12 low basis resistance strain gauges and a MARS-1000 multichannel automated display system.

The deviations from true geometric shape were recorded before the tests using a special instrument. The maximum relative ovalness was determined from the recorded results according to the following formula [4]

\[
a = \frac{2(D_{\text{max}} - D_{\text{min}})}{D_{\text{max}} + D_{\text{min}}} \times 100\%,
\]

where \( D_{\text{max}} \) and \( D_{\text{min}} \) are respectively the maximum and minimum diameters of the shells on measurement in two mutually perpendicular directions of a single cross section.

The measurements showed that the main shells and branch pipes had deviations from true geometric shape that in individual cases exceeded the standard value [4]. These deviations occurred in adjoining zones of branch pipe and main shell. The deviations from linearity were 0.5-3.5 mm, and the relative ovalness of some models was higher than the standard permissible value (\( \alpha = 0.5\% \)) for stability designs.

The models were subjected to hydraulic pressure and evacuation in stages (with the stresses recorded at each stage). The pressure during the tests was recorded with the manometer. Loss in stability of the models was accompanied by a cracking sound with a sharp decrease in pressure in the unit test vessel.

After the tests the model was recovered from the test unit and the type of stability loss analyzed.

The average critical load values \( \bar{p}_c^P \) for models with openings reinforced with branch pipes were compared with calculated critical load values \( \bar{p}_c^S \) derived for similar models without openings and also with the average critical load values \( \bar{p}_c^S \) determined experimentally on models without openings.

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Fig. 1. Model of cylindrical shell with openings reinforced with branch pipes.

Fig. 2. Diagram of unit for stability tests on shells with an external hydraulic pressure: 1) manometer; 2) experimental chamber; 3) assembly cover; 4) safety valve; 5) test model; 6) hydraulic pump.

Fig. 3. Type of stability loss in cylindrical shell: a) without branch pipes; b) branch pipes with \(d = 480\) mm; c) branch pipes with \(d = 800\) mm.

It is clear from the results (see Table 1) that the installation of branch pipes in the openings helps to strengthen the shells. The two diametrically positioned branch pipes affect the type of stability. Plain shells (without openings) with similar geometric parameters underwent stability loss, forming four waves around the circumference (Fig. 3a).

The type of stability loss depends on the dimensions of the installed branch pipes. Thus, with two branch pipes of diameter \(d = 480\) mm \((d = 0.6D)\) the same number of waves occurs around the circumference (see Fig. 3b) as that for the stability loss in the plain shell. The critical load on the main shell with these two branch pipes proved to be higher than for the plain shell. The size of the branch pipe \((d = 480\) mm\) around the shell corresponds to that of a wave of stability loss and is equivalent to ¼ of the circumference. On examination of the ratio of bending rigidity of the cut metal \((E_\text{l}_c = 0.66\) kN·m\) to that of the installed branch pipe \((E_\text{l}_p = 2\) kN·m\) it is clear that the bending rigidity of the installed branch pipe is significantly higher, thus helping to increase the stability of the shell in these zones. The volume of metal under stress around the main shell (in the cross section where the branch pipes are installed) is effectively halved, which also has a positive effect on its load-bearing capacity. The increase in critical load on the shells with two diametrically positioned branch pipes (when