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Control of Mechanical Stresses of High Pressure Container Walls by Magnetoelastic Method

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Abstract. Deformations of the walls of pressure vessels arising in the process of testing and operation, as well as reduce their thickness due to corrosion, to create the prerequisites for the growth of mechanical stresses which accelerating the processes of strain aging, embrittlement of the material and reducing its fatigue properties. This article is devoted to researches of the magnetoelastic demagnetization in the wall of steel vessel of loading by internal pressure. It is established that the increasing pressure on the vessel wall is accompanied by a monotonic decrease in the intensity of the magnetic stray field of local magnetization of steel. It is shown that a magnetic stray field of local magnetization of the wall of steel vessel is non-uniform due to differences in structure and stresses.

It is proposed to use the obtained results to control the stress state of vessels, experiencing multi-axial loads generated by internal pressure (pipelines, oil tanks, etc.)

The method of magnetoelastic of the demagnetization of the steel has a high sensitivity to mechanical stress, the simplicity of implementation and expressiveness compared to the strain gauge and method of coercive force.

1. Introduction

Deformation of vessel walls under pressure, arising in the process of their testing and operation, as well as corrosion decrease in their thickness, create preconditions to mechanical stresses growth accelerating processes of strain aging and embrittlement of the material and reducing its fatigue properties.

At the forefront of solving the problem of high pressure vessels reliability, calculation tasks for the strength, stability and durability are put forward. To solve them, information about the mechanical loads and impacts on the walls is required, analysis of stress-strain state (SSS)that eventually is used in the calculation of their reliability and resource [1,2].

The main factor determining the stress state of the vessel body is process pressure [3]. Under the influence of the internal pressure, vessel walls are in volume stressed state when along the generator the meridional (axial) stress σ_s operates, tangentially to a circle - hoop stress σ_τ, and at standards to the wall - the radial stress σ_r. Radial stress σ_r, acting in the direction of the wall thickness is assumed as equal to zero. Thus, the vessel walls are subjected to biaxial loading.

2. Models and methods

Magnetoelastic method (the method of magnetoelastic demagnetization or magnetoelastic memory MEM) [4-6] of mechanical stresses control has a high strain sensitivity, possibility of contact measurement without breaking insulation coatings, high efficiency, and simplicity of implementation. Magnetoelastic demagnetization is very important and with the application of the equal and unequivocal orthogonal stresses of one sign, and for this reason MEM is a more sensitive indicator of equivalent stresses than, for example, the coercive force.

MEM method studies were carried out on a steel tank of carbon dioxide extinguisher OU-3 in which biaxial stress state was produced by internal pressure of water.

Experimental setup scheme for studying the stress state of extinguisher cylinder by the magnetoelastic, coercimetric and strain-gauge methods is shown in Figure 1.

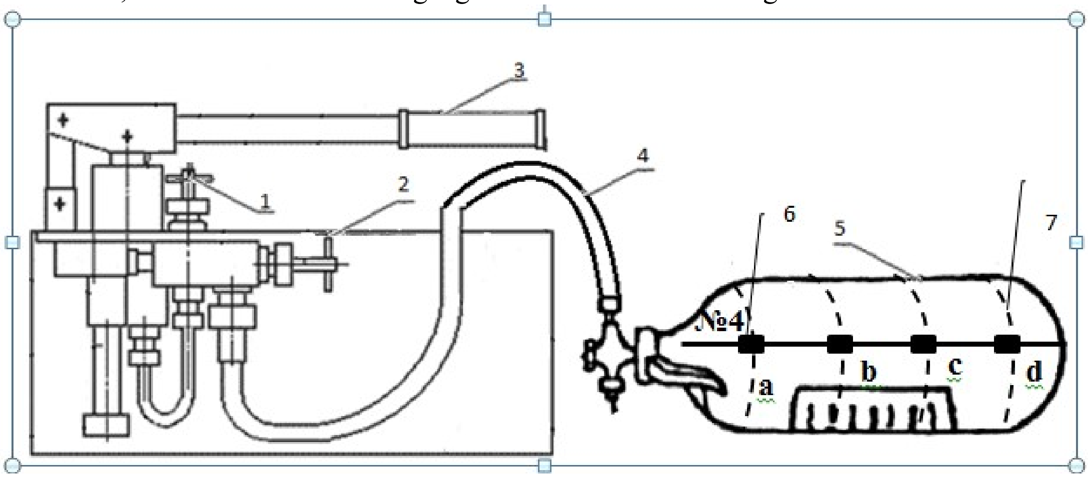


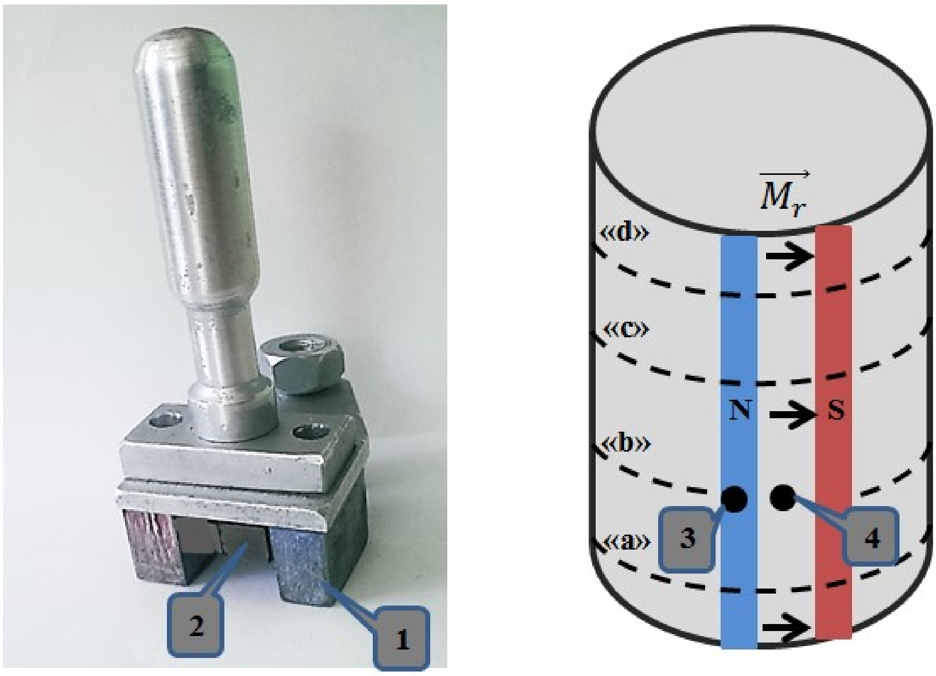
Figure 1. Scheme of laboratory installation of extinguisher cylinder for studying the stress state 1-manometer; 2-valve of pressure relief; 3-pressurization lever; 4-rubber hose; 5- extinguisher cylinder; 6 places of sticking four pairs of tensoresistive sensors on one of the cylinder №4 meridional lines; 7- circular lines (a, b, c, d).

Installation consists of the extinguisher cylinder and is connected to it with a manual testing pump RP 30 (hydraulic pump). Extinguisher cylinder is a hollow cylinder with convex bases, made of carbon steel. The height of the cylinder is 450mm, outer diameter is 107mm, wall thickness is determined by means of ultrasonic thickness gauge UDT-40 in five different points and is equal to 5.5 mm. The pressure in the container was produced with water under a maximum pressure P = 3 MPa.

On the lateral surface of cylinder along the generators four straight meridional lines (№1,2,3,4) were applied with a marker, connecting the top of its bases and four equidistant circular lines (a, b, c, d) perpendicular to them (Figure 1). In intersection points of the meridian line №4 with circular lines, tenoresistive sensors recording meridional ε_s and circular ε_τ deformation of the cylinder wall under internal pressure were pasted. With magnitude of these strains, respectively meridional σ_s, circular σ_τ and equivalent σ_{ekv} mechanical vessel wall stresses [7] were determined. The other three meridional lines (№1,2,3) were intended for magnetoelastic and coercimetric research.

Extinguisher cylinder was fixed in a non-magnetic body in a horizontal position away from possible sources of magnetic fields and was filled with water. Local magnetization of cylinder wall perpendicular to σ_s action was carried out, the initial value of normal H_{n1} and tangential $H_{\tau 1}$ components of the magnetic stray field of the local magnetization (LM) in the areas of intersection of meridian and circular lines with a fluxgate magnetometer IKNM-2FP was measured. Gradually increasing the internal pressure in the cylinder by an equal amount, new indications of flux-gate magnetometer H_{n2} and $H_{\tau 2}$ at the same points were recorded.

The magnetization of extinguisher cylinder wall was carried out by scanning its surface along the meridian lines of U-shaped magnetizing device (Figure 2). Thus, on the surface of the cylinder a band was made with a local residual magnetization $\overrightarrow{M_r}$ perpendicular to its generatrix (meridian line) (Fig.2b). With this method, demagnetization factor remains constant, which allows tracking changes in the structure and the stresses in the steel.



a b

Figure 2. "U-shaped" magnetizing device (a) and band of local residual magnetization on cylinder side wall (b): 1-pole pieces «N» and «S»; 2- magnets; 3,4-points of measurement of normal Hn and tangential Hτ components of the scattering field LN

Dependence of change normal ΔHn = Hn1- Hn2 and tangential ΔHτ = Hτ1- Hτ2 components of the magnetic stray field LN along the meridian line №3 in the areas of its intersection with the circular lines on the value of internal pressure in the cylinder are shown in Fig. 3. The full line approximates the results of measurements along the meridian line №3.

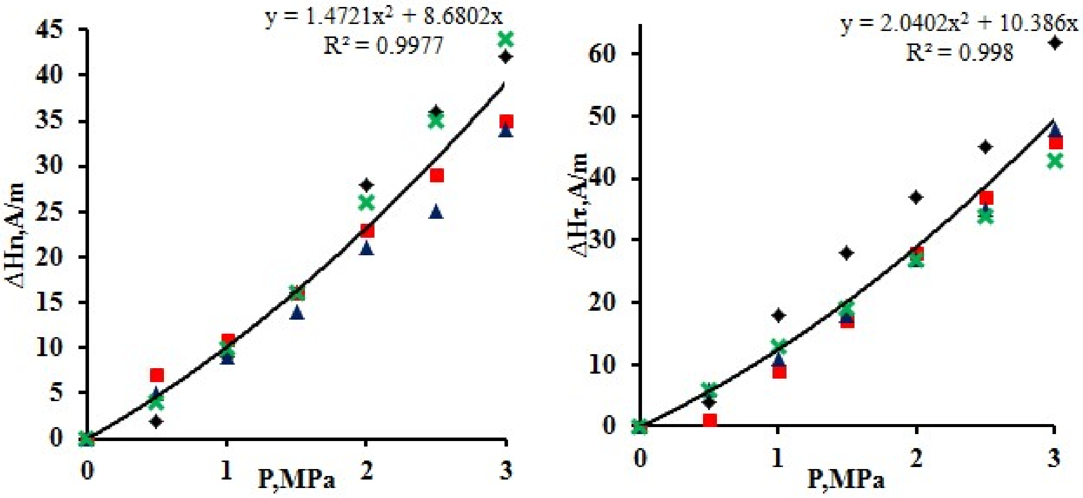


Figure 3. Dependence of change of normal ΔHn and tangential ΔHτ components of the magnetic stray field LN in the areas of intersection of the meridian line №3 and circular: ♦ - «a»; ■ - «b»; ▲ - «c»; X - «d» from changes in the internal pressure in the cylinder

The largest change in the tangential component of the magnetization field is observed in a zone of the ring "a" located at the bottom of the cylinder with outlet pipe and the minimum at the area of the ring «d» from another bottom. Obviously, this is due to the fact that in the central part of cylinder side wall, circular voltage is greater than the meridional [8]. It should be noted that in the zone of lines «a» and «d», located close to cylinder bottom ΔHn of magnetic field changes equally. This can be explained by the fact that the bottom of cylinder has a spherical shape, and therefore there should be implemented the same circular and meridional stresses, leading to equivalent steel magnetoelastic demagnetization.

To understand magnetic processes that occur in biaxial deformation of a cylinder steel shell, cylinder metal can be represented (excluding the shape factor) as the material in which two unequal light magnetic axes are formed: one - along a circular, and the other - along the meridian tensile stresses. With the growth of stresses the domain structure is changing, leading to the steel demagnetization.

Average values of coefficients Kn and Kτ of a magnetoelastic demagnetization of steel cylinder shell along the normal and tangential directions, calculated for the maximum value σ_s and σ_τ, made:

$$K_n = \frac{\Delta H_n}{H_{n1} \cdot \sigma_s} \approx 0.7 \cdot 10^{-8} Pa^{-1};\ K_\tau = \frac{\Delta H_\tau}{H_{\tau 1} \cdot \sigma_\tau} \approx 0.41 \cdot 10^{-8} Pa^{-1}$$

The magnitude of circular σ_τ and meridional σ_s stresses in controlled points on the surface was evaluated based on the results of tensometric measurements corresponding to deformation of container sidewall caused by internal pressure. The results of this evaluation are presented in Figure 4.

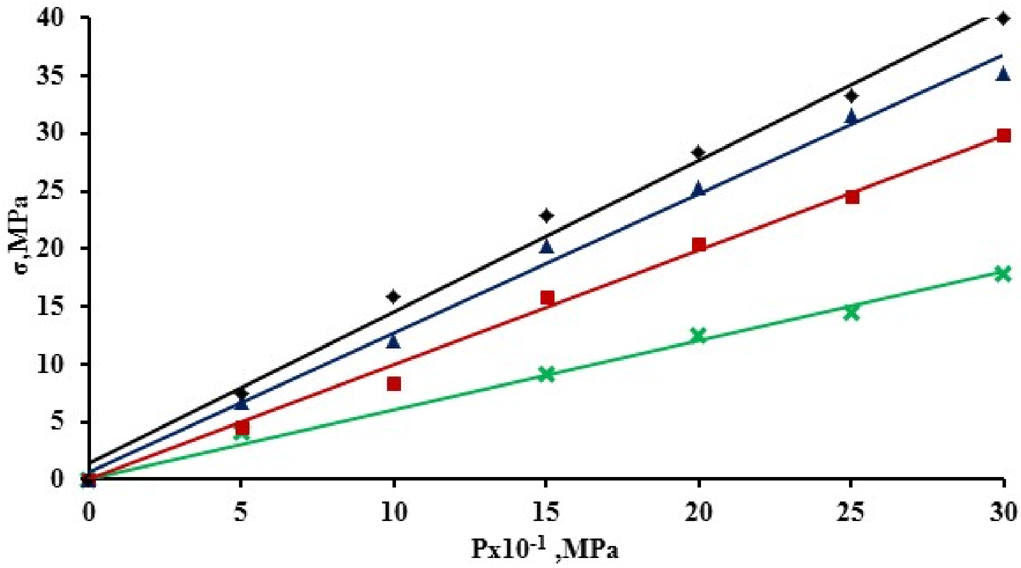


Figure 4. Dependence of mechanical stresses in the vessel wall, defined tensometrically on the value of internal pressure in it: ♦ -circular stresses σ_τ («c» line); ■ - meridional stresses σ_s («c» line); ▲ - circular stresses σ_τ (line «a»); × - meridional stresses σ_s («d» line).

In the central part of the vessel (line "c") the largest circular and meridional stresses and circular stresses near the upper base of the cylinder are generated. The latter can be explained by proximity of location of circular line «a» to the outlet pipe of cylinder. Minimum stresses are defined at another bottom (line «d»). In research [7] it is noted that based on the aggregation of a large number of experimental data obtained in our country and abroad the most loaded node in a container with pressure is pipes junction. The relative change in the cylinder wall deformation along the meridional and circular line is equal to $\varepsilon_s \sim 18 \cdot 10^{-5}$ and $\varepsilon_\tau \sim 32 \cdot 10^{-5}$, respectively, which is much smaller than the relative change of the magnetic stray field LN $\varepsilon_n \sim 13 \cdot 10^{-2}$ and $\varepsilon_\tau \sim 16 \cdot 10^{-2}$.

At biaxial loading as a criterion for strength the value of the equivalent stress is taken σ_{ekv} that in the offered work is determined by the energy of the theory [9]:

$$\sigma_{ekv} = \sqrt{\sigma_\tau^2 + \sigma_s^2 - \sigma_\tau \sigma_s}, \quad (1)$$

From the value σ_{ekv}, the reliability of the vessel wall is defined, determining its stress-strain state. For the central part of side wall of the vessel, the maximum σ_{ekv} ~ 36 MPa, and near its bottom - σ_{ekv} ~ 30 MPa.

Evaluation of cylindrical shell strength will be carried out according to the method of permissible stresses. According to this method, the maximum equivalent stresses in the dangerous section shall not exceed the permissible [σ]:

$$[\sigma] = \eta \cdot min\left\{\frac{\sigma_T}{n_T}; \frac{\sigma_B}{\sigma_B}\right\}, \quad (2)$$

where η - coefficient, which for welded vessels and devices is equal to 1; σ_B, σ_T - tensile strength and yield strength; n_B, n_T - margin of strength by tensile strength and yield strength at the estimated temperature, respectively. According to regulatory documents n_T = 1.5 and n_B = 2.6. In this paper, a cylindrical shell material is steel St.3. The estimated temperature is 20 ° C. Limiting stresses for this steel at 20 ° C and shell thickness <20 mm are: σ_B = 460 MPa, σ_T = 350 MPa. Condition (3) is satisfied.

In the areas of intersection of the circular (a, b, c, d) and meridian lines №1,2,3 of extinguisher cylinder sidewall, measurements were made of the coercive force of steel along the meridian and circular (perpendicular) directions by a coercimeter - structurescope KRM-C-K2M. The measurement results of coercive force Hc‖ along the meridian line №3 and Hc⊥ along the the circular lines are shown in Table 1.

Table 1. Results of measurement of the coercive force

Internal pressure in the container P, MPa	circular line «a»		circular line «b»		circular line «c»		circular line «d»	
	$H_{c\parallel}\cdot10^2$ A/m	$H_{c\perp}\cdot10^2$ A/m	$H_{c\parallel}\cdot10^2$ A/m	$H_{c\perp}\cdot10^2$ A/m	$H_{c\parallel}\cdot10^2$ A/m	$H_{c\perp}\cdot10^2$ A/m	$H_{c\parallel}\cdot10^2$ A/m	$H_{c\perp}\cdot10^2$ A/m
0	12.3	10.3	11.5	9.6	11.6	9.9	11.9	10.3
0.5	12.2	10.3	11.5	9.5	11.5	9.8	11.6	10.2
1.5	12.2	10.3	11.5	9.5	11.5	9.8	11.7	10.2
2	12.1	10.3	11.5	9.4	11.5	9.7	11.7	10.1
2.5	12.2	10.3	11.5	9.4	11.5	9.7	11.6	10.0
3	12.2	10.2	11.5	9.4	11.6	9.6	11.6	10.0

It was found that in the initial state and with growth of the pressure in container, the coercive force measured along mutually perpendicular directions in all areas of intersection of the circular lines (a, b, c, d) and meridional lines (№1,2,3) on the surface of container, remained practically unchanged.

Conclusion

It is shown that the loss of the normal and tangential components of the magnetic stray field of the local residual magnetization of the container wall with an increase in internal pressure can be the metrological parameter of the equivalent mechanical stresses;

the coercive force of the cylinder steel shell at its biaxial deformation remains unchanged at low voltages, and can not be an indicator of their level;

It is shown that the magnetoelastic method of steel demagnetization is highly sensitive to mechanical stresses, easiness of implementation and expressiveness in comparison to tensometric method.

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