THE EXPERIENCE OF GAS PIPELINE STRESS-STRAIN STATE CONTROL WITH USAGE OF THE METAL MAGNETIC MEMORY METHOD AS COMPARED WITH CONVENTIONAL METHODS AND STRESS CONTROL MEANS

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ABSTRACT

Test methods and means for characterising the stress-strain-state (SSS) of pipes in a gas pipeline compressor station were compared. At first the SSS determination methods and means were evaluated under laboratory conditions, and then under field conditions. The test objects were a special hydraulic test bench; supercharger manifold piping systems; a compressor station input loop; a duster manifold piping. For calibration artificial strains were impressed to the last two objects. The following SSS determination methods and means were applied: strain measurement; magnetic Barkhausen noise; metal magnetic memory (MMM) method; amplitude-phase frequency characteristics (APFC) method; hardness measurements; calculations; design-experiment method.

IIW-Thesaurus keywords: *Pipelines; Pipework; Elbows; Compressors; Oil industry; Service conditions; Stress; Stress concentration; Strain; Measurement; Electromagnetic fields; Strain gauges; Precision; Calibration; Comparisons; Nondestructive testing; Eddy current testing; Ultrasonic testing; Other test methods; Hardness; Computation; Practical investigations.*

1 INTRODUCTION

A comparison of test methods and means for characterising the stress-strain-state (SSS) of pipes in a gas pipeline compressor station were carried out in May 2000. The tests were performed according to a program and an agreement approved by the Gas and Gas Condensate Transportation Department of GAZPROM JSC, the “Orgtechdiagnistica” Information Technical Centre, and DAO “Orgenergogas” together with OOO “Volgotransgas”. 25 institutions were invited to participate to compare their test techniques: 21 of them agreed to take part in the testing; 13 organisations participated directly and 3 as observers.

At the first stage the evaluation of the SSS determination methods and means was carried out under laboratory conditions (specimens in the tensile test machine of the State Oil and Gas University), and at the second stage it was carried out under field conditions at the OOO “Volgotransgas” KS-7 “Lyskovskaya” compressor station.

The test objects were:
– A special hydraulic test bench;
– The supercharger manifold piping systems of the plants No. 2 and 3;
– The compressor station input loop;
– The duster manifold piping.

For calibration artificial strains were impressed to the last two objects.

In the course of testing the following SSS determination methods and means were applied:
– Strain measurements (Kyowa instrument – ITC “OTD”);
– Magnetic Barkhausen noise (Stresscan-500s instrument – ITC “OTD”, EAC Vniigas, “LMZ” JSC; “Intromat” instrument – “RKK” company; “Pion-01” instrument – OOO “Diakont”);
– Metal magnetic memory method (TSC-1M-4 instrument – Energodiagnostica Co. Ltd);
– Amplitude-phase frequency characteristics method (Siton-PP-NB instrument – “Contact Scientific Production Centre” JSC);
– Hardness measurements (Temp-2 instrument – Rsuog);
– Calculations (Cosmos/M program – ITC “OTD”);
– Design-experiment method (based on data obtained with Laser Beacon instrument – PTU “Volgogasenergoremont”, Cosmos/M program – ITC “OTD”, Triflex program – OOO “GiproGasCenter”, “Conpipe” program – CIAM).

The paper presenting the review of the compared testing results under field conditions is published in report [1]. This report can be summarised as follows:

Doc. IIW-1568-02 (ex-doc. V-1219-02) recommended for publication by Commission V “Quality control and quality assurance of welded products”

2 THE HYDRAULIC TEST BENCH

In order to calibrate the instruments of the participating parties six reference intrinsic pressure values were specified and controlled in the test bench (0, 20, 40, 60, 80, 100 kg/cm^2). Then the participants determined the intrinsic pressure of the unknown object (controlled with the same reference manometer), according to the results of pressure measurements in positions where their instruments were calibrated. The results shown by instruments based on the magnetic Barkhausen noise demonstrated in this case rather good correlation with the manometer values in the high stress range (the error was within 10%). The average error was about 15%.

3 THE DUSTER OUTLET PIPING

At first this section was not stressed. In the initial state, strain gauges were fixed to sections where the highest stress values were expected according to calculations using the Cosmos/M code. Then the pipe was strained using a strainer to an elongation of 10 mm. The difference between the calculated and measured (with strain gauges) axial stresses in reference platforms was not more than + 4...- 3%. None of the instruments presented were able to demonstrate results close to the reference values – differences of over 30% were documented. As indicated by the TSC-1M-4 instrument (metal magnetic memory), in two of the three objects stress concentrations were detected. By using the Siton-4 scanning instrument at these places stress anomalies in the metal near-surface layer were revealed, which were not registered by all other instruments. However, according to ultrasonic non-destructive tests, the presence of macroscopic metal defects and heterogeneity in these zones was not confirmed.

4 THE INLET LOOP

Before testing the pipeline was opened and a geodetic survey of the initial height position was carried out. By using the Cosmos/M code, strains and stresses for this section were calculated simulating a swelling load. At positions where the predicted stresses were expected to be maximal, strain gauges were fixed and reference readings were taken. Then the pipeline was strained (jack screwed) to the specified value (+ 8mm in the most strained section), and repeated strain measurements and height position measurements were carried out. The difference between calculated and measured stress values was not more than 7%. Then, by external features, deformation was artificially impressed and camouflaged in order to perform a blind test. None of the testing teams documented deviations larger than 30%. The closest results were given by the following instruments: Pion-01 (Diakont) – the average precision was 33%, and Stresscan-500s (ITC “Orgtechdiagnostica”) – the average precision was 36%. Two of the five indications documented by the TSC-1M-4 instrument were interpreted as stress concentration zones. According to the Siton-4 scanning instrument readings, stress anomalies in the near-surface layer were detected. However, ultrasonic nondestructive testing did not reveal the presence of macroscopic metal defects and heterogeneity in these zones.

5 SUPERCHARGER INDUSTRIAL PIPELINES

This object was the most problematic from the point of view of the real stress verification because its initial state was unknown.

In the following, details of the above-mentioned SSS control methods and means and their results are considered.

Figure 1 shows a piping section of the gas-pumping station No. 3 (GPA-3) of the OOO “Volgotransgas” “Lyskovskaya” compressor plant. The gas pipeline was under gas pressure. The indicated stresses control zones No. 1, 2, 3 and 4 were selected by the steering committee, based on calculated and design factors. Table 1 shows the results of stress measurements (MPa), carried out using various methods and means in control zones 1, 2 and 3. Design stresses in the gas pipeline

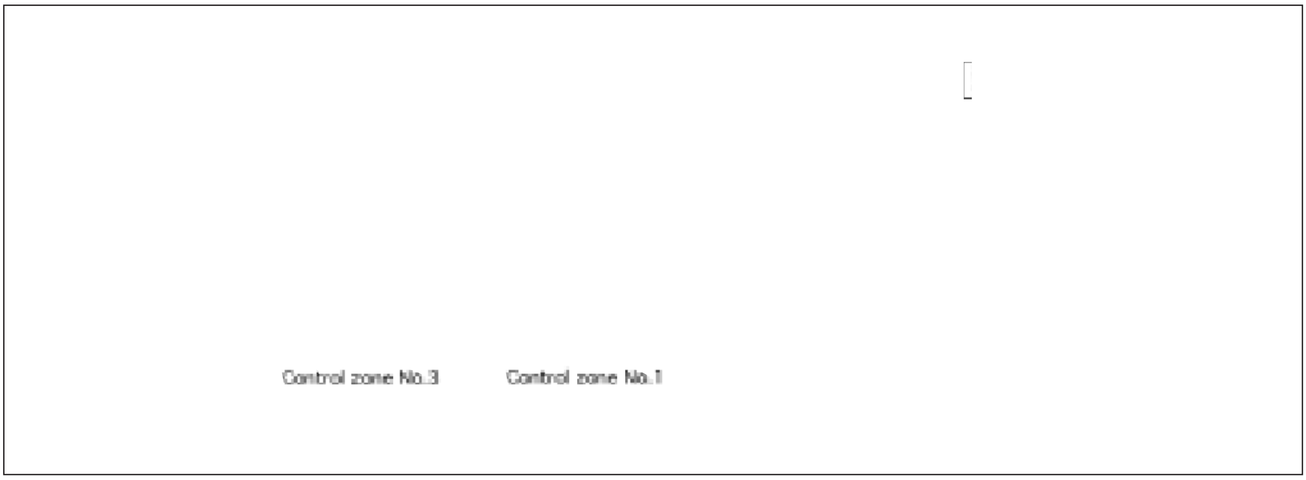


Fig. 1. Section of gas-pumping plant No.3 (GPA-3), pipe bends of the OOO “Volgotransgas” “Lyskovskaya” compressor plant.

Table 1

Test method name	Control zones		
	No. 1	No. 2	No. 3
Design	95	95	80
Strain measurement sensors	186	102	176
Barkhausen noise (Stresscan-500s)	136	95	300
Barkhausen noise (Intromat)	- 27	8	35
Barkhausen noise (Pion-01)	38	40	–
APFC testing	- 154	74	77

operational status were obtained based on the real pipe wall thickness and gas pressure. Stress values were obtained using strain gauges, and were calculated based on the difference of metal strain on the pipe surface the hot and cold condition, i.e. under gas pressure load and after its release.

From table 1 one can see that, according to the strain gauge readings, the stresses exceed the design values by a factor 1.5-2. Table 1 shows further the measurement results obtained using various types of instruments based on the magnetic Barkhausen effect. Stress data measured with these instruments in the same inspection zones differ abruptly from the strain gauge indications. In zone 1 even the stress sign is wrongly indicated.

Table 1 also shows stress measurement results carried out with an instrument based on the new measurement method of the material amplitude-phase frequency characteristics (APFC testing, ZAO "Contact NPC's" development, Saint-Petersburg, Russia). The instrument's readings for a signal penetration depth of 0.02 mm into the metal are shown.

The APFC testing instrument is an eddy current equipment based on the dependence of the metal's electric conductivity and permeability on crystal lattice strains under mechanical stress effect.

Based on the stress measurement results shown in table 1 one can draw the conclusion that none of the checked measurement systems has demonstrated a good correlation with design data.

In Figure 2 the measurement results concerning the stress-strain states along elbows and pipes using the APFC and the metal magnetic memory (MMM) method are compared. The measurements were carried out on the same elbows and in the same zones that were shown in Figure 1 and table 1.

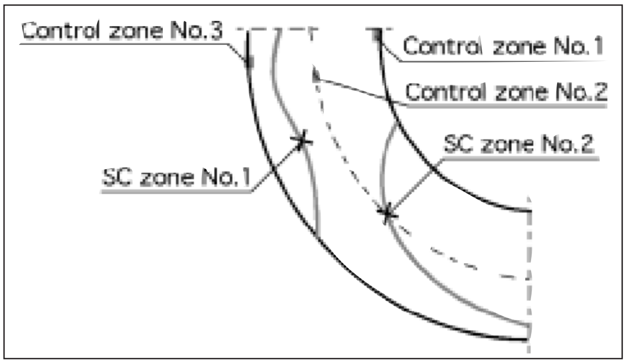
As a result of testing bends using MMM and appropriate instruments (TSC-1M type instrument – tester of stresses concentration, the development of Energodiagnostika Co. Ltd, Moscow, Russia), stress concentration zones (SC) were revealed, characterised by a local sign change of the measured residual magnetisation (refer to lines $H_p = 0$ in figure 2).

Figure 3 shows the results of H_p field measurements in the SC zones determined by MMM on the examined bends. It is seen from figure 3 that SC zones are characterised by an abrupt change in the H_p field measured simultaneously by three sensors according to a special method (refer to the upper part of the measured magnetic signatures, called "magnetogram"). According to the applied method, the field gradient dH_p/dx is automatically calculated (presented in the lower part of the magnetogram) and indicates the stress concentration level.

The magnetograms presented in Figure 3 show that the (dH_p/dx) field gradient in the SC zones reaches maximum values of 45-60 x 10^3A/m². According to the experience with MMM applications concerning gas pipelines, such field gradient values are conform to stress levels near the yield strength.

Figure 2 shows that $H_p = 0$ lines corresponding to stress concentration lines are not located near the inspection areas defined and proposed by the steering committee.

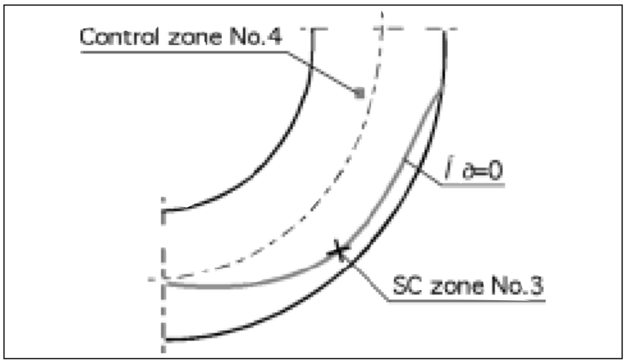
That same Figure 2 indicates the $H_p = 0$ lines according to the maximum stress concentration zones corre-



Control zone No. 1
$\square_m^{axl}$ = 130 MPa at h = 0.2 mm

Control zone No. 2
$\square_m^{axl}$ =124 MPa at h = 0.2 mm
$\square_m^{axl}$ =171 MPa at h = 0.02 mm

Control zone No. 3
$\square_m^{axl}$ = - 32 MPa at h = 0.2 mm



Control zone No. 4
$\square_m^{axl}$ = 77 MPa at h = 0.2 mm

In SC zone No. 3 at h = 0.2 mm
$\square_m^{axl}$ = 150 MPa
$\square_m^{\square}$ = 268 MPa

In SC zone No. 3 at h = 2 mm
$\square_m^{axl}$ = 105 MPa
$\square_m^{\square}$ = 110 MPa

Fig. 2. Measurement results of pipe elbows characterising the stress-strain- state by using APFC and MMM.

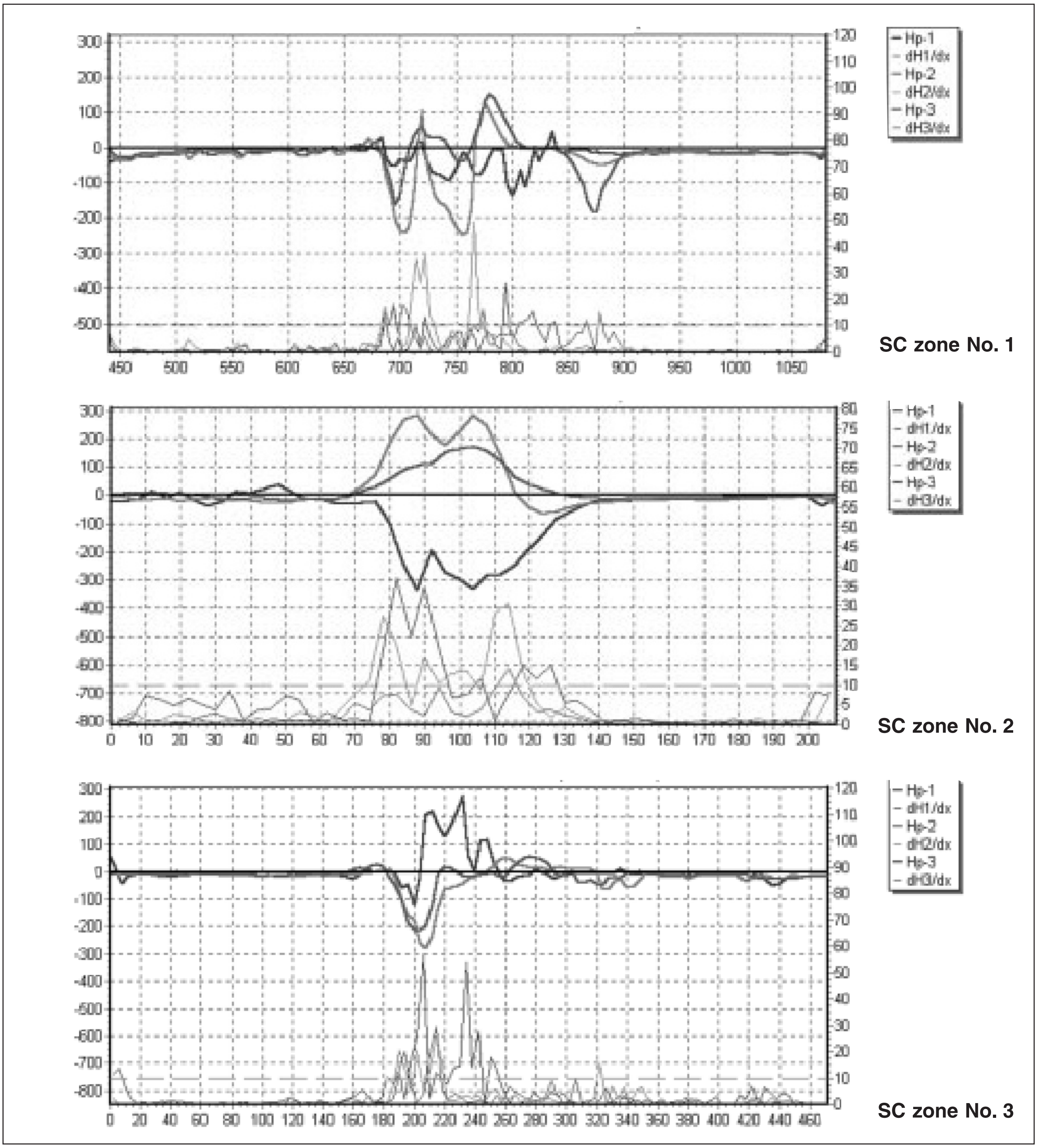


Fig. 3. Results of H_p magnetic field measurements in stress concentration zones (SC) determined by the metal magnetic memory method.

sponding to maximum field gradient values (SC zones No. 1, No. 2, No. 3).

From the stress measurement results using the APFC method, as shown in figure 2, the following conclusions can be made:

– A large scattering of the indicated stress values in all inspection areas defined by the steering committee.

– Approximately an agreement with the strain gauge readings in inspection zones No. 1 and No. 2 for the signal penetration depth of h = 0.2 mm.

– For the signal penetration depth of 0.02 mm the APFC instrument readings are obviously not reliable due to the influence of the metal surface roughness.

It should be noted that at the location of SC zone No. 3 (at the H_p = 0 line) and for a signal penetration depth of h = 0.2 mm, the measurement results of the APFC instrument showed good agreement with the MMM testing data. At the APFC sensor location along the H_p = 0 line in the maximum field gradient zone (SC zone No. 3) the instrument indicated a value of 150 MPa, and at the perpendicular sensor location – 268MPa.

The interpretation concerning the H_p = 0 line as the line of main stresses appearing on the surface of the pipe under workload influence is given elsewhere [2, 3].

In the course of laboratory and commercial tests it was determined that the H_p = 0 line corresponds to slip bands of high dislocation density formed along the wall thickness and the pipe section. It is known from the theory of strength and fracture mechanics that the development of the most harmful damage of a component is given at positions where locally the material is influenced by the main tensile stresses. Crack initiation can occur along directions perpendicular to the stress direction. Based on these assumptions, perpendicular to the $H_p = 0$ lines determined by MMM testing, the maximum tensile stresses are to be present on the gas pipelines surfaces, and along the lines there should be the maximum of stresses in the compression range.

Coming back to the measurement results using the APFC and MMM methods in SC zone No. 3 at the $H_p = 0$ line, a good evidence of the above mentioned interpretation can be stated. Perpendicular to the $H_p = 0$ line and according to the APFC and MMM data, the maximum stress value of 268MPa and the maximum magnetic field gradient value of $dH_p/dx = 60 \times 10^3$A/m^2 were obtained. Measuring along the $H_p = 0$ line, both methods indicated approximately values of half of this size (150MPa according to the APFC data and $dH_p/dx = 32 \times 10^3$A/m^2 according to MMM).

Certain results of the comparison of stress measurement techniques presented here show the high level of complexity of this objective.

The problem of stress inspection of real components in operation may be separated into two inspection tasks.

At first, all existing inspection methods and means are ineffective under practical application conditions due to metrological reasons, and second, these methods may only be applied effectively, in so far as the locations of stress concentration in the test object are predetermined.

It is known that metal deformation processes during the operation of the components are mainly conditioned by dislocation slipping and shear deformation. Here the metal fatigue damage accumulation can occur under low and high-cycle fatigue conditions. When in a general case the SC zones are unknown, it is an open question how good the conventional stress-strain-state measuring techniques can detect the relevant stress, i.e. the maximum stresses causing shear deformation.

It is obvious that only “passive” SSS diagnostics methods based on the use of energy radiated by the structure itself like acoustic emission or the MMM are the most suitable for practice.

The commission representing the interest of Gazprom, and according to the results of the comparison of various stress measurement methods and means, made the following conclusions:

– At the present stage none of the tested means for stress determination in the pipe body under actual compressor plant operating conditions, applied separately, is able to provide sufficient authentic data on the stress-strain-state.

– In order to reduce the inspection efforts concerning SSS measurements on pipelines, preliminary examinations by using scanning instruments based on the metal magnetic memory method should be applied.

– To evaluate the stress-strain-state of pipelines it is necessary not only to simply determine the stress size, but first to find zones influenced by the maximum stresses, and only then measure the size of these stresses. To solve this task it is recommended to use the MMM instruments in combination with other stress size measuring techniques.

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