SEASONAL DEFORMATION PROCESSES AT UNDERGROUND GAS STORAGE STATIONS

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Abstract
This article is concerned with the problem of establishing process equipment deformation regularities, in particular, gas engine compressors at the compressor station of underground gas storage facility in Bohorodchany due to ground topographic surface vertical movements caused by gas flooding into and extraction from the reservoir bed in different seasons. Values of longitudinal and lateral pitches of gas-engine-compressor units' foundation plates were determined using the results of topographic surface vertical movements monitoring. This provides an opportunity to predict adverse processes in gas engine compressors operation. On the other hand, this monitoring facilitates resolution of land resources sustainable and efficient use issues at underground gas storage territories.
Key words: deformations, gas engine compressors, topographic surface movements, monitoring.

Introduction

As regards the global ranking of underground gas storage capacities, Ukraine ranks second in Europe. Arrangements of underground gas storage facility (UGSF) and its process operation are connected with withdrawal of land areas for wells, process pipelines, compressor stations and other industrial facilities. In certain cases during gas storage facility operation cultivated land changes, ground surface subsidence, topsoil and groundwater regime disturbance, as well as wells, process piping and gas engine compressors operation disturbances occur. Hence, there is a need of UGSF safe operation monitoring. In particular, integrated monitoring is performed at such facilities consisting of geochemical, geophysical, geodetic and special industrial surveillances with nondestructive testing methods. One of these methods can be the method based on geodetic measurements results.

Research methodology and materials. Discussion and results

The research objective is determining quantitative indicators of gas engine compressor foundations' deformation parameters on the basis of geodetic measurements. The research methodology is based on the results of long-time geodetic measurements performed at Bohorodchany UGSF. The papers of A. Maznitsky, I. Perovych and R. Oleskiv most completely reveal the issues of UGSF safe operation in modern science and practice.

The issues related to ground surface technogenic movements' impact on underground gas storage facility tightness are considered in the research paper (Maznitsky, 1995). The publication of I. Perovych" Geodynamic processes of underground gas storage facilities territories" is dedicated to ground surface monitoring at UGSF. It contains established main regularities of ground surface movement, and mathematical approximation of vertical movements processes on the basis of geodetic measurements (Perovych, 2004). The article R. Oleskiv, V. Sai "Ground surface deformation at underground gas storage facilities in Ukraine" reveals research related to establishing regularities of gas storage facility roof movements' impact on deformation parameters of rocks, casing tubes and production tubing in production wells bores. Bohorodchany UGSF, which is one the largest in Western Ukraine, was chosen as pilot facility (Oleskiv, Sai, 2015).

Special geodetic network was built at UGSF territory consisting of primary level Line 1 with total length of 6.1 km, based on two bunches of support benchmarks equipped beyond the reservoir bed boundary. The first group of support benchmarks include RP 1, RP 2 and RP 3, and the second group include RP 4, RP 5, and RP 6. Support benchmarks' groups are laid into the basement rocks (Fig. 1).

Two additional level lines were arranged in order to determine an aggregate picture of ground surface vertical movements throughout UGSF territory: Line 2 and Line 3. Level Line 2 is supported by operating benchmarks RP 157 and RP 53 of level Line 1. This level line is used for determining vertical shifts of the ground surface, the well mouths, as well as for distributing the common system of heights upon observation over vertical movements of engineering buildings, utilities, process equipment and gas compressor units.

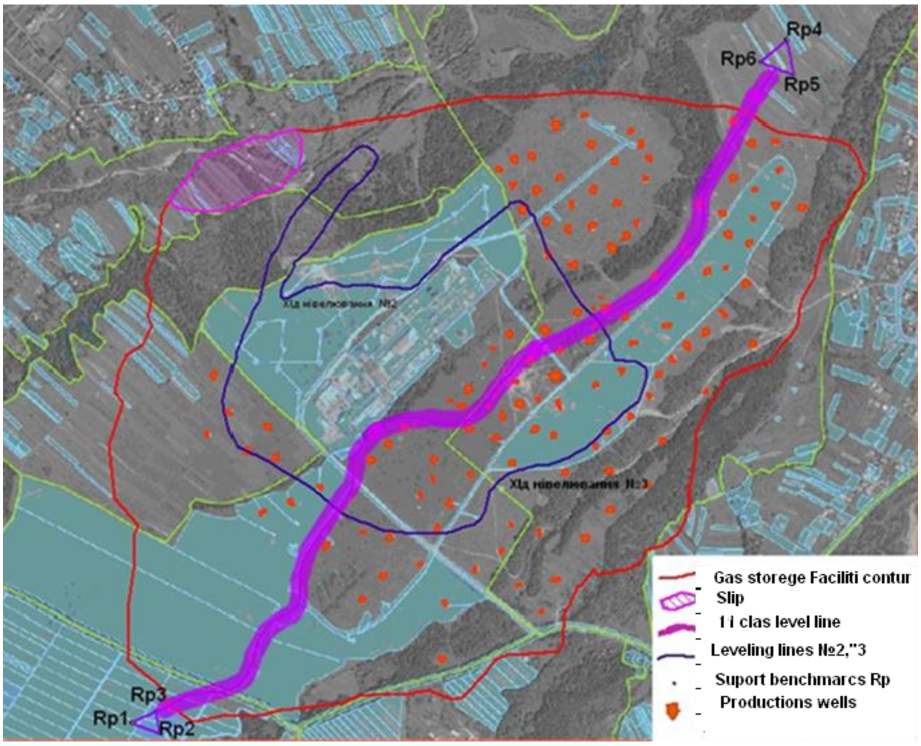

Fig. 1. Vertical geodetic control network diagram

Level Line 3 as well as 2, are supported by operating benchmarks RP 157 and RP 53 and used for determining vertical movements of the ground surface and wells.

According to the existing requirements, heights of operating benchmarks were determined by second-order levelling method.

Stability of benchmarks' base (bunches of support benchmarks) was determined by V. Runov's method.

Eleven series of observations were performed at this UGSF in total, associated with two boundary processes of UGSF operation. The first boundary observation process is carried out after full gas flooding into the reservoir bed (autumn), the second one is made after full gas extraction from the reservoir bed (spring). Therefore, heights of operating benchmarks obtained after geodetic measurements processing will represent dynamics of vertical movements to the full extent.

The mean square exceeding error per 1 km of line was measured for each series of observations

$$m_{1km} = \sqrt{\eta^2 + \tau^2} \quad (1)$$

where η - a random error,

τ - a constant error.

Based on the results of calculation in all series of observations $m_{1km} \langle 5mm$, that corresponds to the requirements of second - order levelling.

Using the data of UGSF roof movements' average values calculations, the chart of operating benchmarks' vertical movements was provided (Fig. 2).

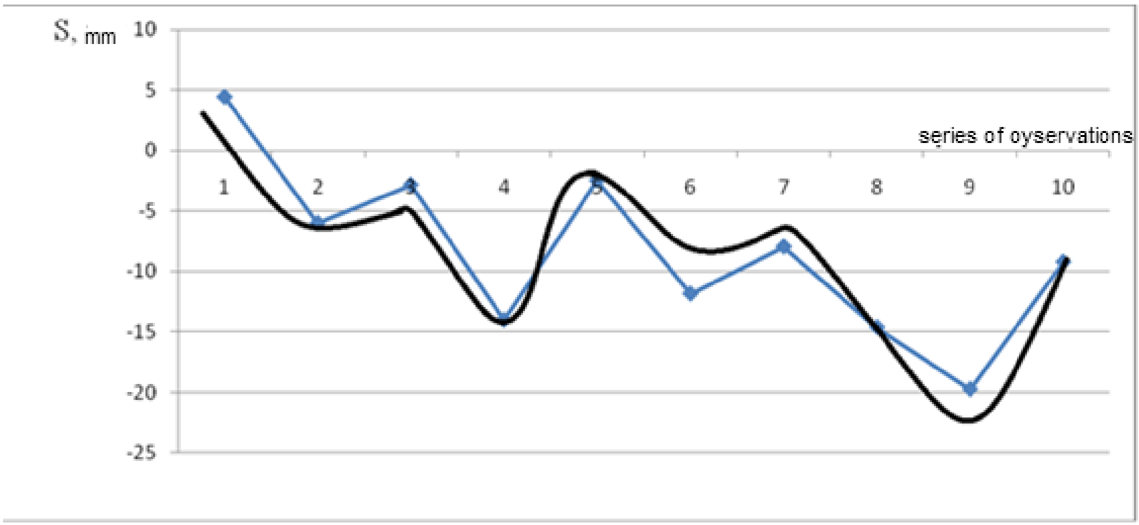

Fig. 2. UGSF roof vertical movements

Vertical movements' approximation function is the following:

$$\Delta S(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + \sum_{j-1}^{n} \left[A_j \cos(jt) + B_j \sin(jt) \right] \qquad (2)$$

where $a_0, a_1, a_2, a_3 \ldots$, A_j, B_j – empirical coefficients,

t – forecast period.

Data on vertical movements of the well mouths upon full load of UGSF reservoir bed and gas extraction present some features of interest (Fig. 3).

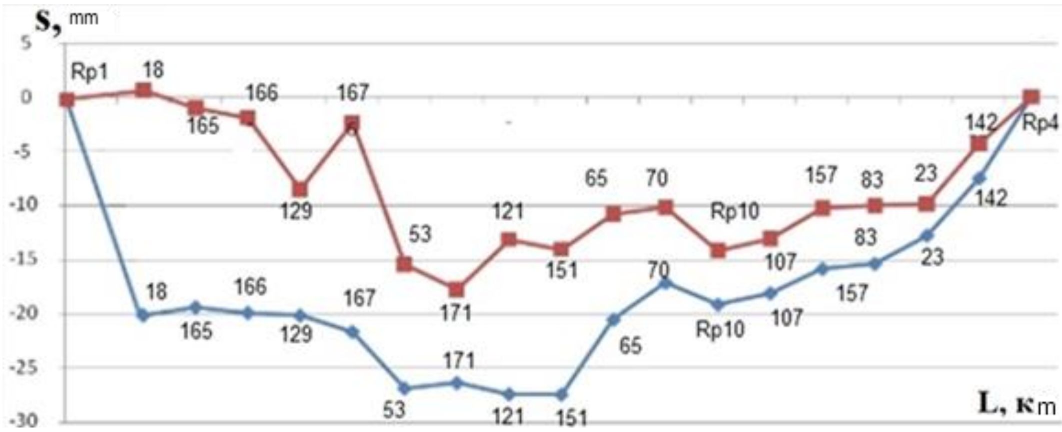

Fig. 3. Vertical movements of well mouths by level line 1

Analysis of the obtained results allows to make a conclusion that the well mouths are lowered upon gas extraction, and flow up upon loading. This phenomenon has a cyclical pattern and a negative impact on UGSF operation process. Moreover, the maximum range of movements is at UGSF center and the minimum one is at its edges.

A special attention in UGSF safe operation system shall be paid to determining deformation parameters of engineering buildings and gas engine compressors. For this purpose special bench marks were installed at supporting columns of engineering buildings, foundation plates of gas engine compressors and engineering elements of compressor shop inlet and outlet piping. High-altitude position of the mentioned marks was made under the second-order levelling program.

It should be noted that there are six gas engine compressors (GEC) in the compressor shop, and bench marks were laid in foundation plates of each GEC along the foundation edges. Therefore, four marks are installed in each plate. Average values of GEC foundations' vertical movements, as well as values of longitudinal and lateral pitches for the observation period are provided below (Table 1).

Table 1

Gas engine compressor foundations deformation

GEC number	Vertical movements, mm	Pitches, mm/m	
		Longitudinal	Lateral
1	+12.3	+0.20	+0.54
2	+8.4	-0.28	-0.21
3	+9.8	-0.19	+0.96
4	+10.2	-0.16	-0.21
5	+9.8	-0.15	-0.05
6	+8.6	+0.16	-0.02

Foundation vertical movements for each GEC were calculated by the formula:

$$\Delta S = H_c^{\circ} - H_c^{k} \quad (3)$$

Where $H_c^{\circ}; H_c^{k}$ – average value of heights from four bench marks in the initial and final measuremenal series.

Longitudinal and lateral pitches of foundation plates for separate GEC are calculated by the formula

$$k_{1,2} = \frac{\Delta h_{1,2}}{l_{1,2}} \quad (4)$$

Where $k_{1.2}$ – pitch in longitudinal (1) and lateral (2) directions of foundation plate,

$\Delta h_{1,2}$ – average value of difference in bench marks exceeding in longitudinal and lateral directions, mm,

$l_{1,2}$ – average distance between the bench marks in longitudinal and lateral directions, m.

The analysis of the results provided in the table allows to make a conclusion that vertical movements of all foundation plates have a positive value that indicates the buckling of ground surface at the compressor station territory in the central part of UGSF.

Foundation plates pitches for various GEC differ both by value and direction (+; - signs). The most adverse for operation are lateral pitch of foundation plate of GEC № 3 with the size of 0.96 mm/m and pitch of GEC No. 1 with size of 0.54 mm/m. These pitches can result in GEC vibration, and possibly, in GEC bearings breakdown that will require special engineering operations.

Conclusions

The specified research reflects a real picture of ground surface geodynamic movements of operated underground gas storage facilities. It was established that dynamics of ground surface and process equipment vertical movements has a definite cyclical pattern connected with UGSF operation conditions.

Deformation parameters of gas engines compressors' foundation plates were determined on the basis of processing of geodetic measurements. This is an important constituent part of general methods of UGSF safe operation nondestructive testing.

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