Change of magnetic properties of metal in the zone of stress concentrator

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Abstract. Studies show that there are certain problems in assessing the stress-strain state of structures by magnetic control methods, so it is necessary to carry out additional theoretical and experimental studies of magnetic parameters on standard samples from structural steels, which will help to reduce uncertainty of magnetic control results. In operation, dependence of intensity of own magnetic field of scattering in eight directions is established from concentrator of stresses at tension of cylindrical sample with artificially created concentrators of stresses in the form of overcooler with diameter of 2 mm from steel C 20 in elastic area. The analysis of the obtained dependencies revealed a change in the intensity distribution of the own magnetic field of metal scattering in the vicinity of the stress concentrator. In general, the distribution of the strength of the intrinsic magnetic field of the metal scattering in the zone of the stress concentrator tends to increase when the stresses are removed from the concentrator, but there are areas where the strength of the intrinsic magnetic field of the metal scattering is reduced when the stress is removed from the concentrator, which may indicate an intended fracture zone. There are no sharp changes in the intensity values of the own magnetic field of metal scattering at increase of tension load in the elastic region.

1 Introduction

The efficiency of modern oil and gas enterprises is largely determined by the safety of operation of technological pipeline systems, which depends on their operational reliability and durability. However, long-term impact of structural-process and operational factors leads to reduction of reliability and safe operation of pipelines, which leads to failure of operability and subsequent destruction. In order to detect and eliminate damages in a timely manner, a stress-strain state is evaluated and stress concentration zones are identified. Many years of research have shown that stress concentrator zones are the primary sources of the beginning of the metal destruction process. In these zones there are processes unfavourable to the structures (disturbances of continuity, corrosion, plastic deformations, welded joints, etc.) [1].

The modern development of methods and means of ensuring industrial safety of oil and gas facilities and the achievements achieved at the same time do not reduce the number of accidents and incidents on pipeline systems and related environmental problems of a man-made nature, which indicates the need for further more detailed study and improvement. Among the current methods of obtaining reliable information on the technical state of an object, non-destructive test methods are most used, which are based on correlation of structurally sensitive parameters of metal from the value of mechanical stress.
In order to obtain reliable information on the technical state of pipelines during operation, it is advisable to detect not only macroscopic defects of continuity, but also to monitor the stressed-deformed state of the material with detection of stress concentration zones in order to ensure the required level of safe use of pipeline transport. Therefore, obtaining additional data on change of physical and mechanical properties of metal in the vicinity of zones of stress concentrators during operation is relevant.

2. Methods of control of stress-strain state of oil refining equipment with identification of zones of stress concentrators

Analysis of various methods of determining the acting stresses in the equipment material, which are based on different physical principles, having their advantages and disadvantages, revealed that magnetic methods of non-destructive testing when assessing the stress-deformed state of the oil and gas equipment material have the greatest efficiency in field operation due to high productivity, safety and economy [2].

Studies of the intense deformed state (IDS) of metal by magnetic control methods were carried out by many domestic and foreign authors, Among which it is necessary to highlight the works of Manitski V. V. [2, 3, 4, 8], Dubova A.A. [5, 6, 7] and Vlasova V.T. [7], Wildanova R.G., Zagidullina R.V. [8], John WILSON Gui Yun TIAN, Simon BARRANS [9], Shougao ZhU, Ping WANG, Gui Yun TIAN, Haitao WANG [10], Aginea R.V. [11,12], etc.

Therefore, the use of magnetic control methods in IDS estimation is relevant.

Evaluation of metal IDSV by magnetic methods to date is carried out on the basis of various magnetic indices: anisotropy of coercive force (ACF) [11, 12], magnetic permeability and magnetic susceptibility [13], intensity of own magnetic field of scattering (MSF) [14-21], coercive force [22, 23]. Measurement of the intensity of the own magnetic field of metal scattering by the method of magnetic memory of metal does not require preliminary preparation and magnetization of the measured zone, so the work carried out studies to detect the dependence of change of the intensity of the own magnetic field of metal scattering (MSF) in the zone of the stress concentrator (SC) during sample stretching.

3. Change of magnetic field intensity of metal scattering in the zone of stress concentrator at change of stress-strain state

Studies were carried out on cylindrical samples of steel 20 cut from an electric welded pipe with a diameter of 57 mm, a length of the sample of 300 mm, a thickness of 3 mm with artificially created stress concentrators in the form of an overdrill with a diameter of 2 mm and a depth of 2 mm. The stress concentrator is located 150 mm from the edge of the sample (figure 1).

![Figure 1. Samples.](image)

The samples were mounted in the grips of the IR 5113-100 dynamometer machine and loaded in the elastic region to a load of 5 kN in 1 kN pitch.
In the theory of strength, the uniaxial stress state of the metal is estimated by an equivalent mechanical stress, the value of which is compared with the permissible mechanical stress set for the metal in the uniaxial stress state [24, 25, 26]. Total effective mechanical stress of metal in flat stressed state (in 4 theory of strength) [26]:

$$\sigma_{ef} = \sqrt{(\sigma_x + \sigma_{x0})^2 + (\sigma_y + \sigma_{y0})^2 - 2 \cdot \eta \cdot (\sigma_x + \sigma_{x0}) \cdot (\sigma_y + \sigma_{y0})},$$

(1)

where $\sigma_x$, $\sigma_y$ — main mechanical stresses acting in the metal plane;
$\sigma_{x0}$, $\sigma_{y0}$ — residual mechanical stresses in the metal plane;
$\eta$ — poisson ratio (for structural steels $\eta = 0.29$).

The own magnetic field of scattering intensity was measured by the IKN-2M-8 instrument in the vicinity of the voltage concentrator in eight directions (figure 2). Normal and tangential components of SMDS intensity were recorded, then the resulting own magnetic field of scattering intensity was calculated by formula [5]:

$$H_p = \sqrt{H_n^2 + H_t^2},$$

(2)

where $H_n$ - normal component of tension own magnetic scattering field, A/m;
$H_t$ - tangential component of tension own magnetic scattering field intensity, A/m.

Measurement results are shown in figure 3.
Dependency analysis (figure 3) revealed a different pattern distribution of the resulting own magnetic field of scattering intensity in each direction from the stress concentrator. The highest values are observed in the upper directions 1, 2 and 8. But for directions 1, 2, 3, 4, 7, 8 there is the same distribution of own magnetic field of scattering intensity with linear increase at distance from the voltage concentrator. Significant differences are detected for directions 5 and 6, which tend to decrease, which may indicate a change in direction of the own magnetic field of scattering intensity vectors. In this direction, the sample will subsequently begin to collapse [19]. To confirm this result, additional studies must be carried out with sample destruction.

The change in the resultant intensity of the own magnetic field of scattering metal in the absence of load indicates that magnetic control methods can reveal the concentration zone of the stress of the structure in the unloaded state of the structure. However, it is very difficult to predict the load behavior of the stress concentrator, i.e., if there may be several potential fracture areas in the material in the initial state, only one will remain after the start of loading [19]. Therefore, it is advisable to carry out studies to detect changes in magnetic properties in zones of metal stress concentrators during loading.

4. Conclusions
In order to increase the reliability of the obtained data when assessing the stress-strain state in the materials of the equipment, additional studies of magnetic parameters from the influence of load factors in the zones of stress concentrators are necessary.
Studies have shown that in the material of the cylindrical own magnetic field of scattering, when stretched in the elastic region, non-uniform changes in the intensity of the own magnetic field of scattering occur in the vicinity of the stress concentrator zones, from which changes it is possible to determine the intended fracture zone.

References
[1] Kireev D M 2002 Ensuring safe operation of a branched network of underground process pipelines (Ufa) p 136
[2] Kluev V et al. 2004 Nondestructive test: reference: Magnetic control methods Mechanical engineering 7(6) 832
[3] Zaharov In A, Besludko G Ya and Mugitski V F 2008 Coercitimeters with mobile magnetic device Control. Diagnostics 1 6-8
[4] Zakharov In A, Borovkova M A, Komarov In A and Mugitski V F 1992 Influence of external stresses on coercive force of carbon steels Flaw detection 1 41-6
[5] Dubov A A and Dubov Al A 2003 Method of monitoring the stressed-deformed state of the article by magnetic fields of scattering Pat. The Russian Federation No. 2207530 (Moscow: Rospatent)
[6] Dubov A, Dubov Al A and Kolovnikov C M 2008 Magnetic Metal Memory Method and Control Devices Tutorial (Moscow: TISSO CJSC) p 364
[7] Vlasov B T and Dubov A 2004 Physical Foundations of Magnetic Metal Memory Method (Moscow: TISSO CJSC) p 424
[8] Zagidulin R B, Mugitski V F and Zagidulin T R 2007 Calculation of the field of residual magnetization of the deformed steel plate Journal of the University of Bashkortostan 2 12-4
[9] Wilson J, Tian G Y and Barrans S 2006 Residual Magnetic Field Sensing for Stress Measurement and Defect Detection ECNDT September (Germany: Berlin) pp 1-9 Retrieved from: http://www.ndt.net/article/ecndt2006/doc/We.4.2.1.pdf
[10] Zhu S, Wang P, Tian G Y and Wang H 2008 Metal Magnetic Memory Testing Technique for Stress Measurement 17th World Conf. on Nondestructive Testing Oct (Shanghai: China) pp 25-8
[11] Aginei R B, Kuzbozhev A C and Andronov I H 2007 Algorithm for determination of mechanical stresses in pipelines metal by coercive force of metal Oil and Gas Case 5(1) 235-40
[12] Aginei R B, Kuzbozhev A C, Teplinsky U A and Andronov I H 2007 Taking into account the state of the material of the structure when determining mechanical stresses by the coercive method Control Diagnostic 5 6-8
[13] Sandovsky B A and Feinschminth E M 2013 Study of magnetic permeability of steel samples in a uniform variable field at elastic strain on extension Of the Earth. higher education institutions. Instrument-making 56(3) 58-64
[14] Condrashova O G, Naumkin E A and Kuzeev I R 2006 Determining the resource of safe operation of oil and gas equipment by assessing adaptive properties of metal by changing its magnetic characteristics World community: problems and solutions 19 16-26
[15] Naumkin E A, Kuzeev I R, Condrasova O G and Prokhorov A E 2004 Change of magnetic parameters at accumulation of fatigue damage in steel 09Г2C World community: problems and ways to solve 16 106-11
[16] Kuzeev I R, Naumkin E A and Condrashova O G 2006 Evaluation of adaptive properties of metal by change of its magnetic characteristics for determination of resource of safe operation of oil and gas equipment Electronic scientific journal Oil and gas case 1(4) 124-33
[17] Haibullina L B and Vasilyev B 2013 Impact of stress-strain state of shell structure on magnetic characteristics of Oil and gas: electron. scie. journal. 5 376-84
[18] Haibullina L B and Naumkin E A 2013 Influence of stress-strain state of steel shell structure 20 on change of permanent magnetic field intensity Current problems of technical, natural and humanities 7 240-3
[19] Naumkin E A 2011 Methodology for forecasting the life of oil and gas equipment operated under cyclic loading conditions at the stage of design and operation (Ufa)

[20] Naumkin E A, Condashova O G, Prokhorov A E and Sharipkulova A T 2005 Influence of mechanical deformation on change of magnetic state of materials Engineering, innovation, investments 6 235

[21] Gumer R S et al. 2005 Control of stressed-deformed state of oil pipelines by magnetic memory of metal Problems of collection, preparation and transportation of oil and oil products 64 11-4

[22] Gorkunov E S and Zakharov B A 1995 Coercitometers with attachment magnetic devices (overview) Flaw detection 8 69-88

[23] Zaharov In A, Besludko G Ya and Mugitski V F 2008 Coercitometers with mobile magnetic device Control. Diagnostics 1 13-4

[24] GOST 1497-84 1984 Metals. Tensile test methods (Moscow: Standard) 28 p

[25] Leibo A H 1963 Petroleum Refinery Mechanic Reference Book. grant (Moscow: Science) p 840

[26] Darkov A B and Shapiro G C 1989 Resistance Materials (Moscow: Higher School) p 624