Pipeline condition monitoring on the basis of fiber optics

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ABSTRACT: Two perspective methods of monitoring of safety oil-and the gas pipelines, intended for prevention of emergencies are considered. It is shown, that extended fiber-optical sensors on the basis of single-fiber multimodes interferometers allow to carry out the integrated control of process of occurrence of cracks over pipelines and to make an estimation of the sizes of cracks. An another way of the monitoring based on use of threshold fiber-optical sensors and time-domain reflectometry, will allow with a high degree of reliability and with high accuracy to determine places of occurrence of cracks in pipelines. Both ways are complementary and show expediency of their sharing for monitoring a safety of pipelines and other designs.

1 INTRODUCTION

A number of industries constantly requires development of a reliable quality monitoring of serviceability and durability of used and created large-sized designs: vessels of a high pressure, pipelines, turbines of hydrostations, courts, oil- and gas extracting systems and oil platforms, planes, high-rise buildings and constructions, etc. [1-2].

Now development of modern economy of all countries of the world is inextricably related with oil and gas expanded use and refining . It is caused by that:

- The given kind of raw material is cheap enough and accessible;
- On continent and on a shelf of the seas still there are big stocks of oil and gas;
- The problem of transportation of this kind of raw material is solved simple transportation use of pipelines.

As result, we can ascertain the following facts:

- In the world the tendency of increase in creation complex both expensive oil-and gas complexes and platforms on a shelf is observed;
- The number of consumers of oil and gas steadily grows;
- There is a creation of the extended both ramified inside and transcontinental network extended both ramified inside oil-and gas pipelines.

Alongside with it there is also a number of complex problems among which it is necessary to note that:

- The majority of deposits are in the hard-to-reach areas and outlying places that demands creation of the extended both ramified networks oil- and the gas pipelines maintained in a complex environment;
- Are observed significant loss of transfer production, also environmental contamination as even insignificant cracks of pipelines result to bleeding oil and gas;
- At significant cracks or breaks of pipelines there are failures and, as consequence, significant material losses, damage of the expensive equipment, destruction of people, infringement of ecology.
- New and difficult problems are put with practice of extraction and transportation of oil and gas on continent and on a shelf of the seas. Huge platforms, which cost it is estimated hundreds millions dollars, should work in conditions of absolute stability, durability and reliability. Destruction of designs making them and places of their connections as a result of wave and wind loadings and corrosion are capable to result not only in significant financial losses, but also to destruction of people and ecological accidents.

Destruction of pipelines, platforms and producing complexes is caused by a number of the reasons: occurrence and development of cracks (including fatigue) and joint action of loadings and -active corrosion environments: aggressive influence of subsoil waters, thawing of a snow, rains and other nature-climatic factors.

Table 1. Pipelines characteristics

The projected standard of length of oil-and gas pipe main	(10-12) or (18-24), m
Connection	Welding in blocks
Technological protection of welding seams	A covering of joints an anticorrosive film
Stacking of pipelines	As a rule, in trenches
Working pressure	7,5, MPa
Distance between compressor stations	100-150, km
Average number of welded seams pipes between compressor stations	8333 – 12500

In Table 1 characteristic numerical characteristics builded both maintained oil-and gas pipelines, showing integrated approach and scale of systems of an oil-and-gas complex are resulted [3].

As at any stage of work with oil and gas, be it extraction, transportation or use, always there is a risk of their outflow, ignition and explosion, it makes extremely important a problem of development of remote and precision methods of studying and the control of various mechanisms and processes of destruction of various designs, and also diagnosing of a condition and integrity of the main oil and gas pipelines and the used process equipment in difficult operational conditions and on significant distances.

Modern means of diagnostics in an oil-and-gas complex widely use optical, electric, magnitodynamics, ultrasound, etc. gauges of physical fields parameters, and also hardware of the control. Significant progress of techniques of fiber-optical communication lines (FOCL) has led to occurrence of a new direction in metrology - fiber-optical sensors (FOS) of physical fields parameters. The combination of the advanced techniques and technology FOCL to modern achievements in areas opto- and microelectronics have opened wide prospects for creation of various gauges of physical fields parameters which on a number of the characteristics favorably differ from other analogues executed on other element base. Further, such advantages of FOS, as: high sensitivity, speed and noise immunity, the small sizes and weight, combination one element of functions of transmitting and sensitive environments, and also ample opportunities on their interface to a modern communication facility and computers have created preconditions for creation of essentially new ramified measuring systems [4].

Theme of the present report is discussion of two optoelectronics methods of remote monitoring of developments of the cracks resulting in destruction of designs and elements oil-and gas pipelines arising as a result of mechanical and climatic influence on them.

2 EXTENDED INTERFEROMETRIC FIBER-OPTICAL SENSORS FOR MONITORING INTEGRATED DEFORMATIONS OF OIL-AND-GAS DESIGNS AND PROCESSES OF FORMATION IN THEM OF CRACKS

Based on design features, all fiber-optical sensors can be divided into two types: point and extended (Fig. 1). Point FOS (Fig. 1á) are intended to make measurement of physical fields parameters in the certain point of space. Extended FOS (Fig.1в) make measurements along the certain trajectory of stacking of a sensitive element, summarizing signals from various points [4].

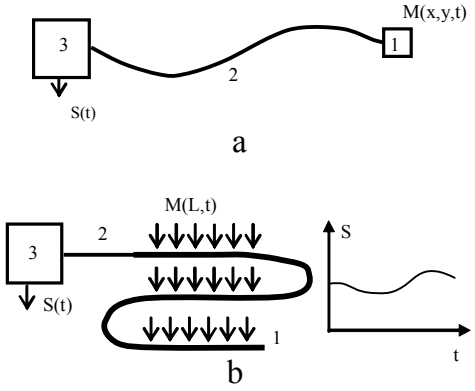

Figure 1. a) Scheme of Point FOS; b) Scheme of Extended FOS.
1- sensitive element; 2-transmitting optical signal FOCL; 3-electronic block.

Properly from Fig.1, irrespective of type, the FOS will consist of three mainframes: 1-the sensitive element (SE) intended for recognition of result of external physical field influence on fiber- optical waveguide (FOW) and its transformations to change of one parameters light wave guided in FOW; 2-tolerant to external influence transmitting radiation of the optical fiber communication line and 3- the optoelectronic block. Into structure of the block 3, as a rule, enter: a source of radiation, the device of an input /output of radiation in FOW, a photodetector, system of processing of the registered light signals, intended for transformation of the last to a target electric signal with the set parameters, or forming a vision.

For last 20 years various designs of extended FOS which allow to measure with high accuracy practically all known physical parameters have been offered and investigated. Our efforts have been directed on development of physical principles of creation of the most sensitive - phase FOS as the

techniques of optical intrferometry allows to make measurements of small variations of a phase of fashions **~10^{-8}** rad. [4], that potentially allows to register extremely small changes of mechanical conditions of designs. In the works we mainly were guided by one-fiber designs interferometers, as the most simple or the steadiest on to a uncontrollable influences of an environment: one-fiber multimode interferometers (OFMI).

OFMI optical scheme contains multimode OFW only [5-7] in which there is modes crosstalk an interference of light waves. OFMI registers change of a difference of phases between the modes guided in OFW, caused by external physical influences on OFW. The complex of the followings executed in works has allowed to establish, that the value of modes crosstalk differences of phases guided in FOW light radiations is defined basically by lengthening FOW and practically does not depend on other factors of deformation, for example, a bend of an FOW. In a problem of designing of FOW it allows to consider a problem about measurement of parameters of deformation fields by measuring transducer on basis OFMI in terms of absolute lengthening sensitive site FOW.

Result of an interference of the big number of fashions with various phase velocities is high sensitivity of FOS basis OFMI. Unfortunately such modes crosstalk the interference is accompanied by occurrence complex and high contrast speckle structure of a field of radiation, that strongly complicates processing such signals. Studying of character of change speckle pattern of a field of radiation from OFMI [8-10] has allowed to develop correlation principles of processing of optical signals such interferometers using principles of a peak and holographic spatial filtration . Carried out theoretically and experimental researches [4] have allowed to establish, that power of a correlation signal received on an output of both types of filters, is function of the maximal additional difference of phases ($\Delta\Phi_{\max}(t)$) between directed fashions in OFMI: $P_{out}(t) \propto \sin c^2(\Delta\Phi_{\max}(t)/2)$.

In result the metrological characteristic of FOS on OFMI base are determined by numerical aperture, length and material type of used FOW. By mince of this parameters selection it is possible to achieve of OFMI sensitivity threshold on to its axial deformation as (10^{-4} – 10) με and measurements dynamical range in static regime as $(30 \div 40)$ dB.

The developed principles of a amplitude and holographic correlation filtration of a speckle-pattern of a radiation field from SFMI have been based the created methods of an adaptive spatial filtration of signals SFMI . It also has allowed to solve a problem low-frequency fading of the interference signal, caused by casual uncontrollable influences, such as: drift of temperature, technological vibrations, casual mechanical influences, drift of frequency of the laser, etc. [10]. It has made possible their operation in real conditions. For realization of a method of adaptive spatial filtration (ASF) the phenomenon fanning, arising owing to nonlinear optical interaction of light waves on dynamic holograms in photorefractive crystals $Bi_{12}TiO_{20}$ (BTO) was used.

The result of a competition of plural scattered waves in BTO conducts to occurrence of characteristic time of recording of a stationary set volume dynamic diffraction gratings of the correlation filter is illustrated by experimental dependence of response ASF on pulse influence on SFMI (fig. 2).

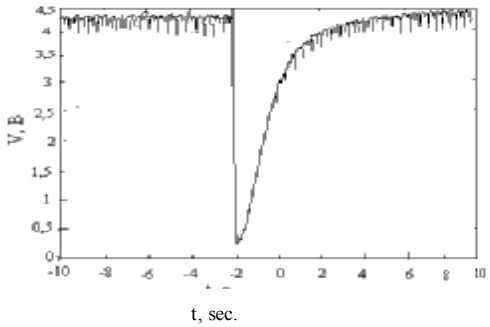

Figure2. The oscillogram of the response of the adaptive correlation dynamic filter on pulse influence on SFMI.

Therefore any fast changes ($\tau<\tau_R$) in a picture of a field of radiation from MFI on an input in BTO will not be reflected in a condition of the spatial filter that results in modulation of a output signal.

If changes will be slow ($\tau<\tau_R$) or rare the old correlation filter will be erased and will be generated new, corresponding to the changed spatial distribution of intensity of radiation to an input in BTO. In this case the output signal remain constant. As the constant of time of record of the correlation filter can change considerably enough at change of size of the external electric field enclosed to a crystal, structure and orientation BTO, it has opened an opportunity of management of characteristics of adaptive correlation spatial filters at realization of method BTO. On Fig. 3 experimental dependence of the amplitude-frequency characteristic such ASF is resulted. Measuring systems on the basis of such filters have been used for research of processes of

deformation composed materials in real time and in real conditions.

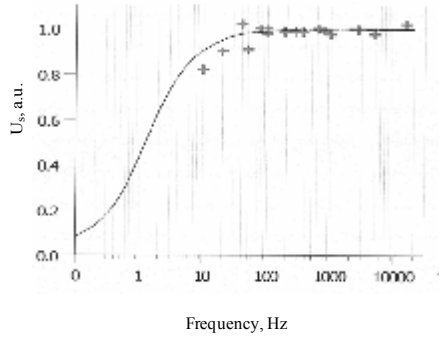

Figure 3. Theoretically and experimentally measured spectral characteristic of the adaptive spatial filter on basis BTO.

Due to the small sizes and the high flexibility, sensitive elements of extended FOS can easily take root into objects from composed materials, for example in concrete designs (fig. 4), without change of its mechanical characteristics.

It has been used for creation of the devices intended for studied of deformations of designs under influence of external loadings both in static, and in dynamic modes. On Fig. 5 results of change of a difference of phases between modes in extended FOS on a basis two-modes SFMI, arising owing to lengthening an optical path of a sensitive element of the gauge built - in the concrete beam subject to bending deformation are submitted [11].

At embedding extended FOS in a design from composed materials the opportunity of integrated monitoring and the analysis of process of formation of cracks arising.

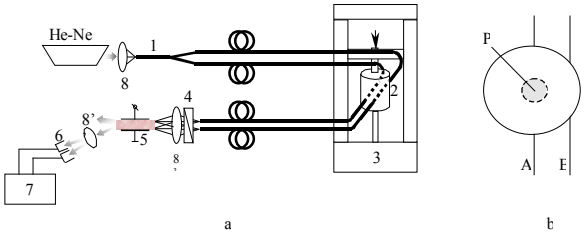

Figure 4. a) Experimental setup for processes of cracks arising in solid states monitoring (1- FOW. 2- solid states under investigation; 3 – catching mashin; 4- polarizer; 5 – BTO; 6- photodiode; 7- signals processing system.
b) Schema of FOS implantation in solid states.

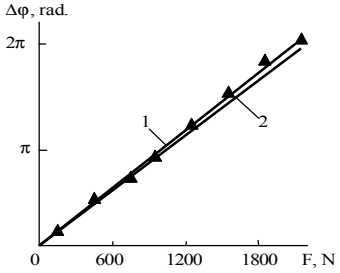

Figure 5. Dependence of a difference of phases between modes of two-modes SFMI as a function from size of loading on a design of a concrete beam. 1 - experiment, 2 - calculation.

On Fig. 6 the oscillogram of signals of extending FOS built - in in a concrete beam is resulted. Peaks on the oscillogram mark the moments of formation of cracks, and the width of peak appears an arising crack proportional to the size.

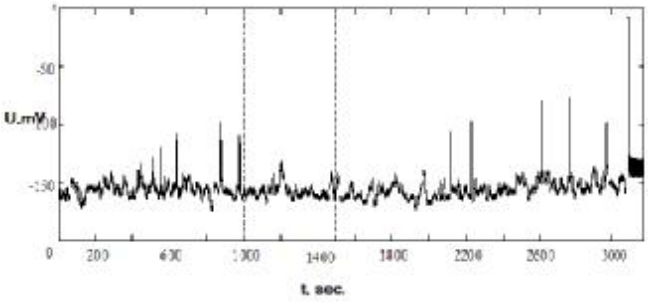

Figure 6. The time-dependence of signals extended FOS built - in composed material under loading.

3 SYSTEM OF THE REMOTE CONTROL OF PIPELINES CONDITION

At system engineering the remote continuous of safety control the extended pipelines, it is necessary to provide transfer on the long distances of the information on a condition of the big number of FOS of the control on to the main control center and information on a place of failure on to the technical repair items serving the controllable pipeline. As the measuring system should be extended (see. Tab. 1) in a normal condition of the pipeline FOS's should not bring significant losses in a transmitted signal. For the decision of this problem it was offered to create extended system of monitoring of a condition of pipelines as continuous FOCL in which the threshold FOS of breaks placed in especially dangerous places, as a rule, in places welded or flanged of connections of pipes (Fig.7) are included.

As at break welded, flanged and other types of connections of pipelines there is a moving one pipe

concerning another in this place there is a break of an FOW line (Fig.8). The fact and a point of break of a fiber-optical waveguide can be registered with help Optical Time Domain Reflectometer (OTDR). It allows fast and without the big expenses to carry out monitoring a safety condition of the pipeline on significant distances.

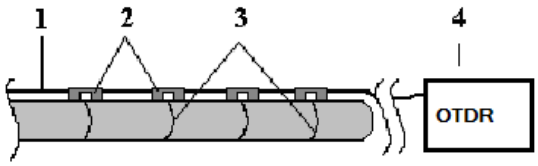

Figure 7. The circuit of system of monitoring: 1-FOCL; 2-threshold FOS; 3-connections of pipes; 4-OTDR.

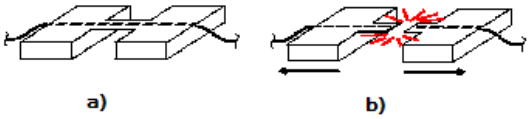

Figure 8. An illustration of a principle of work threshold FOS: a) a condition before formation of a crack; b) a condition after operation.

Sensitivity of threshold FOS on to the size of the formed crack or gap's value connections depends on type used FOW and the size of an cladding. In Table 2 an experimental values of the maximal sizes of operation of the threshold FOS, received for various diameters of polymeric FOW's cladding are represented.

Table 2. Threshold displacement

Threshold displacement (for FOW with diameter 125 µm), mm		
Fiber in a polymeric cladding in diameter of 1 mm	Fiber in a polymeric cladding in diameter of 0,25 mm	Fiber without a polymeric cladding in diameter of 0,125 mm.
0,932	0,557	0,068

On fig. 9 the photograph of damages put of pipeline with threshold FOS is showed. The reflectogram the place of damage which is posed on distance 1500m is showed on fig.10.

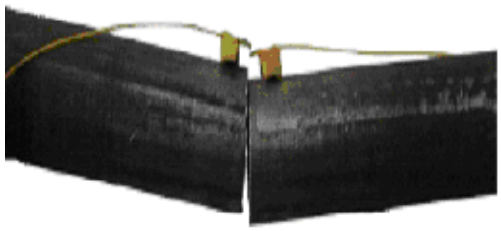

Figure 9. Photo of a place of break of a welded seam of pipeline together with worked threshold FOS.

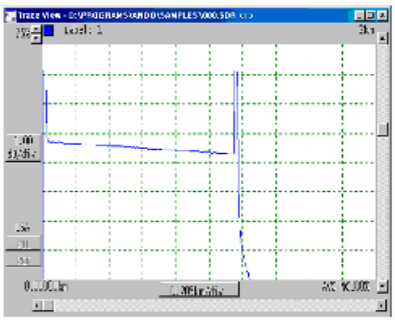

Figure 10. Reflectogramm of extended controlled line with the worked FOS.

Essentially important also it appears, that developed by us threshold FOS do not bring losses of optical capacity in FOCL, that allows to arrange in measuring system practically unlimited number of FOS along all extended pipeline and to supervise safety of everyone connections.

4 CONCLUSION

In the present work two perspective methods of monitoring of a condition oil-and the gas pipelins, intended for prevention of emergencies have been considered. As it has been shown, extended fiber-optical sensors on the basis of single-fiber multymode interferometers allow to carry out the integrated control of process of occurrence of cracks over pipelines and to make an estimation of the sizes of cracks. It has experimentally been established, that the minimal size of a registered crack can not exceed 10 microns. In this case the limit of the size resolution is defined types of a fiber- optical waveguide and quality of its connection or introduction in the controllable pipeline or a design. The another method of monitoring is based on use of threshold fiber-optical sensors and time-domain reflectometry. As it has been established, it allows from 100 % probability and with high accuracy to determine places of occurrence of cracks in pipelines and designs. Sensitivity of this method depends on

type of a used fiber optical waveguide and a material and the size of its protective cover. This method also can be used for an integrated estimation of cracks arising process in pipelines by means of measurement of value of power attenuation of the reflected signal.

Both ways are fireproof and allow to make the removed monitoring of a condition of pipelines and designs on distances up to 200 km. Inherently these methods are complementary and at monitoring pipelines and designs can be used as independently, and in common.

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REFERENCES

Proc. 3rd China-Japan-Us symposium on Structural Health Monitoring and Control./By Edition of HonganLi, Hui Li, Guoxin Wang. - Dalian: Dalian university of technology Press. 2004, p.369- 378.

Ishlinsky A.Yu. Mechanics: ideas, tasks, aaplications. - Moscow, “Science”, 1985.

Guleikova N. Pump iron.- Gazprom, №11, 2004, p.40-42.

Kulchin Yu.N. Distributed fiber-optic measuring systems. Moscow: “Fizmatlit”, 2001.

Kulchin Yu.N., Bikovsky Yu.A. et.al. Correlations reconstruction speckl pattrn in multimodes fiber-optical interferometer. – Quantum electronics, 1990, v.16,No. 8, p.1080-1083.

Kulchin Yu.N., Bikovsky Yu.A. et.al. Signals holography matched filtering in sensors based on multimodes fiber-optical interferometer. - Quantum electronics, 1990, v.17,No. 1, p.95-98.

Kulchin Yu.N., Bikovsky Yu.A. et.al. Amplitude spatial filtering for signals multimodes fiber-optical interferometer processing.- Quantum electronics, 1990, v.17,No. 10, p.1377-1378.

Kulchin Yu.N., Kamshilin A.A., Jaaskelainen T., Adaptive correlation filter for stabilization of interference fiber-optic sensors. // J. Appl. Phys, Lett, 1998, v.73, № 6, p. 705-707.

Kulchin Yu.N., Romashko R.V. et.al. Multichannels correlation filter based on photorefractiv crystal for evaluated speckls fields processing. J. Tech. Physics Lett., 2000, v/26, No. 12, p.23-27.

Kulchin Yu.N. Adaptive distributed 0ptoelectronic information-measuring systems.- Uspechi Physical Sciences.- 2003, v.173, No.8, -c.17-23.

Kulchin Yu.N., Vitrik O.B. et.al. Fiber-optical interferometry method for deformation of bildigs constructions investigation.- Izvestiya VUZ Bildering, 2001, No. 6, p. 113-117.