

## REMOTE CONTROL MEASURING SYSTEM BASED ON STRAIN SENSORS

Anatoliy Druzhynin, Yuriy Khoverko, Ihor Ostrovkyi, Roman Koretskyi, Stepan Nichkalo

Lviv Polytechnic National University  
druzh@polynet.lviv.ua

**Abstract:** The paper describes an automated wireless monitoring system developed for stress-strain state of main pipelines. Since the most damages occur in the main pipelines' areas of intense plastic deformation, their remote control in such areas is of significant interest, and one of the solutions to the problem is the proposed measuring system based on Si-whisker sensitive elements.

**Key words:** whisker, deformation, automated system.

### 1. Introduction

Due to intensive aging of main pipelines (MP) there arises a problem of integral methods improvement for their technical diagnostics [1]. The most incidents of pipeline refusals refer to the places of intensive plastic strain, occurring in overstrained zones of technical defects and defects of assembling (welding), in areas of intensive corrosion damages, etc [2,3]. Dynamic and static loads resulting from pipeline operation lead to damages of two main types, namely: cracklike and corrosive. The intensive damages can be caused by periodic testing by changing working pressure in a pipeline required by technical regulations [4].

The aim of the paper is to propose an alternative approach to pipelines control, particularly to change the existing normative rules on periodic testing of pipelines at loading of maximal pressure for permanent monitoring of pipeline state with the use of wireless sensor systems based on Si-tensoresistors.

### 2. Theoretical background

One can consider a regime of fluid flow in a pipeline. The regime depends on Reynolds number. In general, Reynolds number for fluid flow can be expressed by the following equation:

$$Re = \frac{\rho V d}{\mu} \quad (1)$$

where  $V$  is the flow velocity,  $d$  is the internal pipe diameter,  $\rho$  is the flow density,  $\mu$  is the dynamic flow viscosity. If Reynolds number is less than critic value  $Re < 2320$ , the regime of flow movement is laminar, but if  $Re > 2320$ , the regime becomes turbulent. In particular, for a 820 mm diameter pipe, intended for

transporting oil with kinematic viscosity of about  $\nu = 12-25$  cSt, the critical value for flow velocity while transiting to turbulence movement is of  $(4-8) \cdot 10^{-2}$  m/s. In fact, the oil velocity in arterial pipelines is usually 3-4 times greater than the critical turbulent transition value and can be  $\geq 1-3$  m/s. So, the fluid flow is turbulent.

The turbulent movement of the flow is known to be accompanied by pressure pulsation as well as local velocities. Such pressure pulsation can lead to pressure change of 10% from the working value and can be measured during permanent monitoring of the pipeline.

Another cause of pressure pulsation in a pipeline is related to irregular processes in the fluid flow. Those processes are caused by such operations as starting or stopping the pipeline, on/off turning of the units, complete or partial closure of valves, switching of tanks, pumping or dumping of the product, and other technological operations incurred in the transport of the product. As a result of such operations, any change in the flow velocity is accompanied by producing shock waves of increased pressure. An example of oil flow at density  $\rho_0$  and velocity  $V$  in a pipe of length  $L$  with an initial cross section area  $\omega_0$  is presented in Fig.1.

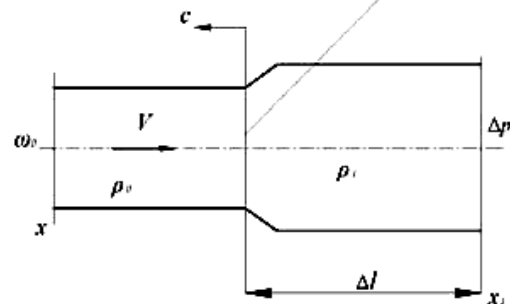


Fig. 1. Schematic spreading of shock wave in a pipeline accompanied by pressure increase

The oil flow can be described by Zhukovsky equation

$$\Delta p = \frac{\rho_0}{\Delta V c} \quad (2)$$

where  $\Delta p$  is the pressure boost due to the action of a shock wave,  $\Delta V$  is the value of velocity change. The

value  $c=\Delta l/\Delta t$  is the velocity of shock wave propagation in a pipeline with elastic parameters of the fluid and the pipe, where  $\Delta l$  is the length of a pipeline section, in which the fluid came to a stop and pressure and diameter of the pipe increased over the period  $\Delta t$ . In our case – for a stiff pipeline – the value  $c$  can be presented by the following equation:

$$c = \left(\frac{K}{\rho}\right)^{1/2} \quad (3)$$

where  $K$  is the modulus of elasticity for the pipe material,  $\rho$  is the fluid density in the wave of increased pressure.

Taking into account the equations (3) and (4) one can conclude that any change in the flow velocity in a pipe results in a proportional change in the fluid flow pressure. Thus, for a steel pipeline, the flow velocity can reach 1000 m/s, and 1 m/s velocity change causes 0,9 MPa pressure change. Shock waves arising in the pipe can spread over long distances, constantly attenuating by virtue of dissipation of mechanical energy. A certain correspondent change of surface strain creates certain loads, which can be expressed by the equation of mass balance in the perturbed part of the pipe:

$$\frac{\Delta V}{c} = \frac{\Delta \rho}{\rho_0} + \frac{\Delta \omega}{\omega_0} \quad (4)$$

Taking into account the condition of balance between the pressure in the pipe and ring strains arising in the pipe walls one obtains the following dependency for relative enlargement of the pipe cross section in the course of shock wave propagation:

$$\frac{\Delta \omega}{\omega_0} = \frac{d_0 \Delta p}{E \delta} \quad (5)$$

where  $d_0$  is the initial internal pipe diameter,  $E$  is Young's modulus of the pipe material,  $\delta$  is the pipe wall thickness.

Taking into account the equations (5) and (6) one can conclude that in arterial oil pipelines there is a essential pressure pulsation to be measured in the process of permanent monitoring.

### 3. Experimental basis.

For diagnostics of arterial pipelines a wireless measuring system of pressure pulsation has been developed. The main component of the system is a strain sensor based on a Si-tensoresistor made on whiskers. The general view of the strain sensor is shown in Fig. 2.



Fig. 2. General view of a strain sensor based on Si-whiskers

Tensoresistors on the basis of Si-whiskers differ from common discrete Si-tensoresistors by their unique mechanical properties, they allow measuring the dynamical and static loads on a wide amplitude range, and are workable at widened working temperature intervals – from cryogenic temperatures up to +350 °C. They are featured by flexible production technology with minimum waste of semiconducting materials [6]. The mechanical tests of the developed tensoresistors have showed that they can serve for more than  $10^7$  load/unload cycles with strains up to  $\pm 1 \cdot 10^{-3}$  r.u. without cracks and destruction. Tensoresistors on the basis of Si-whiskers stand tensile-compressive strain  $\varepsilon=5 \cdot 10^{-3}$  r.u. (0,5%). They can operate under harsh conditions (intense centripetal acceleration, vibration, overloading, shock acceleration). A tensoresistor designed on p-type Si-whiskers with diameters of about 30  $\mu\text{m}$  and boron concentration of about  $(1\div 5) \cdot 10^{18}$  has the most optimal characteristics at the temperature interval ranged between +20...+350 °C [5]. Its gauge factor at 20°C is equal to 100-140, when temperature resistance coefficient is about  $(0,08\div 0,12)$  %/K. Working characteristics of the tensoresistor is shown in Fig.3. As it can be seen the linear dependency of output voltage on strain is observed in whole measurable range.

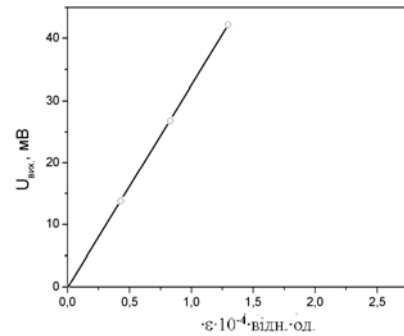


Fig. 3. Dependency of sensor output signal on applied strain at  $T=300$  K

Signal processing takes place by using the equations (4) and (5). For this purpose microcontroller Atmega8 has been used as it possesses the following parameters: 8 kbytes of program memory, 512 bytes of data memory, 1 kbyte of operative memory, 23 available lines of input/output, 10-bit ADC with six channels.

Owing to the wide, programmatically built-in periphery one can amplify signals received from a Wheatstone bridge which serves as primary transmitter of the system. Temperature correction is realized by using the "bridge in bridge" scheme. The working bridge serves as one of the external bridge's shoulders, a signal from which is conveyed onto the other channel of the microcontroller correcting temperature of the main strain sensor. The block-scheme of the measuring system is shown in Fig. 4.

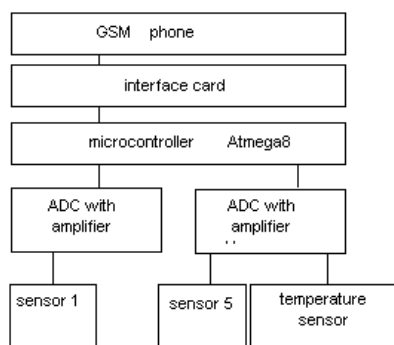


Fig. 4. Block-scheme of measuring system

Monitoring of pipeline areas is realized by using GSM net in the following way: by means of a mobile phone a signal is transferred onto a server for further processing. The system allows providing the feedback for passing requests to the sensors. Low cost of GSM phones and microcontrollers together with simple software make the measuring system compact and economically advantageous.

#### 4. System test

The developed measuring system (Fig. 6) has been approbated in an arterial pipeline. A set of tensoresistors was placed along the pipeline in suspicious areas (as a rule in the welding zones). After the two-hour pipeline monitoring, the data obtained were sent onto the laboratory server. Typical pipeline destruction is shown in Fig. 5.



Fig. 5. An example of typically destroyed pipeline



Fig. 6. Experimental measuring system

#### 5. Conclusions

By using the unique characteristics of the developed sensors we have proposed an intelligent system enabling to monitor remote areas for initial pipelines diagnostics and, using the GSM network, to send information to PC users via mobile phones. Owing to tensoresistive sensors based on silicon whiskers the developed intelligent system provides high sensitiveness, compactness and mobility. Low-cost of mobile phones and microprocessors equipped with relevant software allows efficient usage of the measuring system energy resource.

#### References

1. Hrib V.V. Diagnosis of technical condition and residual life prediction of trunk pipelines. – M.: TsNIITYe neftekhim, 2004.– 50 p.[Rus]
2. Paton B.E., Semenov S.E., Rybakov A.A., About the ageing and assessment of metal gas pipeline // Avtomaticheskaya svarka. – 2000. – № 7.[Rus]
3. Haleev V.B., Karpachev M.Z., Khramenko V.I. Main pipeline. – M.: Nedra , 1986
4. Kharebov H., Kuzmin A.N. Improved diagnostic techniques pipelines using the method of acoustic emission // V mire NK. – 2009. – № 4.[Rus]
5. Druzhinin A.A., Maryamova I.I., Kutrakov O.P., Pavlovsky I.V. Silicon microcrystals with high piezoresistance at cryogenic temperatures for sensors application. // Sensorna elektronika ta mikrosistemni technologii. – 2004. – № 1. – С. 69-77.[Ukr]
6. Druzhinin A.A., Maryamova I., Kutrakov A., Liakh-Kaguy N. Silicon whiskers for sensor electronics // Materials of XIII International conference Physics and technology of thin films and nanosystems, Ivano-Frankivsk, Ukraine.- 2011.- Vol. 1.- P.29.

#### ВИМІРЮВАЛЬНА СИСТЕМА З ВІДДАЛЕНИМ КЕРУВАННЯМ НА ОСНОВІ СЕНСОРІВ ДЕФОРМАЦІЇ

А. Дружинін, Ю. Ховерко, І. Островський,  
Р. Корецький, С. Нічкало

В даній роботі описано розроблену автоматизовану безпроводну систему для попереднього моніторингу напружено-деформаційного стану ділянок магістральних трубопроводів. Оскільки більша частина відмов магістральних трубопроводів припадає на області інтенсивних пластичних деформацій, то їхній контроль у віддалених районах викликає значне зацікавлення. Одним із варіантів вирішення даного завдання вимірювальна система на основі сенсорів деформації, в яких, чутливими елементами є ниткоподібні кристали кремнію.



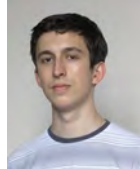
**Anatoliy Druzhynin** – DSc, professor, Head of the Department of Semiconductor Electronics at the Institute of Telecommunications, Radioelectronics and Electronic Engineering.



**Stepan Nichkalo** – a junior research associate of the Department of Semiconductor Electronics at the Institute of Telecommunications, Radioelectronics and Electronic Engineering.



**Yuriy Khoverko** – PhD, a senior research associate of the Department of Semiconductor Electronics at the Institute of Telecommunications, Radioelectronics and Electronic Engineering.



**Roman Koretskyi** – a postgraduate student of the Department of Semiconductor Electronics at the Institute of Telecommunications, Radioelectronics and Electronic Engineering.



**Ihor Ostrovskiy** – DSc, a professor of the Department of Semiconductor Electronics at the Institute of Telecommunications, Radioelectronics and Electronic Engineering.