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DISTRIBUTED AUTOMATIC LEAK TESTING & CONTROL SYSTEM

V.P. Lukonin, S.G. Sazhin
Department for Automation of Technological Process and Enterprises
Dzerzhinsk branch
Nizhny Novgorod State Technical University, Dzerzhinsk, Russia

Abstract: Most of the chemical-technological processes are extremely dangerous. Conventional monitoring systems based on stationary gas analyzers do not give information about where medium leaks from. This report describes a new way of constructing automatic system for potentially dangerous medium leakage localization at the actuating production lines. Design concept of automatic leakage's monitoring and control system with the distributed network structure are considered. The information channel works out at one-chipped base with semiconductor gas-sensitive element. Diminutireness ($1sm^3$), low power consumimg (<1W), high sensitivites (1ppm), fast response (1s) and low cost allow to mount sensors of this type closely to potential dangerous technological communications (stuffing-boxes, flanges and etc.). These systems provide high alarms and gas leakeges localization with sufficient accuracy.

Keywords: leakage's monitoring, gas-sensor; Technical Diagnostic

1 INTRODUCTION

The modern technological processes in atomic, chemical, biological etc. industries are characterized by usage high-toxic and a explosive substances. Frequently during maintenance there are crashes resulting in to derivation of dangerous densities in air of a working area. There are some paths of a development of consequences of a similar crash:

- At absence of human victims and the corruptings of the process equipment are carried out: a stopping of the technological process, detection of reasons of origin of a crash, holding of measures on elimination of consequences of a crash and starting of the technological process. The firm carries expenditures bound with a unscheduled stopping of production;
- At presence of human victims and corruptings of the process equipment of a different degree of gravity, are carried out: a stopping of the technological process, estimate(estimation) of possibility of restoring of the process equipment, liquidation of consequences of a crash and starting of the technological process. The firm carries major expenditures on restoring of inventory, pays the different penal sanctions etc.

It is obvious, that from the technical and economic points of view usage a automatic monitoring systems of a process equipment conditions is necessary. Now for solution of the given task are used different gas analyzers installed in an industrial zone. However, the similar systems allow to gain only integrated estimate of gas danger and do not give the information on a leakages origin places. The available statistical information specifies units of the technological schemes most subject to non-hermetic.To them first of all treat flanges and stuffing-boxes.The installation in immediate proximity from potential places of leakages of the high-sensitive, extrasmall and inexpensive gas sensors joined in a common automized information system, will allow to troubleshoot of early diagnostics of hermetic of the working process equipment and essentially will reduce expenditures to detection of defects places.

Usage only systems of automatic monitoring does not solve a problem by bound with necessity of a technological process stopping. The development of new active methods of a control is necessary not only to detect defect, but also to provide possibility of negative consequences decrease called to datas by defect, down to complete elimination of the defect. With this purpose the strategy of the limited acts upon parameters of the technological process is offered, for lowering the value of leakage without a stopping of the technological process.

2 AUTOMATIC MONITORING SYSTEMS of HERMETICALLY EQUIPMENT CONDITION

The distributed automatic monitoring systems of hermetically equipment condition consist of the following main bodies (see. Fig.1): sensors of leakage potentially of dangerous environments, resources of transmission a defectoscopic information and a sensors signals processing system of based on the monitoring station (the industrial computer). A basis principle of leakages detection is a control of potentially dangerous substance density change in an operative gas sensor zone. The dependence of density on the leakage value is defined by a differential diffusion equation:

$$E\frac{dC}{dt} + W\frac{dZ}{dt}\frac{dC}{dZ} = D\frac{d^2C}{dZ^2} + \lambda(Z)Q_{esc.} \qquad (1)$$

Where, E is the environment density coefficient; C - the detected gas concentration; t - time; W - the convective component of mass transfer to the inspection area; D - coefficient of molecular diffusion in air under normal conditions; λ(Z) - allocation of defect places on a controlling surface;$Q_{esc.}$ - flow value through a leak; Z- leaks coordinate (x, y, z).

Depending on a sensor installation conditions of the expression (1) changes initial and boundary conditions. The solution of expression (1) gives the count formula of the measured density of potentially dangerous substance in an installation site of a sensor in the value to integry hermetic of a unit of the technological scheme. The signal, obtained from a sensor, is transmitted to the monitoring station. The software installed on the monitoring station, realizes primary processing of a signal, will spend a statistical estimation of reliability and puts the obtained information in the database of the automatic monitoring system of hermetically of the process equipment. The results of processing are represented

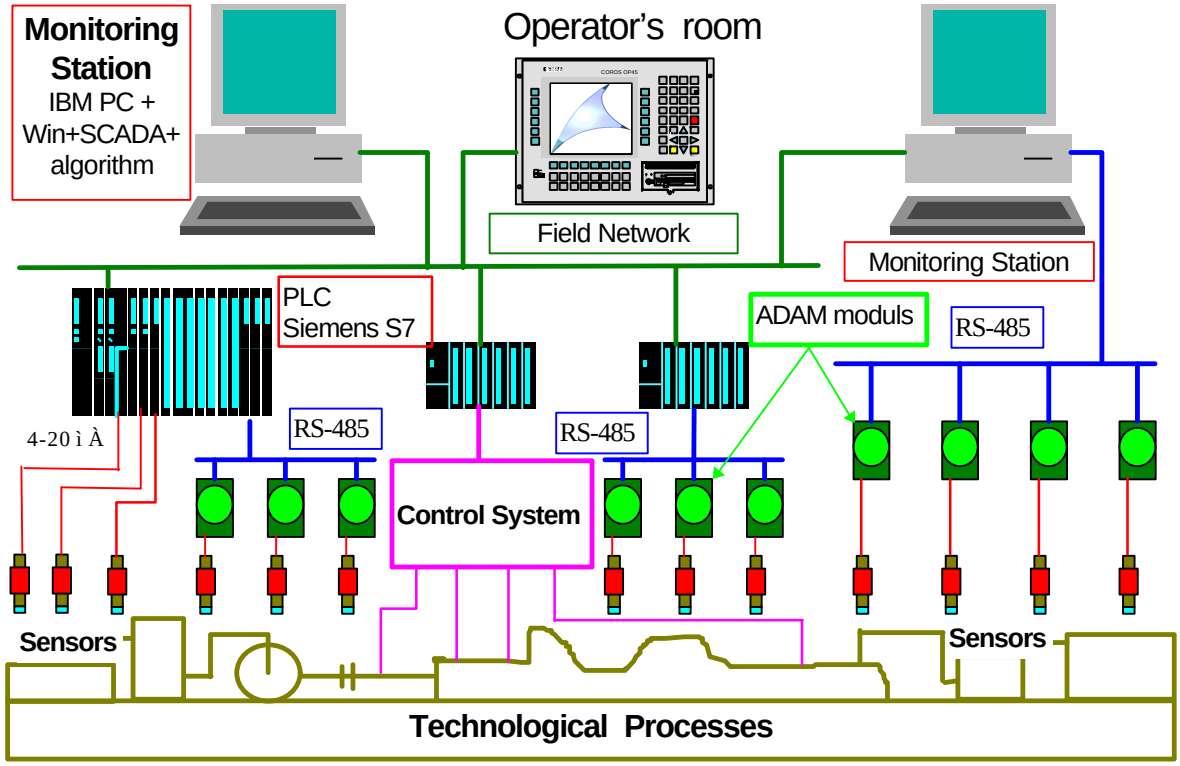


Figure 1. The Structure Scheme of Distributed Automatic Monitoring and Control System

on the display operator of the monitoring station in real-time mode and as the paper report for the indicated time slice. As a matter of record software of the server of the operator on special algorithms shapes control action on the technological process. The effect is carried out by correction of output signals of devices of the available system of automation. At restricted change parameters influential in the value of leakage (pressure, temperature etc.) is provided decrease of the gas stream value through defect.

2.1 Sensors

Support of safe holding of technological processes in which access highly-toxical and explosive substances demands a continuous automatic control of a working area air condition with maximum as possible by points of a control.
Apart from the classical requirements to sensitivity, selectivity and a response time of a gas control at build-up of distributed automatic detection systems of small densities potentially dangerous substance the special requirements should be showed to gas sensors:

- Absence of a gas pumping systems, importing perturbation in a concentration field and lowering possibility of further processing with the purpose of a leakages localization. The operation of the sensor should be carried out in the diffusive mode;
- Low cost providing economic feasibility of a multipoint control. The production of sensors should be high-technology production and to provide the low cost price;
- Extrasmall sizes and less power enables installations of sensors in hard-to-reach places of the technological communications.

To the listed above requirements obey gas sensors, manufactured on integral chips technology (on the basis of resistors, diodes, MOS and hybrid structures):

- Resistive type (oxides of metals - SnO2, ZnO; organic semiconductors; Pd/Pt catalytic sensors);
- Electrochemical (potentiometric electrodes, solid electrolytes);
- Metal- Oxide- Semiconductor Structure - MOS (capacitors and transistors - Pd-Pt/SiO_2/Si with different width of silicon oxide);
- Structures with a Shottky barrier (Schottky diodes, MOS-diodes, thyristor effect sensors with composition: metal - semiconductor Pd/ZnO);
- Masses - sensing sensors (quartz microweighing and sensors with usage of surface audio waves SAW- $LiNbO_3$ a quartz);
- Optical sensors (optoelectronic semiconducting laser + phototransistor; optic fibber sensors - laser + gas sensitive optic fibber + photodetector; photoaudio)

The gas analytical system constructed on reduced types of sensors allow to detect a wide spectrum toxical and explosive gas with high sensitivity ((10ppm) and a small response time (1s).

The principle of a microelectronic gas sensors operation is grounded on registration of change of physicochemical properties called by an adsorption of a detected gases on a sensors surface. Despite of distinctions of occurring physicochemical processes in sensors the first stage of detection the adsorption is common and in many respects defines such parameters as a response time and selectivity of sensors. The process of an adsorption on a microelectronic sensor surface is featured by the differential equation of a mass transfer:

$$\frac{dG}{dt} = k_2 \times \left(G_t - G\right) \times p - k_1 \times G \qquad (2)$$

Where G- density of gas molecules on unity of a sensor surface ; G_t - density of fissile centres in a sensitive element of the sensor; k_2 and k_1 - speed of an adsorption and desorption; ð - partial pressure of gas on a sensor surface.

The defects development of the technological communications and equipments is the long-time process. Therefore for the majority of situations of measurement usage of stationary solution of expression (2) is fair at dG/dt = 0. Ad-hoc density of gas molecules on unity of a sensor surface will be defined by expression (3) appropriate to a gold Lengmur - isotherm of an adsorption.

$$G = \frac{G_t \times p}{\left(p - \frac{k_1}{k_2}\right)} \qquad (3)$$

The leakages control of a high-toxical gases is characterized by necessity of detection of minimum densities. The partial pressure toxic gas on a sensor surface tends to zero ($ð \to 0$). The expression (3) is conversed to linear type:

$$G = G_t \times p \times \frac{k_2}{k_1} \qquad (4)$$

Despite of small values of change speed of gas molecules density on a sensors surface just the dG/dt value is for a condition prediction of a technological equipment. The change of the given value is watched on special a prediction algorithm of a defect development and is stored in the database of the monitoring station.

For different types of sensors as the informative parameter may be: the value of an electrical current through structure of the sensor, capacity of a sensor, electrical resistance and etc. The definition static and dynamic characteristics of sensors is carried out on the basis of a physicochemical processes simulation in a sensors structure. The main parameter influential on a sensor output signal is the density of a detected gas molecules on a sensor surface ,

$$I = \varphi(A, G) \tag{5}$$

Where the I-informative parameter of a sensor; A - vector of parameters defining mode of sensor operations.

2.2 Devices of a information transfer

The choice of a transmission channel structure of a defectoscopical information is the important factor of a accuracy measurement and reliability control. The structure and estimate of possible build-up of information channels is reduced in table 2.

Table 2. Structure of a information transmission channels.

1	Structure of a information transmission channels	Reliability	Accuracy	Cost
1	The sensor → Analog Transducer → Analog Indicator	-	-	+
2	The sensor → Analog Transducer → Microprocessor Controller → Monitoring Station	±	±	±
3	The sensor → Analog-to-digital Converter → Digital Indicator	-	±	+
4	The sensor → Analog-digital Converter + Microprocessor → Digital indicator	+	+	±
5	The sensor → Analog-digital Converter + Microprocessor → Network Interface → Monitoring Station	+	+	-
The system of estimates: (-) - is satisfactory; (±) - it is good; (+) - is excellent.				

The carried out analysis of transmission channels structure of a defectoscopical information has shown, that for a distributed automatic systems of potentially dangerous leakages monitoring of channels under numbers 2 and 5 (Table 2) most approach.

2.3 System of a sensors signals processing

All increasing requirements to a accuracy measurement and a analysis speed, necessity in most cases processings of signals in a real-time, support of reliability of results - all these requirements underline importance and urgency of a problem of synthesis of effective algorithmic support of the automized systems of a leakages monitoring.

The complexity of selection of an informative component of a gas sensors signals is a hindrance to complete usage of all potential possibilities of such analytical instruments. The output signals of analytical instruments have a number of features hampering holding of automatic control:

- Major dynamic ranges of their change;
- Distîrtions called by noise, interferences, hindrances;
- Mutual influence of analyses components and etc.

At the same time a estimates errors of signals parameters define quality of the analysis as a whole. The elimination of this disadvantage is possible on the basis of wide usage of computer facilities at build-up of the automized monitoring systems.

The special urgency thus gain algorithmic support of these systems, on which quality substantially depend efficiency and quality of the system as a whole. The input sensor signal can be circumscribed phenomenological or regressional by models. The phenomenological model takes into account character of processes occurring in the instrument. The standard model of a signal of an analytical converter represents additive mixture of a useful signal S (t, Θ), drift g (t) and a hindrances component δ(t):

$$Y(t) = S(t,\Theta) + g(t) + \delta(t) \tag{6}$$

Where Θ - vector of evaluated parameters, X-matrix of explanatory variables.

The processing algorithm of the information from a gas sensor should include the following operations:

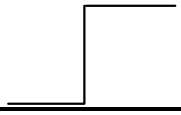
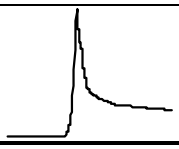
- Digitization of a signal;

- Filtering of its builders from mixture, acting in processing, of a signal with interference;
- Correction of a basic signal and a signal drift;
- Detection of a useful signal and estimate of signal parameters.

Besides the standard algorithm should include also a blocks of execution supplementary operations for providing: normal operation of handlers, control of reliability, control function by a gas sensor.

The different forms of useful signals meeting in practice of a leakages control are represented in table 3.

Table 3. The forms of useful signals from microelectronic sensors of leakage.

Density	≈ 1 ppm	≈ 100 ppm	≈ 1%val.	Disrupture
Stream	$1*10^{-6}$ W	$1*10^{-4}$ W	$1*10^{-2}$ W	
The form Useful signal				

The greatest complexity is represented by an estimate of a obtained information reliability at small leakages and crashes. As the waveform is visible from table 3 at small leakages corresponds to a background component drift, and at large leakages corresponds to impulse interference. The solution of the given problem consists in usage a integral reliability criteria based of a moments method.

The important role in a safety of technological installations is played by the automized systems of a crashes prediction working in real-time mode. The algorithms of prediction work on the basis of the information on a change speed of a potentially dangerous substances density and correlation dependences of technological process parameters with parameters of potential leakages. The prediction is carried out on a time in use of installation (forecast per day, month) or on guessed change of technological mode of process (forecast for rise of temperature, pressure).

3 CONTROL SYSTEM of the DANGER LOWERING PROCESS

Elimination of leakages through flanges and stuffing-boxes are reduced to support of more dense connection of sites of datas of units. The execution of these operations in conditions of presence of major leakages of dangerous substances is possible only at a production stopping. It gives in large financial expenditures and possible human victims among serving staff. For lowering danger at detection of leakage it is necessary to realize the limited control of a technological process parameters with the purpose of lowering the a stream value through the derivated leak. The limited control will allow within the framework of deviations, allowed on technological modes, to not discontinue production and to not reduce quality of released production. Thus there is a task of synthesizing of a limited control algorithms on the technological process parameters.

There are different approaches to development of algorithmic support of composite adaptive control systems (program change of a regulators coefficients, direct gradient methods self-adapting regulators, usage simulated of neuron networks, and as fuzzy logic). In a figure 2 the generalized algorithmic structure of interaction by an automatic control system of the danger lowering process and the technological process control system is shown.

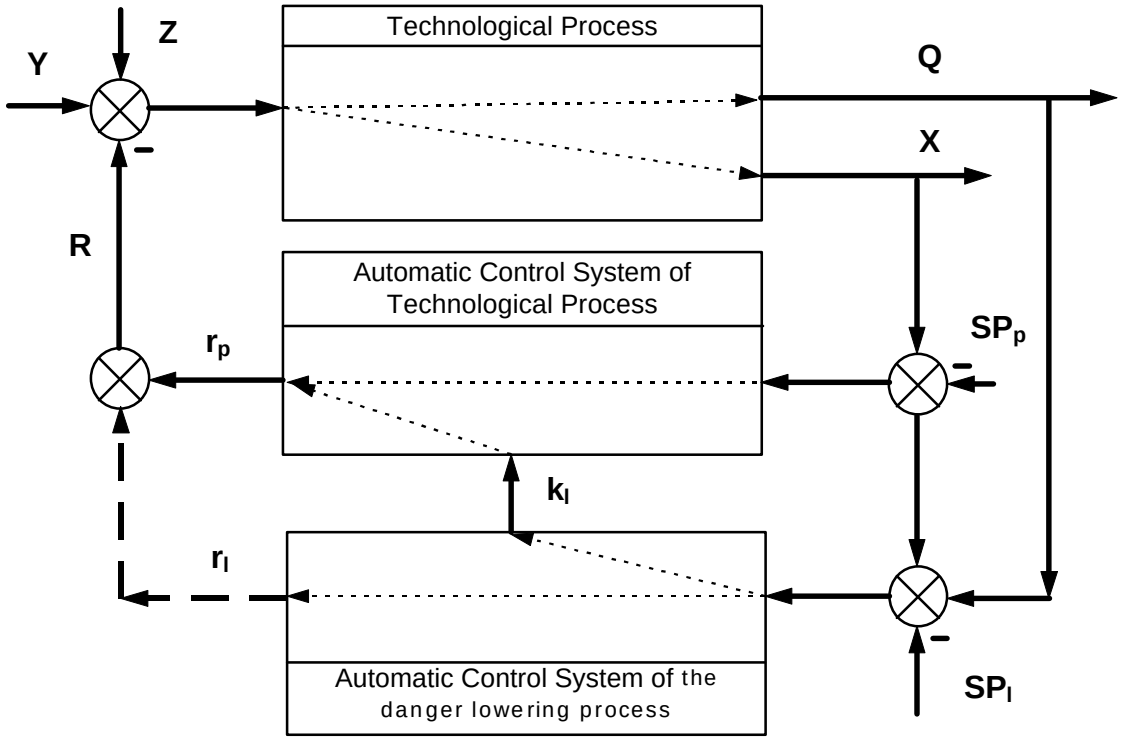


Figure 2. The algorithmic structure of interaction by an automatic control system of the danger lowering process and the technological process control system.
Y- a vector of data-ins; Z- a vector of perturbations; X- a vector of controlled parameters; R- a vector of controlling parameters; Q- a vector of of leakages; SP_p and SP_l - vectors of the set-points; r_p and r_l - vectors of control actions; k_l - vector of correcting acts.

The automatic control system of a danger lowering process gains the information on the value and lokalization of leakage Q, compares it to technological parameters X and works out correcting effect k_l. The control system of the technological process with the registration k_l realizes control of the technological process data-ins Y using control action R. Until then while the leakages are not detected correcting acts equally to zero and does not influence a course of the technological process.

4 CONCLUSION

The introduced concept of build-up of distributed automatic control and monitoring systems of a potentially dangerous substances leakages allows essentially to increase safety of technological processes and to lower expenditures on liquidation of a crashes consequences. The further theoretical and experimental research of a distributed leakages detection and control of abnormal technological processes is necessary.

AUTORS: Vadim P. Lukonin, Sergey G. Sazhin, Department for Automation of Technological Process and Enterprises, Dzerzhinsk branch Nizhny Novgorod State Technical University, boulevard Mira 21, 606023 Dzerzhinsk, Russia, Phone 007 8313 335916, Fax/modem 007 8313 330504, E-mail: ngtu-d@kis.ru