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Software and Hardware for Industrial Automation in the Management of Remote Leakage Detection Control

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Abstract

We explore the architecture and the concept of building an automation remote leakage detection system, in particular – a system for collection and processing of information. As practice shows, the development of those systems is a lengthy and time-consuming process involving management of heterogeneous hardware and analysis of large amounts of data. To implement the task, it is proposed to use the SCADA industry standard, universal communication protocols, and for data processing – open source database management systems and cluster analysis algorithms. Consider the nature of the flow passing through the defects and its relationship with the sensitivity of the control. A universal approach makes it possible to develop a scalable problem-oriented system. This approach takes into account the information received and processed during the leakage detection process.

Keywords: remote leakage detection, mass-spectrometry, SCADA, OPC-Server, Modbus

1 Introduction

Leakage detection is a type of nondestructive testing performed to identify crosscutting defects. It is based on registration of passing of probe material through the defects. During the leakage detection process it is necessary to ensure safety of the staff, high sensitivity of the control process and integration of the control systems directly into the process line. Commonly instrumental leakage detection methods are used, they require complex equipment management and working with semi-structured data. Such remote leakage detection systems are unique, created especially to solve specific problems, and there is no single universal approach for their automation.

Today, there is a large number of tools and process automation systems, including the ones for non-destructive testing. The lack of a universal approach, diversity and often incompatibility of the equipment used, analysis of large amounts of unstructured data turn the development of an automated control system into a long and laborious task. As a result the systems of this kind often can be described as containing poorly aligned components, inefficient data processing algorithms and complex at maintaining performance. In addition, the requirements of a modern enterprise demand using of a single information space, so the measurement equipment and the remote leakage detection systems must be selected carefully according to the characteristics allowing being included in this space.

The target of the submitted work is to develop an automated computer based remote leakage detection control system.

To achieve this target the following research objectives should be addressed:

- development of the control system's architecture and the choice of the equipment for introduction it into a single information space;

- development of the data analysis system for processing the data obtained during the control process;

- development of a unified approach to the automation of remote leakage detection, including the one based on OPC servers and set of Modbus protocols.

2 Data Analysis Unit

Evaluation of the product is based on a comparison of the values of the flow test substance, penetrating through the defects, with the acceptance level, depending on the norm of tightness (Fig. 1). If the acceptance level is exceeded the product is considered to be leaking. Before the evaluation process it is necessary to "clean" the signal of noise and possible artefacts – distorted values resulting from the measurement and data transmission errors.

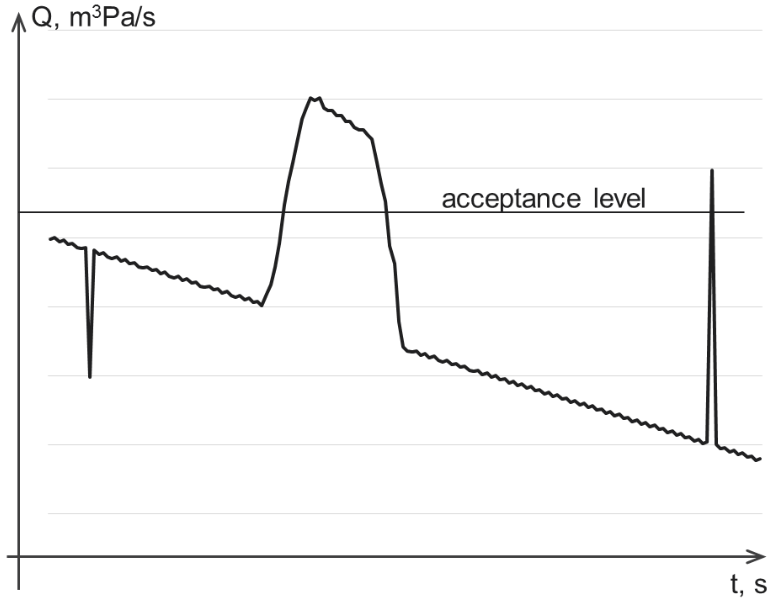

FIGURE 1 Graph of the flow the test substance over time.

Also, any system has signal fluctuations that might be flattened using averaging. Such filters are used in processing of images to make changes of their sharpness [2]. In this case, each point on the graph is replaced by a weighted average of its neighborhood that provides smoothing of the signal. Filter kernel (i.e. each weight value when calculating the average) can be varied depending on the desired result.

Noise compensation can be performed in a static or a dynamic mode. The static mode involves subtraction of the noise part from the signal, the noise part is a constant value obtained when configuring the system. The dynamic compensation is based on monitoring of the slope angle of the signal curve and subtracting a straight line with a slope coefficient tgα.

$$Q = Q_{\Sigma} - t \cdot tg\alpha \quad (1)$$

where Q – flow of the test substance after the dynamic compensation, Q_{Σ} – total flow; t – time.

$$tg\alpha = \left| \frac{Q_2 - Q_1}{t_2 - t_1} \right| . \quad (2)$$

Removal of artifacts and maximum value search are based on the cluster analysis method on the weighted pair-group average amount. The aim of the cluster analysis is to identify groups of multidimensional objects (clusters), represented by dots of the geometric space.

Let`s imagine n objects as a set I = {I_1, I_2 ... I_n}, then the vector X_j = [x_{ij}] corresponds to each series of measurements of the i characteristics of the object j.

The set I can describe a plurality of measurements of the vectors X = {X_1, X_2 ... X_n}, and N measurements can be represented in matrix form:

$$X = [X_1, X_2 ... X_n] = \begin{vmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{vmatrix}. \quad (3)$$

As the association criterion for making clusters Euclidean distance between pairs of vectors $d(X_i, X_j)$ is used:

$$d(X_i; X_j) = \sqrt{\sum_{k=1}^{N} (x_{ki} - x_{kj})^2}, \quad (4)$$

which can be represented as a matrix:

$$\Delta = \begin{vmatrix} 0 & d_{12} & \cdots & d_{1n} \\ d_{21} & 0 & \cdots & d_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ d_{n1} & d_{n2} & \cdots & 0 \end{vmatrix}. \quad (5)$$

The algorithm for distribution of values into the clusters is used, so that the distance between the objects in the cluster is less than the distance between any objects in the cluster and the rest of the set.

Finding the optimal number of clusters is carried out using the efficiency index [5]:

$$PI = \sum_{q=1}^{Q} \sum_{k=1}^{K} u_{qk}^2 \left[d^2(c_k, \bar{x}) - d^2(x_q, c_k) \right], \quad (6)$$

where Q – number of the objects, K – number of the clusters, u_{qk} – degree of membership of the object to the cluster $u_{qk} \in [0, 1]$, d – Euclidean distance, c_k – vector of the cluster`s center, $\bar{x}$ – the arithmetic mean of all vectors.

The efficiency index consists of the difference of the inter-cluster and the intra-cluster differences, and the maximum corresponds to the optimal number of clusters.

Because the curves representing the time dependency of the flow can be characterized as smoothly changing it can be assumed that the artifacts will appear in the clusters with a minimum number of members. To remove the corrupted values it is enough to remove the most numerically small clusters.

By using the method of cluster analysis the amount of the resources spent on the search for the maximum value is reduced. It uses the linear search algorithm, in which the first is the search for the cluster with a maximum average value of its members. After that, the maximum value is found in that cluster. When using this algorithm, one can be sure that the excess of the acceptance level is not caused by any noise fluctuations or random artifacts.

The possibility of modeling and documentation of data in an off-line mode is provided. This mode includes: creating a graph representing the time dependency of the flow of the test substance, data re-filtering and evaluation of the product shelf-life. According to the results of the monitoring process technological documents can be created in electronic format and printed on paper (protocols and reports) on demand.

3 Simulation of passing of the test substance through the defect

This concept is applied to create the computer based automated system for remote mass-spectrometry leakage detection in canisters' closing welds after filling them with radioactive waste.

Because the controlled weld is a closed one, it is necessary to reach the concentration of the test substance in the container volume, which is sufficient to provide the required sensitivity control. Helium is used as a test substance. High concentration level of the test substance is achieved by vacuuming and subsequent crimping of the internal volume of the container with helium before welding. Helium is adsorbed on the surface of the container and its contents and maintains a sufficient concentration; and immediately after crimping the container is covered with a cap, which is then welded to it. The process of leakage detection control includes placement of the local vacuum chamber inside the weld and analysis of the sample gas in the chamber for containing the test substance.

If there are defects, helium remaining after crimping and air trapped in the container before welding will pass through these defects. It can be argued that the nature of the flow passing through the defects is molecular [3], since during the leak detection monitoring the defects to be found are the ones with the corresponding flow of the test substance in the range of $1 \cdot 10^{-4}$ $1 \cdot 10^{-9}$ ... $m^3 Pa/s$. These values are typical for the leaks with a molecular flow, regardless of the configuration of the leak. Let`s consider the equation for Knudsen molecular flow through a cylindrical channel (7) and a gate channel (8):

$$Q_c = \frac{2\pi r^3}{3l}\sqrt{\frac{8RT}{\pi M}}(P_2 - P_1), \qquad (7)$$

$$Q_g = \frac{2\pi \delta^2}{3l}\sqrt{\frac{8RT}{\pi M}}(P_2 - P_1), \qquad (8)$$

where Q_c and Q_g – flow of material going through a cylindrical or slit-like leak, respectively, r, h, δ, l – geometric characteristics of the leak, R – universal gas constant, T – absolute temperature, M – molar mass of the material passing through the leak, P_1 and P_2 – pressure upstream and downstream of a leak.

Using equations (7) and (8), it is possible to obtain the relation of the gas streams flowing through the leak:

$$Q_{He} = B\sqrt{\frac{M_A}{M_{He}}}\frac{P_2 - P_1}{P_A}, \tag{9}$$

where Q_{He} – flow of helium, B – characteristic of the leak, M_A and M_{He} – molar masses of air and helium, P_A – atmospheric pressure.

After putting the values of molar masses into equations, it is clear that the helium flow is about three times higher than the flow of air through the defect. This suggests that even with a low concentration of helium in the container the required sensitivity of the leakage detection control can be reached.

4 Software implementation of the system

OPC servers and SCADA technology have been used to solve the problem. The SCADA technology [6] (Supervisory Control And Data Acquisition) is a hardware and software system designed for managing production processes in real time. The software that implements this technology allows communicating with the automated objects via the input-output drivers or servers. Thus, systems with any number of equipment included in the in-line production line can be simultaneously controlled.

OPC is a technology that uses the single interface to control devices. Its use is especially important for remote leakage detection system. Usually, software developers have to include in the system the set of ready-made drivers and use different tools for developing original software for interacting with non-standard low-level devices. When replacing a device with the similar one made by another manufacturer it is necessary to change a part of the software for its management. OPC unified interface allows different software modules, manufactured by different companies successfully communicate with each other.

In addition to the hardware and software tools mentioned above the Modbus protocol is used – it is an open communication protocol based on a master-slave architecture. The Modbus protocol is used in automation systems for communication between industrial controllers and electronic devices. It is used for data transmission via serial links, RS-232, RS-422, RS-485 (Modbus RTU, Modbus ASCII) interfaces and Ethernet network supporting a stack of TCP / IP protocols (Modbus TCP).

The control system for remote leakage detection is based on a distributed architecture (Fig. 2). This architecture consists of several control centers which are connected to a common control circuit. Because of this the distributed management architecture has no restrictions in the performance of the control center and the length of the communication channels. In addition, it is characterized by wide possibilities of modernization, changing and increasing capacity, component approach, easy commissioning and maintenance. The main software that implements the algorithm is located in the operator's computer, which receives data (with OPC-server and Modbus protocols) from the controller and the leak detector connected with the hub. The controller communicates with the digital and analog signals obtained from pressure sensors, valves, roughing pumps etc.

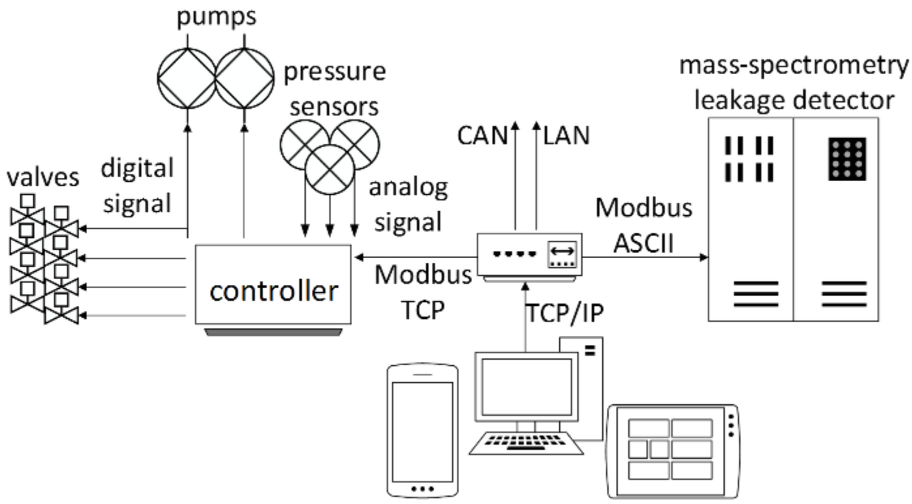

FIGURE 2 The control circuit of the computer based automated remote leakage detection system.

For development of the applied software for the remote leakage detection system the open source and freeware public library Pascal SCADA and Lazarus IDE in Object Pascal for the compiler Free Pascal have been used. These software tools are cross-platform, they refer to the concept of RAD (Rapid Application Development) and they are not proprietary, thereby constantly improving. For information exchange between the parts of the system the OPC-servers (OPC UA, OPC DA) and the data exchange protocols Modbus RTU and Modbus TCP are used. Communication is performed in CSV format [1] and PostgreSQL open source software is used as a relational DBMS (database management system) [4]. Choosing the DBMS PostgreSQL is caused by its compact data representation, a clear hierarchy of levels that determine the degree of data detail, low probability of obtaining errors and data inconsistencies.

Acknowledgements. During this work the hardware and software architecture of the control computer based remote leakage detection system, including the tools for integration of the equipment into a common information space, were defined and built, also the concept of the system analyzing data obtained as a result of a control process has been developed, and a unified approach to automation of remote leakage detection, (also taking into account the OPC-servers and Modbus

protocols) has been designed. With the SCADA and OPC technologies controlling of a system is implemented regardless of different communication protocols between physical devices and can be integrated into the technological line of the enterprise.

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