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Architecture of Compressor Equipment Monitoring and Control Cyber-Physical System Based on Influxdata Platform

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Abstract—**Architecture of the compressor equipment monitoring and control cyber-physical system (CPS) based on the InfluxData IoT platform is proposed. CPS consists of three subsystems: a subsystem of a physical object, a digital twin and an interface. As a technical implementation of the IoT controller, a measuring and control module based on a data acquisition, data transfer and control device - VIDA350, connected to the Telegraf data collection agent of the platform using the MQTT protocol, is proposed. The basic methods of processing raw data from energy meters and sensors of technological parameters, implemented in blocks of on-line and off-line calculations are given. The organization of the digital twin of the compressor using the database of time series InfluxDB and the relational database MSSQL, storing information about changes in the technological parameters of equipment over time, energy efficiency indicators, statistics on accidents and operating time, equipment models, etc., is proposed. The Grafana system and FreeCAD is used for the visualization of equipment in 3D. The use of CPS can increase the efficiency of operation of compressors due to the timely detection of air leaks, minimizing idling, minimizing peak consumption, optimizing process parameters and settings both of the compressors and consumers.**

Keywords—Cyber-Physical System, Information System Architecture, Internet of Things, Digital Twin, InfluxData Platform

I. INTRODUCTION

Most large enterprises, factories and other production facilities are equipped with energy and resource consumption measurement tools. Analysis of energy readings shows that compressed air is one of the most expensive resources used at industrial enterprises. Compressed air is commonly consumed by special transport systems, pneumatic drives of machinery, systems for material refinement or mix agitation, the operation of which is often implemented in asynchronous mode, [1–3].

It is considered that the pressure control systems and compressed air flow control systems built into the compressors ensure optimal consumption of electrical energy. However, in practice, the installation of screw compressors with variable frequency drive does not always give the expected effect. This is due to the following factors:

– firstly, the specialists responsible for improving energy efficiency often find it difficult to show the effect of energy-saving measures in terms of compressed air, because the data necessary for calculations are not available. The number of utility meters is limited, while the constant account for energy used by the numerous additional nodes is too expensive and not rational;

– secondly, big energy consumers limit experts to billing and workload statistics aggregation for a given period of time;

– thirdly, when expanding the range of technical accounting tools, the volume of energy readings over several years becomes so large that the engineering and energy services of organizations do not have enough time or resources to continuously process the information flows about the processes occurring in the pneumatic system.

In this regard, it seems urgent to create a system that has the ability to integrate information and computing resources into the pneumatic system of an enterprise, equipped with a large number of sensors and actuators. Such systems are called cyber-physical (CPS), their components interact with each other using available interfaces and network protocols based on the Internet of Things (IoT) technology, implementing the processing of large amounts of data, visualization of equipment parameters, predictive analytics and intelligent adaptation to changes, [4–8, 10].

The effective functioning of modern and future pneumatic systems of industrial enterprises can be supported only through the continuous improvement of CPS monitoring and control of compressor equipment.

II. THE SYSTEM ARCHITECTURE OF THE CPS FOR MONITORING AND CONTROLLING COMPRESSOR EQUIPMENT BASED ON THE INFLUXDATA PLATFORM

The InfluxData platform is an information aggregator, designed to create various applications and services based on IoT technologies by connecting multiple data collection interfaces, protocols, supporting time series databases and third-party visualization software. It can be integrated as an add-on for the existing accounting and dispatch control systems to implement a large number of analytical functions that contribute to improving the efficiency and quality of assessing the energy efficiency of objects. Since the platform is not specialized for use in the CPS applications for monitoring and controlling industrial equipment (compressors, in particular) it requires adaptation of the calculation units and the creation of a unique digital twin, fig. 1.

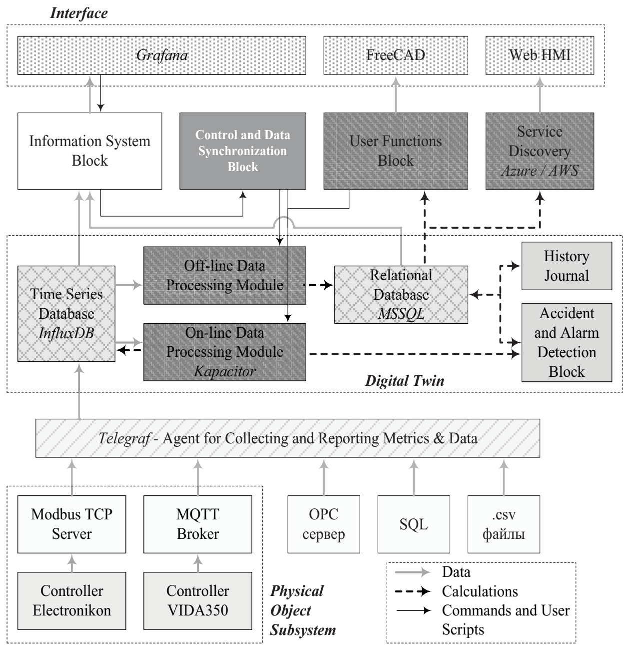

Fig. 1. Simplified system architecture of the FSC for monitoring and control of compressor equipment

CPS consists of three subsystems: a subsystem of a physical object; a digital twin; and a user interface.

A technical implementation of the IoT controller is proposed: a measuring and control module based on a data acquisition, data transfer and control device VIDA350, which is then connected to the Telegraf data collection agent attached to the platform through the MQTT protocol [11]. Communication between the CPS and the compressor is implemented using an Electronikon controller using the Modbus RTU protocol.

The digital twin of the compressor is implemented using the InfluxDB database and the relational database MSSQL, which store information about changes in technological parameters of equipment over time, energy efficiency indicators, statistics on accidents and operating time, equipment models, etc. For 2D visualization of measurements and graphical interpretation of the control panel, the Grafana and FreeCAD for visualization of equipment operation modes in 3D.

The following blocks of the InfluxData platform are presented in fig 1.

Telegraf is a module implementing data collection from devices, files and third–party databases, including Oracle or Wonderware, and their transfer to the database of time series InfluxDB.

InfluxDB is an open source time series database that provides storage of automatic measurements of compressor parameters and their power consumption, including the results of on-line calculations as well as assigning a timestamp to each measurement.

Kapacitor is a module that runs analytical subroutines and computational functions for processing data from the InfluxDB time series database in a stream.

Grafana is a web server that implements a human-machine interface for visualization of time series with the results of measurements and calculations, attributes of compressor equipment, accidents and alarms.

The system is operable both in the local computer network of an enterprise and during remote work session via the Internet. All server components jobs are provided by running native Linux ELF64 binary files under the Linux operating system. However, to run Linux-compatible server applications, you can use a special subsystem of Windows Subsystem for Linux (WSL) - this is a Hyper-V hardware virtualization system for x64-based hypervisor. In this case, the Windows Server 2016 RedStone 3 version should be used as the operating system or Windows 10 from version 1607.

III. The Algorithmic and Functional Support of the CPS for Monitoring and Controlling the Compressor Equipment

The CPS of architecture presented above solves the following tasks:

1. Energy monitoring. The data source can be either a compressor control system or specialized software and information support that collects data (if there are open interfaces) [8, 9]. The Telegraf module implements data collection from electricity metering stations, pressure sensors and air flow based on the concept of industrial Internet of Things using the MQTT protocol. The VIDA350 data acquisition device implements the connection of digital pressure sensors and flow meters on a 4–20 mA current loop, with the subsequent transmission of information through the channels of an internal Ethernet network using Publisher-Subscriber technology. If this level is implemented in the enterprise, then data from external databases of the automated process control system and automated system of electric power technical metering is acquired via OPC protocols or SQL queries.

2. Energy analysis. Processing of energy readings is performed in on-line and off-line modes, including usage of custom functions in the form of Python scripts and using external services of Azure virtual servers. Produced are the following mathematical calculations [13, 14]:

– smoothing filtering of the electrical power (EP) consumption signal via the exponential moving average, as represented by the expression:

$$A_m' = f*A_m + (f-1)*A_{m-1} \quad (1),$$

where - A_m' is the smoothed value of the load profile, A_m and A_{m-1} are the adjacent values of energy consumption per unit of time before smoothing, α is the degree of smoothing in the range from 0 to 1;

– deviations of the actual consumption of energy efficiency from the smoothed value;

– calculation of specific energy consumption per unit volume of air produced for each compressor and group of compressors;

– calculation of energy consumption for different periods of time, including the 1st shift, 2nd shift, 3rd shift, weekends and holidays;

– working hours per shift, day, week, month, quarter, year;

– idle time;

– the number of on / off switches;

– specific energy consumption efficiency per unit of production;

– specific consumption rates of EP units of compressor equipment;

– absolute consumption rates of EP units of compressor equipment;

– Estimation of total costs for the production of compressed air in terms of value;

– evaluation of the efficiency of compressed air production;

– total consumption of energy efficiency by type of compressor.

3. Energy modeling. The Kapacitor module implements the calculation of compressor performance indicators based on mathematical models and provides input-output calculation results and simulated data to the InfluxDB database in real time [12, 14, 15]:

– Target function (regression model) characterizing the specific energy efficiency costs per unit volume of compressed air. The target function allows us to estimate the dependence of energy consumption on the parameters of the equipment;

– Target function (regression model), characterizing the specific EP costs per unit of output;

– Mathematical model for calculating the power of the compressor. The following expression is used to calculate the display output of screw–type compressor:

$$Nu = (k–Q)/1000*[Pb*(e*m–1–m)/(1–m)+Ph*(1 / \varepsilon)] \quad (2),$$

Where *Nu* is the power of the screw compressor (indicator), kW;

k – correction factor (from 1.05 to 1.18 depending on the size of the device);

Q – performance under input conditions, m^3 / s;

Pb – suction pressure, Pa;

Ph – discharge pressure, Pa;

e – degree of compression (geometric);

m – indicator of polytropes.

– Theoretical consumption of EP by the compressor according to its mathematical model;

– Deviation of theoretical and actual consumption of energy efficiency;

– Deviation of theoretical and target consumption of energy efficiency;

– Deviation of target and actual consumption of energy efficiency;

Specific and absolute norms of consumption of EP units by the compressor equipment can be determined depending on the mode of operation, accidents, season, production volume. In this case, the planned monthly production volume with the division into shifts should be loaded into the system.

Using the presented system, a methodology for calculating the monthly and daily energy consumption plan for compressor units and the group as a whole can be formed, and an estimate of the influence of factors on the deviation of EP consumption can also be calculated when comparing the plan and fact.

To solve the problems of predicting the consumption of EP, the Azure analytical device can be used, which includes machine learning technologies based on neural network pattern recognition models [16, 17]. For processing load profiles and identifying patterns (typical situations), contour analysis algorithms implemented in the user function block can be applied.

The table 1 shows a comparison of the characteristics of CPS based on the InfluxData platform with the popular software complex "ENERGOSPHERE 8".

TABLE I. COMPARISON OF THE CHARACTERISTICS OF CPS

Comparative signs of	**CPS on InfluxData Energy**	**Energospher e**
Accounting for various types of energy	+	+
Processing of raw data and providing necessary information to users of the system in various types	+	+
Accounting for various technological parameters	+	–
Ability to calculate energy efficiency indicators	+	+/–
Output threshold (minimum and maximum) parameter values	+	+
Calculation of the energybase line	+	–
Construction of target functions based on regression models (Targeting)	+	–
Ability to connect object models	+	–
Modeling equipment udovaniya real-time	+	–
Flexible imaging based on dashboards and widgets	+	–
Calculation of norms of energy consumption	+	–
Energy Forecasting	+	+/–
Appearance of interface,	dynamic, support for 3D	static, charts

IV. Results of Experimental Studies of CPS Monitoring and Control of the Compressor Equipment

Consider the example of the placement of CPS equipment at the industrial enterprise, fig. 2.

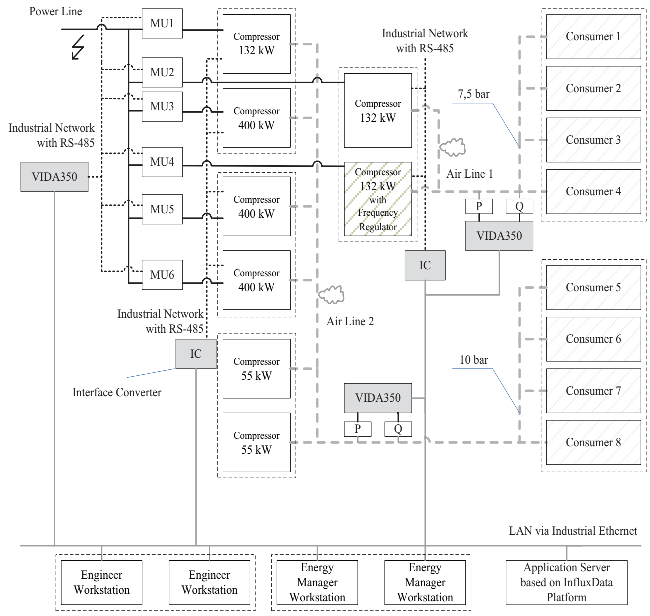

Fig. 2. An example of the layout of equipment CPS

The system includes:

– two compressed air supply lines with pressures of 7.5 and 10 bar;

– Controllers "Elektronikon" compressors (KM) Atlas Copco GA–400 3 pcs .;

– controllers "Elektronikon" compressors (KM) Atlas Copco GA–132 3 pcs., the rest are in reserve;

– metering stations (UU1..6) of electricity consumed by compressors;

– IoT VIDA350 controllers with connected pressure and flow sensors;

– channels and channel-forming equipment;

– interface converters (PI) RS–485 <-> Ethernet;

– existing enterprise LAN;

– apps server;

– workstations for engineer and energy specialist.

The primary data are as follows: the amount of electrical power consumption by each compressor; the amount of compressed air produced by each compressor; operating pressure in line 1; operating pressure in line 2; quantity of products produced.

Visualization of data compressor equipment in the system can be carried out for a different period of time, including day / week / month / quarter / half / year (arbitrary interval). The appearance of the power interface is shown in Fig. 3.

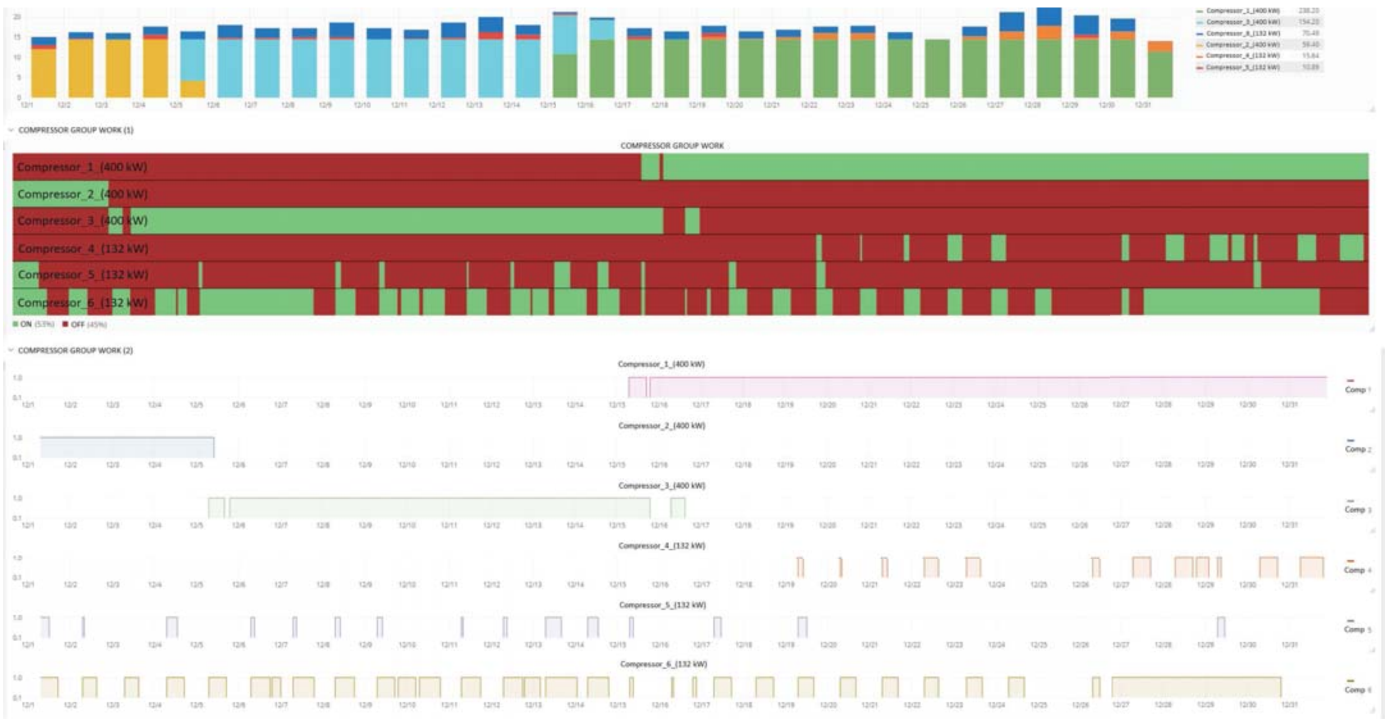

Fig. 3. The appearance of the interface of the automated workplace of the engineer for displaying statistics on the operation of the group of compressors.

Information on the electrical power consumption of the compressors, the production of compressed air, including volume flow and pressure, is displayed. If necessary, other technological information can be displayed, including output.

Mathematical calculations are made, including filtering and statistical analysis. The results are displayed in graphical form using circular and bar charts, including the display of operating time / downtime, the number of inclusions, specific indicators of EP consumption per volume of compressed air and other parameters.

All information is dynamically updated (period of 1 second, can be configured). Provides output to a large screen or video wall.

Information can be displayed both for a group of compressors and for each individual machine. Information output is implemented taking into account accumulation, for example, the total working time from the beginning of the month, an average load profile can be built, as well as the cost of energy expended, fig. 4.

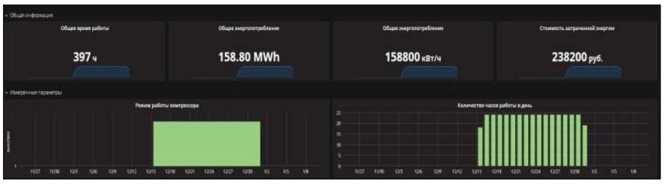

Fig. 4. Appearance of the energy specialist's workstation interface for displaying statistics of the compressor operation using the dark background of the screen form

V. Conclusion

Using the CPS, the cost of energy consumed can be calculated, the amount of air leakage estimated, idle time minimized by a more precise setup of compressors, peak consumption minimized when a ban is imposed on the launch of certain categories of consumers at specified hours. The use of the block of analytical calculations in the system makes it possible to calculate the energy consumption rates of units of compressor equipment and target functions based on nonlinear regression models characterizing the unit cost of electricity per unit volume of compressed air or unit of useful work (manufactured products).

The product is in demand in production because it allows enterprises to effectively carry out energy saving measures, smooth load profiles, correctly distribute compressed air flows, and predict energy consumption.

The developed system can be used to have pneumoaudit conducted by the employees of the enterprise independently.

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