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DIGITAL TWIN OF GAS RECIPROCATING COMPRESSOR UNIT: CONCEPT, ARCHITECTURE & PILOT IMPLEMENTATION

Combination of information and operational technologies has led to a new way of production, to a new technological revolution, known as Industry 4.0. The Digital Twin plays a central role in this technology. The Digital Twin is a predictive maintenance tool, and allows you to simulate various options for device failures taking into account their operation modes, environmental influences and various degrees of wear. The concept of creating a digital twin of a real physical object of research is proposed - an AJAX DPS-180 internal combustion engine with a gas piston compressor, which is designed to pump gas from gas wells. A feature of its work is autonomous long-term operation in the field with the remoteness of the service personnel, direct environmental impact and ensuring the reliability and stability of work. Therefore, monitoring the parameters of the engine with the subsequent prediction of its failures is especially important. The work on creating a digital twin for AJAX DPS-180 is being carried out in cooperation and with the support of Armco-Engineering, the operator of this equipment.

Six stages of the process of creating a digital twin of a given object are shown: collection and preliminary processing of data on the technical state of a real object; early detection of malfunctions, predicting the time of failure; service planning; optimization of financial and time resources for service. Equipping a real object with various sensors made it possible to continuously collect data on its technical condition, and technologies of the industrial Internet of things, such as Big Data and the predictive statistical model, predict failure times with high accuracy.

The developed and implemented schemes for equipping an object with data collection equipment and a diagram of the flow of this data in the Internet of Things are presented. The basis of the data collection system is a microcontroller, a set of a crankshaft speed sensor and thermocouples, a multiplexer and 16-bit analog-to-digital converters that convert thermo-EMF of thermocouples. At the moment, channels for measuring the speed, coolant and exhaust gas temperatures have been implemented. It is proposed to use the ThingSpeak server as a remote resource as a cloud aggregator and carrier of this data. The MATLAB mathematical package integrated into the resource is used as a data analyzer.

Key words: *digital twin, gas reciprocating compressor unit, internet of things, predictive model.*

Introduction

Combination of information and operational technologies has led to a new way of production, to a new technological revolution, known as Industry 4.0. Categories such as Big Data, Machine Learning, Digital Twin, Predictive Model, unknown until recently, have gained exponential development thanks to the advent of Cloud technologies and the Industrial Internet of Things.

The Digital Twin plays a central role in this technology. But what is it? The simplest definition of this concept is given by Gartner Inc.: “A digital twin is a digital representation of a real-world entity or system” [1]. But we would prefer the following definition: “The digital twin is a virtual display of real objects, processes, people and their systems”. The implementation of digital twin is an encapsulated software object that mirrors a unique physical object, process, organization, person or other abstraction.

In the context of this work, we will be interested in the digital twin of an industrial product. They can be classified into two types [2, 3]: Digital Twin Prototype (DTP) and Digital Twin Instance (DTI). DTP describes real physical objects in general, based on a Physical model of an object and is conditionally permanent. DTI reflects the behavior of a specific instance of a real object with which it is associated by “digital threads” - these are flows of information about the state of this real object. DTI is based on a statistical mathematical model and varying in accordance with changes in the physical object in operation. We can say that the DTP is a parent for the real object, which, in turn, gives birth and accompanies the DTI. In some cases, the second parent for the DTI may be the DTP.

The real physical object of our study is the AJAX DPS-180 Gas Reciprocating Compressor, designed for pumping gas from gas wells. This is an integrated two-stroke gas internal combustion engine - reciprocating compressor. A feature of its operation is autonomous long-term work in the field with the remoteness of the operating personnel, direct environmental influences and ensuring reliability and stability of work.

Our work on creating a digital twin for it is carried out in cooperation and with the support of the Armco-Engineering LLC - the operator of this equipment.

Digital Twin Creation Process

We see the steps of the implementation process of this project as follows:

Step #1. Concept creation. Determining the goal that is achieved using the Digital Twin. It is necessary to decide what benefit for the enterprise the twin introductions will have in terms of eliminating unresolved problems and/or financial profit.

Step #2. Architecture design. Determine the rational configuration and capabilities of the twin, which will allow with minimal cost and quickly achieve the stated purpose of its use.

Step #3. Pilot implementation. The rapid implementation of a pilot program that will help to show its value to the enterprise, train and adapt the development team, show ways to expand technical solutions.

Step #4. Stabilization and Tweaking. Improving the stability and reliability of the system, improving its interface.

Step #5. Development and expansion. Expanding and increasing the number of "digital threads" - data transmission channels.

Step # 6. Data storage.

One of the most important tasks of the digital twin is to minimize the failures of a real technical object. A modern approach to equipment maintenance is based on the Reliability Centered Maintenance Methodology [4]. At the same time, the following types of services can be used for equipment:

- Failure.

Mean time between failures without maintenance. It is used when the equipment is not critical, it is easy to replace, its repair is accompanied by relatively low costs, or it is aging equipment, which is practically not repairable and finalized until the final failure.

- Proactive.

Search and elimination of possible causes of failure. It is used to ensure the maximum possible overhaul life of equipment through the use of technologies for detecting and suppressing sources of failure.

- Preventive.

Similar to preventative maintenance system. It is prescribed for equipment whose “criticality” is low; this is determined by such factors as low cost of downtime for production, the ability to quickly replace spare parts.

- Predictive.

On-line monitoring and diagnostics of equipment status: allows repairs as needed; allows you not to spend resources on scheduled maintenance of equipment that is still able to work normally; reduces the chance of an unexpected breakdown.

Our Concept of Digital Twin

We are interested in Predictive maintenance which is based on continuous diagnostics and monitoring of equipment status. The implementation of Predictive maintenance is achieved through the sequence of activities:

- Collection and pre-processing of data on the technical condition of a real object.
- Early fault detection.
- Prediction of failure time.
- Service Planning.
- Optimization of financial and time resources for servicing.

The first three points of Predictive maintenance implementation relate to the responsibility of the Digital Twin. Rest is the area of company management responsibility.

Equipping a real object with various sensors will allow the continuous collection of data on its technical condition. Industrial IoT technologies such as Big Data and a predictive statistical model can predict failure times with high accuracy. This will make it possible to quickly take measures to ensure the normal operation of the equipment.

Thus, the Digital Twin is a predictive maintenance tool, and allows simulating various options for device failures taking into account their operation modes, environmental influences and various degrees of wear. It is important that the Digital Twin is always kept up to date through the implementation of continuous communication with real object.

Cloud technology should be used to solve this problem. Figure 1 features the data flow scheme developed and implemented by our team.

As a cloud aggregator and data storage medium, the ThingSpeak server is used as a remote resource. MATLAB mathematical package integrated into the resource is utilized as data analyzer. The choice of this particular resource is explained by the convenience of using all benefits from the environment of scientific and engineering mathematical calculations offered by the MATLAB software for data analysis, mathematical models creation and virtualization of research.

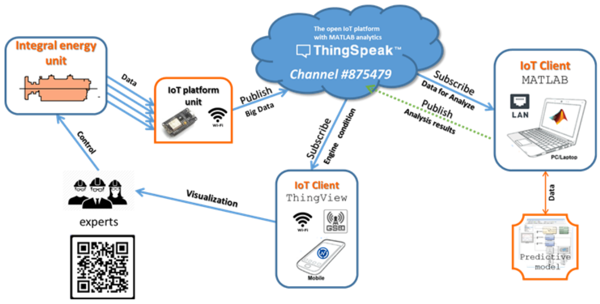


Fig. 1. Data roaming architecture

This project has its own channel on the ThingSpeak server, with an access through the URL address. For connecting and managing data on the ThingSpeak server, the MATLAB package includes special libraries. The results of processing incoming data can be opened to the public access on the server or used for local needs, for example, to create a predictive model.

Object data collection equipment

Figure 2 features the scheme of equipping the facility with data collection equipment.

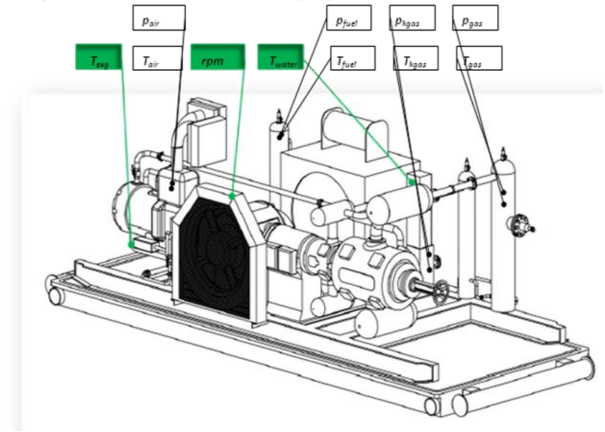


Fig. 2 Object data collection equipment

The basis of the data collecting system is a microcontroller, a set of crankshaft speed sensor and thermocouples, a multiplexer and 16-bit analog-to-digital converters, which converts thermo-EMF thermocouples (Fig.3). The characteristics of the microcontroller are given in Table 1. Fluid temperatures are measured using thermocouples of type J (temp range -35 to 871° C).

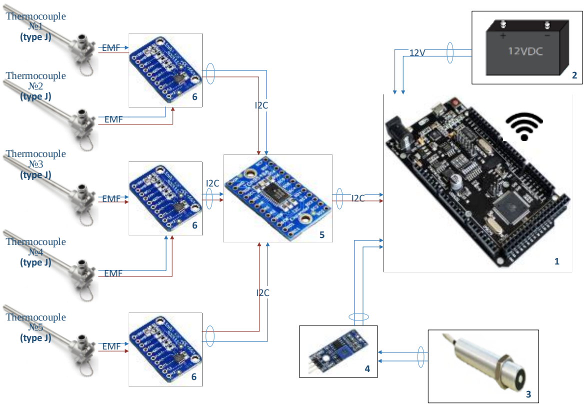


Fig. 3 Data acquisition system diagram
1 – microcontroller, 2 – battery, 3 – engine speed sensor, 4 – comparator, 5 – multiplexer, 6 – analog-to-digital converter

Analog-to-digital converters have two differential inputs and are connected to the microcontroller via the I2C bus. The multiplexer is based on the TCA9548A chip and is designed to connect devices via the I2C bus with the same MAC addresses.

The rotational speed of the crankshaft is calculated from the time period of the signals of the inductive sensor (Magnetischer Pick Up Altronic 791018-2), which is mounted directly opposite the flywheel, and a ferromagnetic plate is fixed to the flywheel.

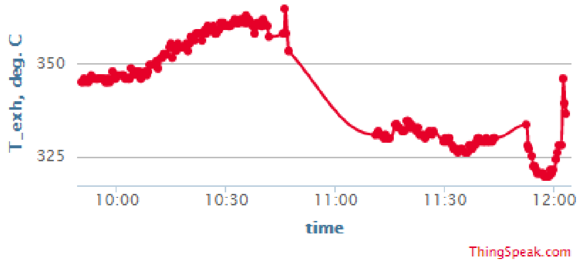
Table 1. Microcontroller specifications

Microcontroller	ATmega2560
IC Wi-Fi	ESP8266
USB-TTL converter	CH340G
Power Out	5V-800 mA
Power IN. USB	5V (500 mA max.)
Power IN. VIN/DC Jack	9-24 V
Power Consumption	5 V 800 mA
Logic Level	5 V
Wifi	Wi-Fi 802.11 b/g/n 2.4 GHz
USB	Micro USB
Clock Frequency	16 MHz
Operating Supply Voltage	5 V
Digital I/O	54
Analog I/O	16
Memory Size	256 Kb
Data RAM Type/Size	8 Kb
Data ROM Type/Size	4 Kb
Interface Type	serial\OTA
Operating temperature	−40° C/+125° C
Length × Width	53.361 × 101.86 mm
Antenna	Built-in\external antenna

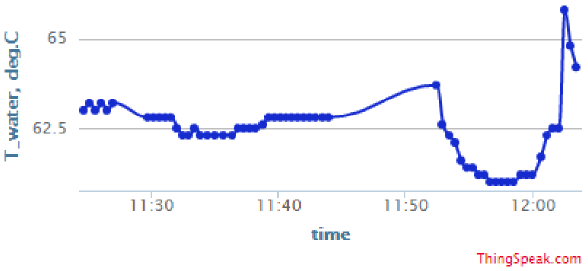
The microcontroller converts and processes the primary information received from the engine speed sensors and thermocouples, and sends the processed information to the server (Fig.4).

You can see their work in real time at the address https://thingspeak.com/channels/875479. The data refresh rate is 21 seconds. You can use the ThingView Android application to monitor incoming data using computer browser or mobile Internet devices.

Next, we proceed to parallel execution of the fourth, fifth and sixth project stages. We believe that this project is, in principle, infinite in terms, because during the life cycle of the real object and its digital twin, it not only lives, but also has the opportunity to develop.



a)



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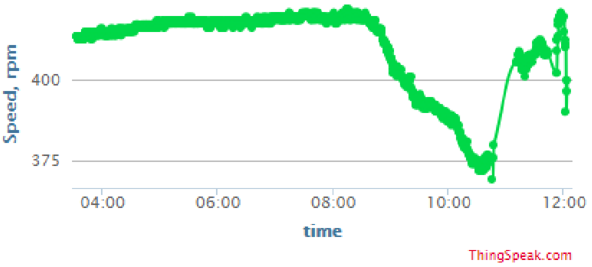

c)

Fig. 4. Remote monitoring of engine parameters (data received from the server ThingSpeak)
a – exhaust gas temperature, b – coolant temperature of the cooling system, c - engine speed

Conclusions

An approach to Predictive maintenance, which is based on continuous diagnostics and monitoring of equipment status the AJAX DPS-180 gas Reciprocating Compressor, designed for pumping gas from gas wells, is proposed.

The implementation of Predictive maintenance is achieved through the sequence of activities: collection and preprocessing of data on the technical condition of a real object; early fault detection prediction of failure time; service planning; optimization of financial and time resources for servicing. The first three points of Predictive maintenance implementation relate to the responsibility of the Digital Twin. Rest is the area of company management responsibility.

Thus, the Digital Twin is a predictive maintenance tool, and allows you to simulate various options for device failures taking into account their operation modes, environmental influences and various degrees of wear.

Cloud technology is used to solve this problem. As a cloud aggregator and data storage medium, the ThingSpeak server is used as a remote resource. The MATLAB mathematical package integrated into the resource is utilized as a data analyzer.

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ЦИФРОВОЙ ДВОЙНИК ГАЗОВОГО МОТОРКОМПРЕССОРА: КОНЦЕПЦИЯ, АРХИТЕКТУРА И ЭКСПЕРИМЕНТАЛЬНОЕ ВНЕДРЕНИЕ

А.А. Прохоренко, С.С. Кравченко, Е.И. Солодкий

Сочетание информационных и операционных технологий привело к новому способу производства, к новой технологической революции, известной как Industry 4.0. Цифровой двойник играет центральную роль в этой технологии. Digital Twin - это инструмент для профилактического обслуживания, который позволяет моделировать различные варианты отказов устройств с учетом их режимов работы, влияния окружающей среды и различной степени износа. Их можно разделить на два типа: прототип цифрового двойника и экземпляр цифрового двойника. Предложена концепция создания цифрового двойника реального физического объекта исследования - двигателя внутреннего сгорания AJAX DPS-180 с газопоршневым компрессором, который предназначенный для откачки газа из газовых скважин. Особенностью его работы является автономная длительная работа в полевых условиях с удаленностью обслуживающего персонала, прямым воздействием окружающей среды и обеспечением надежности и стабильности работы. Поэтому отслеживание параметров работы двигателя с последующим прогнозированием его отказов является особо актуальным. Работа по созданию цифрового двойника для AJAX DPS-180 ведется в кооперации и при поддержке компании «Armco-Engineering» - оператора этого оборудования.

Показаны шесть этапов процесса создания цифрового двойника данного объекта: сбор и предварительная обработка данных о техническом состоянии реального объекта; раннее обнаружение неисправностей, прогнозирование времени отказа; планирование услуг; оптимизация финансовых и временных ресурсов на обслуживание. Оснащение реального объекта различными датчиками позволило непрерывно собирать данные о его техническом состоянии, а технологии промышленного Интернета вещей, такие как Big Data и predictive statistical model прогнозируют время отказа с высокой точностью.

Приведены разработанные и реализованные схемы оснащения объекта оборудованием сбора данных и схема потока этих данных в Интернете вещей. Основа системы сбора данных - микроконтроллер, комплект датчика частоты вращения коленчатого вала и термопар, мультиплексор и 16-битные аналого-цифровые преобразователи, преобразующие термо-ЭДС термопары. На данный момент реализованы каналы измерения частоты вращения, температур охлаждающей жидкости и отработавших газов. В качестве облачного агрегатора и носителя этих данных предложено использовать сервер ThingSpeak как удаленный ресурс. В качестве анализатора данных используется интегрированный в ресурс математический пакет MATLAB.

Ключевые слова: цифровой двойник; газопоршневой компрессорный агрегат; интернет вещей; модель прогнозирования.

ЦИФРОВИЙ ДВІЙНИК ГАЗОВОГО МОТОР-КОМПРЕСОРА: КОНЦЕПЦІЯ, АРХІТЕКТУРА І ЕКСПЕРИМЕНТАЛЬНЕ ВПРОВАДЖЕННЯ

А.О. Прохоренко, С.С. Кравченко, Є.І. Солодкий

Поєднання інформаційних і операційних технологій привело до нового способу виробництва, до нової технологічної революції, відомої як Industry 4.0. Цифровий двійник грає центральну роль в цій технології. Digital Twin - це інструмент для профілактичного обслуговування, який дозволяє моделювати різні варіанти відмов пристроїв з урахуванням їх режимів роботи, впливу навколишнього середовища і різного ступеня зносу. Їх можна розділити на два типи: прототип цифрового двійника та екземпляр цифрового двійника. Запропоновано концепцію створення цифрового двійника реального фізичного об'єкта дослідження - двигуна внутрішнього згоряння AJAX DPS-180 з газопоршневим компресором, який призначений для відкачування газу з газових свердловин. Особливістю його роботи є автономна тривала робота в польових умовах з віддаленістю обслуговуючого персоналу, прямим впливом навколишнього середовища і забезпеченням надійності та стабільності роботи. Тому відстеження параметрів роботи двигуна з подальшим прогнозуванням його відмов є особливо актуальним. Робота зі створення цифрового двійника для AJAX DPS-180 ведеться в кооперації та за підтримки компанії «Armco-Engineering» - оператора цього обладнання.

Показані шість етапів процесу створення цифрового двійника даного об'єкта: збір і попередня обробка даних про технічний стан реального об'єкта; раннє виявлення несправностей, прогнозування часу відмови; планування послуг; оптимізація фінансових і часових ресурсів на обслуговування. Оснащення реального об'єкта різними датчиками дозволило безперервно збирати дані про його технічний стан, а технології промислового Інтернету речей, такі як Big Data і predictive statistical model прогнозують час відмови з високою точністю.

Наведено розроблені та реалізовані схеми оснащення об'єкта обладнанням збору даних і схема потоку цих даних в Інтернеті речей. Основа системи збору даних - мікроконтролер, комплект датчика частоти обертання колінчастого вала і термопар, мультиплексор і 16-бітові аналого-цифрові перетворювачі, які перетворюють термо-ЕРС термопари. На даний момент реалізовані канали вимірювання частоти обертання, температур охолоджуючої рідини і відпрацьованих газів. Як хмарний агрегатор і носій цих даних запропоновано використовувати сервер ThingSpeak як віддалений ресурс. В якості аналізатора даних використовується інтегрований в ресурс математичний пакет MATLAB.

Ключові слова: цифровий двійник; газопоршневий компресорний агрегат; інтернет речей; модель прогнозування.