The Design Concept of Digital Twin

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***Abstract*—According to the article, the modeling process of every digital twin can be divided into three stages: the development of SysML (The Systems Modeling Language) diagrams, the use of AnyLogic as a tool for simulation modeling, and the use of MES (Manufacturing Execution System) for communication with production systems. Also, it is suggested to evaluate the efficiency of a digital production process using two numerical indicators: the OEE (Overall Equipment Effectiveness) coefficient, the MCE (Manufacturing Cycle Effectiveness) coefficient.**

Keywords—digital twin, Internet of Things, Industry 4.0, efficiency, virtual model

I. Introduction

A digital twin is a concept introduced in 2002 by Michael Grieves. Since then, the idea has evolved with the advent of the Internet of Things (IoT), which in turn is one of six basic innovative approaches of Industry 4.0. Gartner (the world's leading research and advisory company) believes that half of the large industrial enterprises will use digital twins by 2021, and, as a result, they will be able to increase their 10% efficiency.

A digital twin is a virtual model of a system, process, or service, which means that digital twins can be used to present a product, factory, or business service.

The digital twin enables real-time monitoring of systems and processes and timely analysis of data to prevent problems before they occur, schedule preventative maintenance, reduce/prevent downtimes, open up new business opportunities, and plan future updates and new developments. While virtual models tend to be general concepts of a system, part, or family of parts, the digital twin is an instance. Digital twin technology provides opportunities to reduce the cost of checking and testing the system while ensuring a timely assessment of the system's behavior [1].

Two essential features are valuable for all digital twins:

- Always display an existing object.
- Represent the real state of the object.

These features facilitate obtaining a real view of the virtual system and its status. As long as the model corresponds to a uniquely identifiable object, and its state is sufficiently accurate, it can be considered a digital twin. If it is necessary, the digital twin itself makes operational changes in the real object.

II. The Digital twin levels

A. Pre-digital twin

Pre-digital twin is a classic virtual prototype, the creation of which is the task for preliminary development. Its main job is to reduce technical risks and identify problems during upfront design.

A virtual prototype is mostly used to verify crucial individual system decisions and reduce specific technical risks in the early stages of the design process.

B. Digital twin

A digital twin is a virtual system model that is capable of incorporating performance, health, and maintenance data from the physical twin. The physical twin can use knowledge from digital twins to improve its characteristics while working in real-time.

At this stage, the digital twin is subjected to all sorts of tests to determine the behavior of the physical twin in various «what if» scenarios. Any deficiencies identified during the inspections on the digital twin are used to carry out corrective actions on the physical twin.

C. Adaptive digital twin

The adaptive digital twin offers an adaptive user interface for physical and digital twins. The essential advantage of this digital twin is its ability to study the preferences and priorities of human operators in different contexts.

D. Intelligent digital twin

The smart digital twin has all the characteristics of an adaptive digital twin. Besides, it has unsupervised machine learning capability discern objects and patterns encountered in the operational environment, and also it is set to accurately study the system and state of the situation in conditions of uncertainty and incomplete observation.

III. DEVELOPMENT OF DIGITAL TWIN

A. SysML as a basis for creating digital twins

SysML (The Systems Modeling Language) is a graphical

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modeling language that supports the analysis, specification, design, verification, and validation of complex systems. SysML can represent the following aspects of systems, components, and other objects:

- Structure, interrelation, and classification.
- Behavior-based on functions, messages, and states.
- Limitations on physical and operational properties.
- The distribution between behavior, structure, and limitations.
- Requirements and their relationship with other conditions, design elements, and test cases.

SysML includes 9 diagrams: package diagram, requirement diagram, behaviour diagram (activity diagram, sequence diagram, state machine diagram, use case diagram), parametric diagram, structure diagram (block definition diagram, internal block diagram) (Fig. 1) [2].

For example, to present the specification of a car we used a simplified version of the SysML, it means that there were only six diagrams for modeling: package diagram, requirement diagram, activity diagram, parametric diagram (Fig. 5), block definition diagram (Fig. 2, Fig. 3), internal block diagram (Fig. 4).

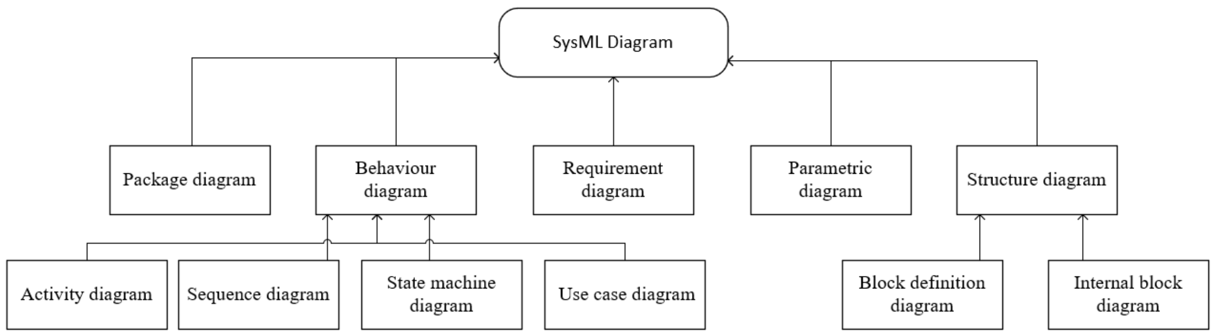

Fig.1. SysML diagram

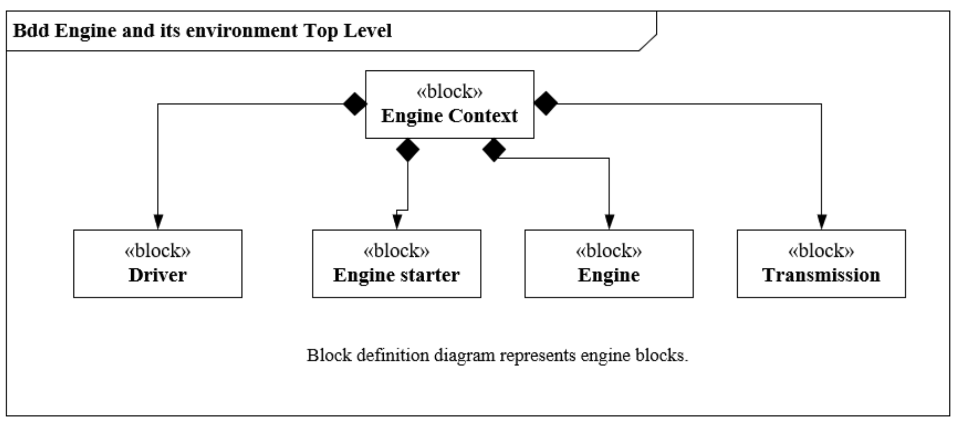

Fig.2. Block definition diagram – top level (car specification).

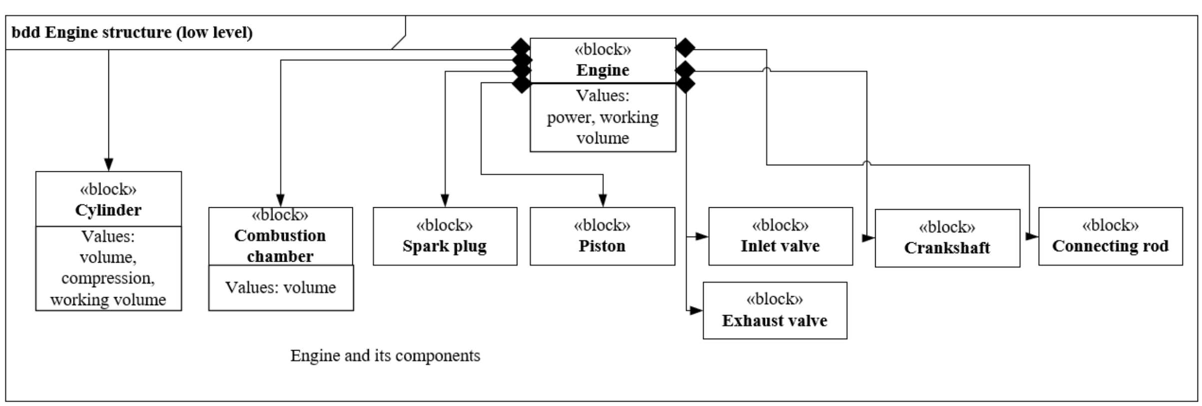

Fig.3. Block definition diagram – low level (car specification).

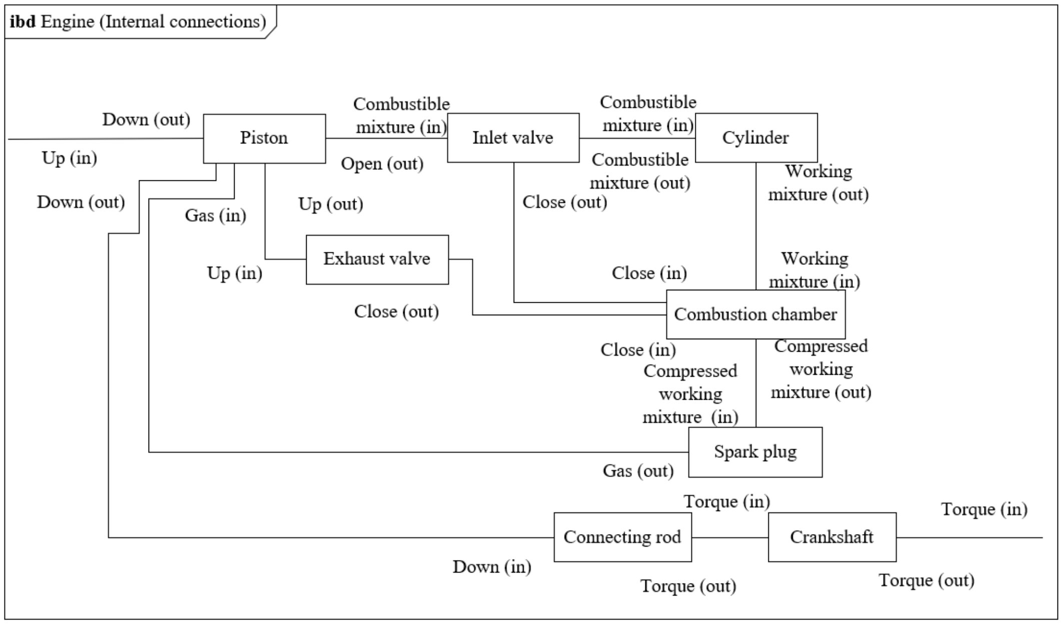

Fig.4. Internal block diagram (car specification).

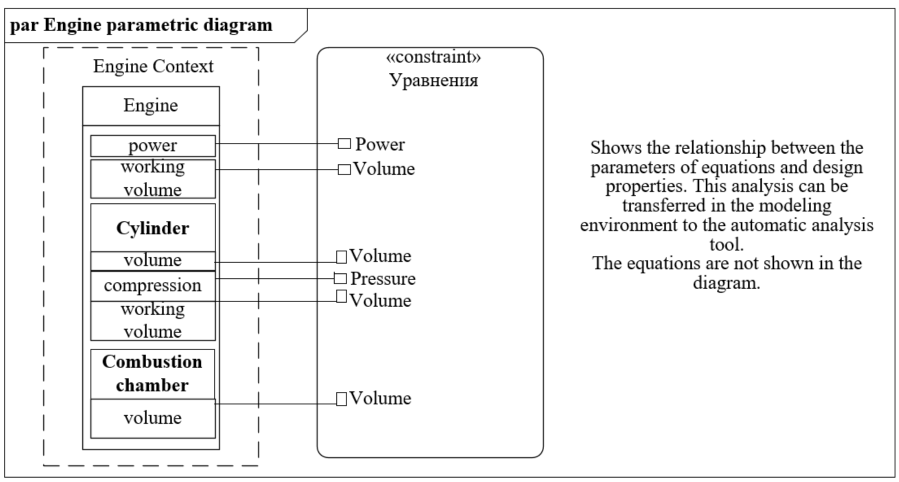

Fig.5. Parametric diagram (car specification).

The first three diagrams are simple, that is why they can be presented in text form.

The package diagram shows all model elements for describing car specifications, and this means that they can be a whole together. In our case, it contains three folders with the following labels: requirements, behavior, structure, parametric.

The next diagram – requirements contain technical and user specifications for car construction and their values (limitations). Our diagram includes the following criteria: capacity, vehicle performance, driving comfort, emissions, reliability, fuel consumption. Insulation, steering gear can limit driving enjoyment.

For the behavior diagram, which has four integral diagrams, we describe one of them - an activity diagram. Each diagram of this type presents one process which describes the activity that a driver can apply to the vehicle. And in this case, the activity diagram is set the car in motion. The process starts with the action – to insert the ignition key and end with – to ensure the transmission of torque to the semi-axle of the front wheels. One of the most critical parts (details) of this process is the engine; that is why the next three diagrams focus on it. These diagrams are not complete and designed for educational purposes to demonstrate the initial capabilities of the SysML language.

SysML can be used at every level of system specification and helps engineers focus on design, rather than on the traditional hierarchical complexity of documents and drawings, it is this modeling language that facilitates the adoption and use of technology. It facilitates implementation in several teams working on large projects.

B. Simulation as the basis of digital twin technology

Simulation is a numerical method for studying complex systems, a heterogeneous mathematical apparatus describes their elements, and a specific connecting model unites them into the informational model.

When it comes to the use of simulation to create digital twins, there is a need to consider several parallel tasks.

The first of them is related to the acquisition of data that is removed from a real object and is necessary for carrying out virtual modeling on real objects.

The second task is to decide on the rationality of using universal software for building simulation models, since in some cases, the most appropriate solution may be the individual development of a simulation model.

The third task arises from practical observations that show that the most effective digital twins are the main advantage of those areas for which formalized methods are an integral part with the usage of mathematical models and terms, but the main reason for creating digital twins technology is to use them in all areas [4].

One of the recognized tools for implementing a simulation model while creating a digital twin is AnyLogic, which is positioned as a powerful and flexible modeling environment.

C. The connection between MES-systems and digital twins

The MES-system (manufacturing execution system) is designed to simulate and control intradepartmental material flows in the control tower. Modern MES is designed to work with modern IoT interfaces as well as for connecting to outdated equipment, which allows it to saturate a vast amount of data with meaning and consistency. In this case, the MES-system works as an intermediate translator layer, which turns the data stream into valuable information suitable for making strategic decisions.

There are two numerical indicators for evaluating the efficiency of a digital production process: the OEE coefficient (Overall Equipment Effectiveness), the MCE coefficient (Manufacturing Cycle Effectiveness).

The OEE coefficient provides the analysis of the behavior of the «digital model» of the production system, and it is the measurement of the proportion of the planned production time, which is necessary for the manufacture of the part without taking into account work in progress.

The formula for calculating the OEE coefficient (1):

$$OEE = C_t * C_p * C_q = \frac{\sum_j \left[F_{t_j} - D_j\right]}{\sum_j \left[F_{t_j}\right]} * \frac{\sum_i [T_i * O_i]}{\sum_j \left[F_{t_j} - D_j\right]} * \frac{\sum_i [T_i * (O_i - Def_i)]}{\sum_i [T_i * O_i]} \quad (1)$$

Equation (1) contains the following: C_t – time coefficient (availability), C_p – performance coefficient (efficiency), C_q – quality coefficient (quality level), j – number of equipment, F_{t_j}– fund of time of work of a unit of equipment (work shift time), D_j – equipment downtime, including planned, i - the number of products produced on this piece of equipment, T_i - tact of release of the product, O_i - amount of manufactured product within F_t, Def_i - reject quantity of a product manufactured within F_t, $\sum_j \left[F_{t_j} - D_j\right]$ - the time available for the output per unit of equipment, $\sum_i [T_i * O_i]$ - the amount of time spent on production, $\sum_i [T_i * (O_i - Def_i)]$ – the amount of time spent on the production of non-defective product.

The second indicator, which describes the digital production model, is the coefficient MCE, which is the ratio of the labor intensity of technological operations that the corresponding production units perform during the processing of products.

The calculation of the MCE coefficient (2):

$$MCE_{ik} = \frac{T_{ik} * O_{ik}}{\sum_j F_{t_j}} \quad (2)$$

Equation (2) contains the following: O_{ik} − development of the production site for parts included in the product, T_{ik} - tact of production in area k, F_{t_j} - operating time of equipment fund.

It follows from this that the OEE coefficient characterizes the density of equipment loading, which turns into a digital model, and the MCE coefficient is a characteristic of the dynamics of the material flow in the digital twin of the production system.

IV. CONCLUSION

The use of digital twins to optimize activity in enterprises will allow them to increase their efficiency by reducing repair costs, reducing information working time, reducing the number of defects, etc. As part of this article, the authors suggest that digital twins divide into 4 levels (4 stages of creation), each of which differs from each other in model accuracy and functionality.

As a development technique, it is proposed to use the SysML language as a graphical modeling language to describe the digital twin, depending on the choice of implementation complexity. The second step is the use of AnyLogic for the development of a simulation model. A link between the developed digital twin and the rest of the enterprise's systems is proposed to use the MES system since it has the required technical capabilities and allows us to calculate the necessary economic indicators.

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