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У цьому збірнику представлені наукові доповіді учасників Міжнародної науково-технічної конференції МТЕ-2023, яка відбулася 16–18 травня в Луцьку, на базі Луцького національного технічного університету. Цей збірник містить загальні відомості про досвід і поглиблення знань із структури, властивостей, технологій одержання металевих, композиційних, керамічних, полімерних і порошкових матеріалів у техніці. Матеріали наукових дискусій присвячені сучасним дослідженням і перспективам розвитку машинобудування в цілому та новим стратегіям розвитку автомобільного транспорту зокрема.

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This Collection presents scientific reports of the participants of the International Scientific and Technical Conference MTE-2023, which took place on May 16-18 in Lutsk, at the Lutsk National Technical University. This collection contains general information about the experience and deepening of knowledge in the structure, properties, technologies of obtaining metal, composite, ceramic, polymer and powder materials in engineering. The materials of the scientific discussions are devoted to modern research and prospects for the development of mechanical engineering as a whole and to new strategies for the development of road transport in particular.

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CONTENT │ ЗМІСТ

The Digital Twin Model of the Spindle Unit

Sapon Serhii [1][0000-0003-1082-6431], Klochko Oleksandr [2] [0000-0003-2841-9455], Ponomarenko Sergiy [1][0009-0003-3260-6541], Dzyuba Dmytro [1][0009-0001-8024-6558]

[1] Chernihiv Polytechnic National University, 95, Shevchenko St., Chernihiv, 14035, Ukraine
[2] National Technical University «Kharkiv Polytechnic Institute»,
2, Kyrpychova St., Kharkiv, 61002,Ukraine
s.sapon@gmail.com

Abstract. The spindle system of any machine tool directly and significantly influence on the efficiency of machining. The dynamic characteristics of the spindle unit during machining are almost impossible to visualize in real time with traditional methods. The use of a digital twin of the spindle unit allows to determine the actual dynamic characteristics with a sufficiently high degree of accuracy. The key component of the digital twin of the spindle unit is its model. It is a set of digital models that describe its design, technological, operational, parameters and physical and mechanical processes that occur during the operation of the spindle unit in real time. The structure, list of characteristics of the digital twin model of the intelligent spindle unit are determined. The stages of its model creation are given, the tasks to be solved at these stages are specified. Building a model of a digital twin of a spindle unit has a two-directional character and cannot be considered a fully completed process, since the model of a digital twin of a spindle unit will be constantly refined and updated until the spindle unit is out of service. High-precision modeling, model integration, model verification, model consistency, mechanisms of functioning and evolution of models - are key issues, that need to be solved when creating a model of a digital twin of a spindle unit.

Keywords: Digital Twin; Intelligent Spindle Unit; Model of a Digital Twin; Spindle.

The dynamic characteristics of the spindle unit directly affect almost all functioning efficiency indicators of the technological machining system. Obtaining the most reliable dynamic characteristics of the spindle unit during operation is an important task for implementing effective intelligent control systems of the machining processes. A promising way to solve this problem is to create digital twins of spindle units.

The concept of digital twins was first proposed by Michael Grieves and described in detail in his work [1]. The idea of creating and perspective of using digital twin of metal cutting machines is highlighted in works [2-4]. The definition of a digital twin of a spindle unit, as a physical object or system, is provided in the article [5]. The definition of the model of the digital twin of the spindle unit is also presented there.

It is proposed to use the tools of Model-Based Systems Engineering (MBSE) [6, 7] to create the model of the digital twin of the spindle unit. According to the MBSE, the model of the digital twin of the spindle unit is an organized architecture of digital models that describe the design, technological, operational parameters of the spindle unit as well as physical and mechanical processes that occur during its operation and reflect the influence of these parameters on the quality and functioning efficiency indicators of the spindle unit in real-time. The digital twin model of the spindle unit also takes into account data on previous periods of operation and information that reflects individual design and technological features of the spindle unit formed during its manufacture.

For the most adequate description of the features of the spindle unit's functioning, its digital twin model should have the following main characteristics: functionality, uniqueness, multiphysics, multiscale, hierarchy, integrability, dynamicity, probability, hyperrealism, multidisciplinarity, computational capabilities.

The components and stages of creating a digital twin model of the spindle unit according to the concept of MBSE are presented and described.

The first stage involves creating three-dimensional geometric CAD models of the spindle unit components, and in the first approximation, modeling the influence of operating processes and loads on the static and dynamic characteristics of the spindle unit in CAE systems. The main task of this stage is the initial rapid multi-physics, multi-scale interdisciplinary modeling and analysis of the spindle unit design without intension for high accuracy of process mapping.

The task of the second stage is to build an ordered architecture of digital multiphysics mathematical models that quantitatively describe the relationships between the parameters of the spindle unit and its quality and efficiency indicators. A specific list of mathematical models is determined by the functional requirements for the spindle unit in the form of a set of necessary and available indicators, which are needed and possible to control in a real spindle unit. At this stage a structured system of data exchange between the models describing the spindle unit functioning is created with the use of artificial intelligence tools.

At the next stage a preliminary check of the adequacy of the built architecture of the digital models of spindle unit is made. Evaluation is carried out on a priori information based on expert knowledge of the physics and mechanics of the processes that occur during the operation of the spindle unit. For this purpose, instead of connecting to the sensors that record the state of the real spindle unit, the created digital twin model is connected to a set of virtual sensors that generate signals similar to real processes.

The 4th stage involves the connection of the created digital twin model to the real spindle unit, adaptation and refinement of the model based on the experimental tests of spindle unit.

The final stage of the digital twin creating involves adaptation of the digital twin model to the design, technological and operational features of a specific spindle unit throughout its entire life cycle. The digital twin model is connected to the data collection, processing and transmission system, which commutates data from the sensors of the real spindle unit. Further, statistically processed data from the sensors of the real spindle unit is transferred online to the digital twin model, which, thanks to this, is updated and refined during the entire life cycle.

Thus, the construction of the digital twin model of the spindle unit has a two-way nature: from general to particular and from particular to general. The combination of these two directions indicates that the construction of the digital twin model of the spindle unit cannot be considered a completely finished process, since the digital twin model will be constantly refined and updated until the operation of the spindle unit ends.

The following key issues must be considered in detail when creating a digital twin model of the spindle unit: high-precision modeling, integration of models, model verification, analysis of model consistency, mechanisms of model functioning and evolution.

The digital twin model of the spindle unit simulates all possible modes of operation of the spindle unit during its life cycle, takes into account the influence of external factors and control processes, allows to predict the resource state, quality indicators and efficiency of the spindle unit operation.

The implementation of the digital twin model also has a number of unsolved issues. First, the stochasticity, nonlinearity and partial uncertainty of the processes in the spindle unit make it challenging to ensure accuracy of the models that form the architecture of the digital twin model. The emergence of discrepancies between models and real objects and processes is difficult to track online. Therefore, the benefit of using models decreases. The second problem is that continuous physical space and discrete virtual space are at different scales. This creates the problem in overcoming the discrepancy in order to implement the integration of the real spindle unit and its digital model. In order to update the digital twin model throughout the life cycle of the spindle unit, the data from the spindle unit sensors and models must be generated continuously. As a result, the problem of integration and preservation of continuously growing volumes of data arises.

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