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Compilation of Requirement System on Development of CNC Machine Tools with Modular Dimensions and Universal Technology

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Abstract **-** The requirement of the Fourth Industrial Revolution is maximum universality in mechanical engineering. This universality extends to the creation of machine tools for implementing manufacturing processes. The purpose of the study provided in this article is to identify a set of requirements that will serve as the foundation for designing a machine tool family with a modular structure that can apply multiple manufacturing technologies. The set of requirements includes investigating the modular structure, identifying applicable technologies, assembling constraints necessary for the development of the user interface and associated parametric design model, and establishing requirements related to the development of a virtual commissioning strategy.

Keywords**:** ***CNC machine tools, requirement system, industry 4.0, modular dimensions***

1. Introduction

One of the most significant criteria for mechanical manufacturing technology in the Fourth Industrial Revolution is the capacity to accommodate specific client expectations in a mass production technical setting. This means that even during the production of items with mass production characteristics, each product should be customized to meet individual customer needs. The development described in this article started on February 1, 2025. The research aims to develop a machine tool family with a modular structure, where the size is determined by the individual customer requirements. The customer also determines whether the machine tool should perform laser cutting, plasma cutting, flame cutting, milling processes, or combinations thereof. This article presents the process of defining the set of requirements necessary for this development.

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2. Literature review

Engineers have been motivated to create new technologies for many years in response to the demand for modular machine tools. Peukert et al. [1] investigated machine tool models and structures to classify modularity options for each solution. According to their opinion, a modular structure can increase sustainability in the field. Abdulai and colleagues [2] analyzed 200 publications on the applicability of modular equipment structures in the construction industry. They concluded that there is a considerable gap in the building industry's modular equipment production. Yevu et al. [3] examined the feasibility of using artificial intelligence to build modular machines. Their research confirmed that artificial intelligence improves modular system development in terms of productivity, worker safety, and operational dependability. Egelmeers et al.. [4] developed a modular development framework for mechatronic systems. With the potential for modular development, engineers will be able to develop various machines and technologies more efficiently and quickly in the future.

A significant requirement of digital manufacturing science is the use of universal machine tools. Bidar et al.. [5] conducted experiments on universal machine tools. The machining machine was capable of performing both milling and additive manufacturing operations. In their research, they examined the possibilities of modifying the geometries created during additive manufacturing with the milling process and the effects of the milling process on the geometry. Yamazaki [6] analyzed the expected impact of the widespread use of multi-tasking machine tools. Based on his study findings, he believed

that these new forms of machine tools would allow for faster and more precise manufacturing, resulting in lower labour demand in the industrial sector. Komatsu et al. [7] analyzed various machining processes to develop an automated selection algorithm for universal machine tools. The selection mechanism can determine the necessary machine tool configuration without human intervention based on the parts to be produced.

From the literature analysis, we can conclude that there is currently a significant demand for developing modular machine tools and universal machining machines.

3. Analysis of initial state

I began my research by analyzing the CNC milling machine, which can be interpreted as the basic machine for the development concept (Fig. 1-2). The analysis covered the structure, mechanical properties, static system of the machine table, motion ranges, and the machine elements used.

Fig 1.: Initial state CNC machine tool

During the analysis of the basic machine, I concluded that the current static system of the equipment does not allow for movement towards modularity, and therefore, the mechanical model related to the machine table must be redesigned. However, the structures associated with the machining unit are suitable for a universal device. Based on the analysis of the motion systems, it can be stated that the basic machine design is suitable for placing two technologies on the machine tool.

Based on the analyses, I concluded that the development of the basic machine could lead to the creation of an efficient universal machine tool family.

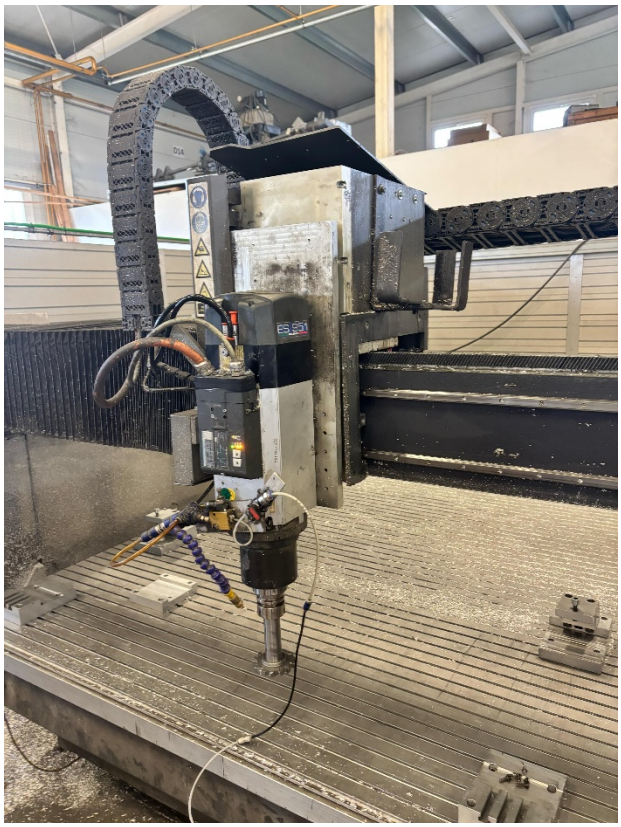

Fig 2.: Spindle of CNC machine tool

4. Development of a system of requirements

To meet the demands of the Fourth Industrial Revolution with our development, a detailed set of requirements had to be developed for the project. As a result of this development, a framework will be available that will allow for the manufacturing of an economical and efficient machine tool family based on individual customer needs

4.1. Modular structure

During the development of the machine tool family, a table with various-sized modules must be created. Module design should consider the general component sizes and dimensional limits found in mechanical manufacturing. The mechanical stability of the modules is also vital to consider, as the universal structure will only be efficient if the modules fit together without significantly increasing vibration tendencies while maintaining excellent rigidity. Another crucial need is that the modules fit together swiftly and precisely. The platform size restriction generated during machine tool transport must also be considered when determining the sizes of the modules and the machine tools that can be assembled from them.

4.2. Applicable technologies

In addition to the modular structure, the customer must be able to choose from the available manufacturing technologies and the size of the machine tool. This level of universality is a completely new concept in the field. As a result of the development process, the customer will be able to select between laser cutting, plasma cutting, flame cutting, or milling technologies for the machine tool body. Our main objective is to create a machine tool design that can accommodate two technologies above the table. The two technologies will be placed on two separate portals, allowing them to move independently of each other.

4.3. User interface and parametric design model

The development will be truly effective if the customer can assemble the machine tool design they wish to purchase themselves. To achieve this, a user interface must be created where the customer can assemble the desired construction variation without intervention from the manufacturing company. The selection will also extend to the workspace size and the applicable technology or technologies. The user interface containing the selection algorithm must be connected with a parametric design model, which will create machine tool design documentation tailored to the customer's individual needs and deliver it to the manufacturing company's engineers. This method will considerably reduce design time and complexity while simultaneously lowering design expenses.

4.4. Virtual Installation Strategy

In establishing the virtual commissioning strategy, our goal is for the customer to test the expected efficacy of their selected design in the digital space. To perform the testing, it is necessary to know the key dimensions and properties of the components the customer will manufacture, as well as other machining conditions. With virtual testing, the customer may discover that a different machine tool with various configurations and sizes will be required and modify their purchase accordingly.

5. Summary

This article presents the initial phase of a research process aiming at developing a machine tool family that is customizable to customer needs, with a modular structure, adjustable workspace, and configurable material removal technologies. In the current phase of the research, the set of requirements needed to establish the future directions and parameters of the design advancements has been identified.

Acknowledgement

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