Industry 4.0 and Multi-tasking machining

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Abstract: *A clear trend of Industry 4.0 and smart manufacturing is to promote the increased use of multi-tasking machine tools. These machines are easily integrated into digital production systems and enable real-time data acquisition, remote monitoring and adaptive cutting processing. The integration of multi-tasking machine tools and digital manufacturing systems will improve the implementation of predictive maintenance, process optimization and production efficiency. Moreover, the development of robotics and AI along with the adoption of Industry 4.0 will increase the market share of these machine tools. The market demand is expected to increase further due to the rise of Industry 4.0. The paper analyzes the main advantages of multi-tasking machining, focusing on the advanced features of multi-tasking machine tools, as well as the latest trend of integrating additive manufacturing processes with CNC machining.*

Keywords*: INDUSTRY 4.0, MULTI-TASKING MACHINING*

1. Introduction

The task of machine tools is to transform semi-finished products with certain mechanical properties into finished parts with the desired geometry, dimensions and quality of the machined surface. As the requirements for the production of parts with higher quality, lower machining costs and shorter delivery times increase, so does the need for machine tools with higher accuracy and machining efficiency. For this reason, machine tool manufacturers are focused on providing the industry with solutions to the key challenges it faces today: improving productivity, skilled labor shortages, energy prices, wage inflation, increasing competitiveness, environmental protection, i.e. how technology and advanced services lead to increased profitability in production. For example, increasing the level of automation of machine tools is one of the solutions to mitigate the negative effects of the lack of professional skills of workers and the tendency to increase their wages. Machine tools must be more productive and sustainable than ever before, i.e. they must allow for higher uptime (the degree of employment during working hours) and faster payback on the investment made in their acquisition.

Multi-tasking is synonymous with nouns like productivity, competence and efficiency. In today's world, where we are surrounded by advanced technology and tight deadlines, multitasking has evolved from a luxury to a necessity. Multi-tasking machine tools have become an important part of smart factories. They combine the functionality of two or more traditional machine tools to form a "super" machine. Integrating multi-tasking machining into the production process can effectively solve quality problems and significantly increase machining productivity because multitasking machining is highly efficient.

The term Industry 4.0 stands for the fourth industrial revolution, which is defined as a new level of organization and control over the entire value chain of the product life cycle, focusing on increasingly individualized customer requirements. Concepts such as „Smart Factory“, „Internet of Things“, „Cyber Physical Systems“ and „Machine to Machine“ are no longer considered science fiction and will soon become reality in the processes of the metalworking industry. The goal of using new technologies in the context of Industry 4.0 is to increase processing productivity (drastically shortening the time between product development and delivery to the customer), efficiency and energy savings. For this reason, major technological transformations are bound to occur. The integration of technological transformations and Industry 4.0 will make the machine tool market the cornerstone of modern production, especially the segment dedicated to the manufacture of multitasking machine tools.

The increasing application of the concept of Industry 4.0 and smart manufacturing in the manufacturing sector is definitely leading the industry to increasingly use multi-tasking machine tools. These machines can be integrated into digital manufacturing systems and enable real-time data acquisition, remote monitoring and adaptive cutting. In this way, the implementation of predictive maintenance and the optimization of the machining process is supported.

The paper analyzes the main advantages of multi-tasking machining, focusing on the advanced features of multi-tasking machine tools and the latest trend of integrating additive manufacturing processes with CNC machining.

2. Multi-tasking machining

The introduction of new technologies and innovations has given rise to a new generation of machine tools known as multi-tasking machining systems. In the world of machining, multi-tasking means combining machining processes on one machine that are traditionally performed on several machine tools. „Complete machining“ is the key word: place the part in the machine once and manufacture it completely. The defined process and program must be perfect in advance, then machining in a single clamping operation becomes a reality. CNC multi-process machining systems are capable of performing a variety of operations with multiple tools and/or spindles in a single setup. Advances in computer technology have transformed these systems from stand-alone production units into complex work cells. Multi-process machine tools typically have multiple control axes (five or more) and, depending on the design, may have multiple spindles. In this context, these systems can contribute to significant manufacturing savings as they are able to machine complex workpieces with multiple features and geometries without the need for multiple setups and transfers between machines.

Multi-process machine tools represent the most dynamic segment of the machine tool industry today. Although their market share is relatively small, their sales are growing steadily as manufacturers increasingly recognize their advantages in machining complex parts. Machining complex parts in one setup and on one machine tool reduces workflows, lowers labor costs and increases productivity and machining quality by eliminating the need for multiple setups.

The tangible benefits of multi-tasking machining systems have attracted the attention of many sectors of the manufacturing industry, including the automotive, injection molds and aerospace industries. These industries see these machining systems as a means to achieve significant machining productivity, improve the quality of machined surfaces and increase profits. However, these machines represent a large capital investment, especially for small metalworking companies, and therefore the right choice of a multi-process machine tool depending on its purpose is an important decision for the company. Failure to make the right decision can have a detrimental effect on user satisfaction and the time it takes to recoup the investment. The savings in machine tool set-up, increased machining accuracy and reduced inventory can be significant if the machine is suitable for the company's production program. Therefore, production engineers and managers are faced with the not-so-easy task of configuring and selecting a multi-process machine tool. Before implementing a multi-tasking system, a decision-maker must be clear about the production goals associated with the use of such complex technology and large capital investments. Currently, there is no industry standard to help solve this problem, and decision making depends on the knowledge and advice of experts in the field of production engineering.

Figure 1 shows a possible framework of factors involved in the decision-making process for a selection of a multi-tasking machining systems [1].

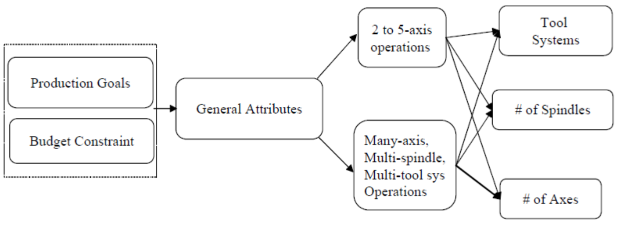

Fig. 1 *The framework of factors for selecting a multitasking machining systems*

Process integration is the ability to perform multi-axis turning, milling, drilling along different axes, grinding, gear making, etc. on one and the same machine. The latest trend is the development of hybrid multi-process machine tools that combine subtractive (by removing material) with additive processes.

3. The most important advantages of multi-tasking machining

The three main advantages of multi-tasking machining are accuracy, productivity and machining costs.

1. Greater accuracy of the end product

Since positioning is no longer required after each operation, accuracy is increased, especially for workpieces with complicated geometry and plane relationships.

2. Reduction of production and non-production times

The reduction in machining time is achieved by the simultaneous operation of several tools or the simultaneous operation of several tools on several spindles. Machines with two or more spindles enable synchronous and asynchronous operation. Synchronous operation means the production of the same product on all spindles and asynchronous production of different products at the same time. Asynchronous operation makes it possible, for example, to produce the "left" and the "right" part in the same operation or to machine the same part from all sides, so-called six-sided machining.

The time required for set-up is significantly reduced by having only one machine on which all machining operations are carried out in one operation without interrupting work, as shown in Figure 2 [2]. All machining steps can be automated, from the placement of the preparation material to the removal of chips and the removal of the finished part from the machine tool.

3. Reduction of production costs

Major savings in production costs result from the fact that machining is carried out on a single machine. These savings include: the need for a smaller number of machine tools, a smaller number of tools because only one machine tool needs to be equipped, lower power consumption, no need for intermediate storage, a smaller footprint for machine tools, cheaper machines for tool maintenance, etc. Figure 3 shows the "DONE IN ONE" concept of the company "Yamazaki Mazak", which represents the integration of all necessary machining operations to obtain a finished product from preparation on one machine in one operation and significantly reduce production costs.

The WFL Millturn Technologies GmbH & Co uses a similar slogan "ONE TIME CLAMPING - MACHINE COMPLETE".

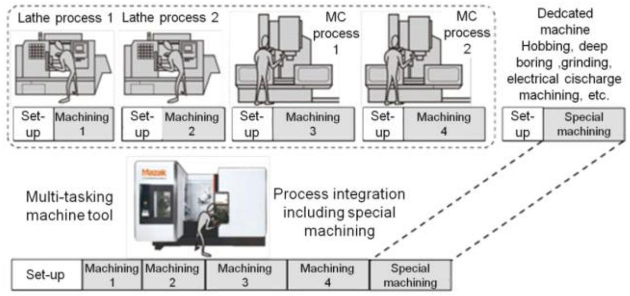

Fig. 2 *Process integration by multi-tasking machine tool including special machining*

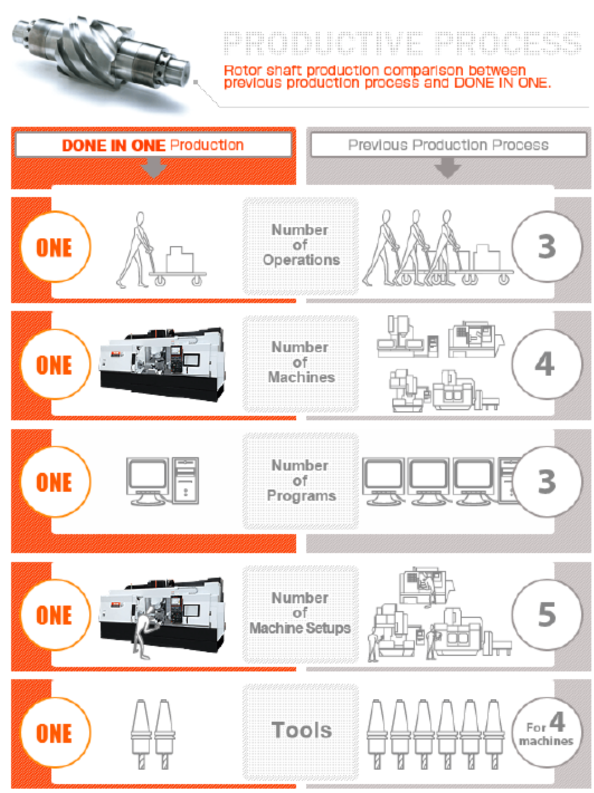

Fig. 3 *"DONE IN ONE" concept (source: Yamazaki Mazak Co.)*

Other potential benefits of using multi-tasking machine tools include:

- a higher throughput for small and medium batches,
- greater flexibility, which makes it possible to constantly change the characteristics of the workpieces to be machined.

The great flexibility of these machine tools results from their design and the possibility of programming the machine without having to work on the machine itself. The design of multi-tasking machines is increasingly modular, which means that different configurations of machine tools may be required depending on requirements. Machine programming is independent of the machine and there are a number of programs available to simulate the machining process. By simulating the machining process, it is possible to gain insight into the position of the workpiece and the path of the tool (it is possible to change the geometry of the workpiece or start manufacturing a new product with virtually no interruption to machine operation).

The manufacture of aircraft components, for example, requires the use of precision manufacturing processes such as turning, milling, drilling, jig boring, grinding, polishing, etc. in multiple setups. Aircraft part manufacturing often involves complex shapes, large part sizes and the use of exotic metals – all features that complicate the production process. On the other hand, the use of multi-tasking machines offers considerable advantages for the production of these components. In the case study [3], which involved the production of some typical components such as covers, housings, valves, etc., the objective was to quantify the techno-economic advantages of using multi-tasking machine tools compared to the individual use of several machine tools. An attempt was made to compare the production of aircraft components with multiple machine tools, i.e. multi-tasking machines, in terms of production time and costs, number of set-ups, etc.

The results of a comparative study between the use of multi-machine tools and multi-tasking machine tool for the production of aircraft components are shown in Figures 4 and 5. It can be clearly seen that the use of multi-tasking machine tool can significantly reduce the number of adjustments and therefore the overall time and cost of manufacturing these components.

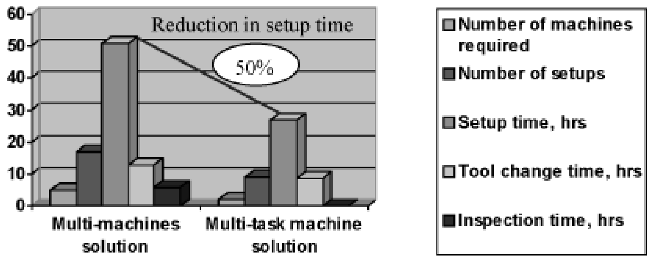

Fig. 4 Time comparison between multi-machines and multi-tasking machine tool

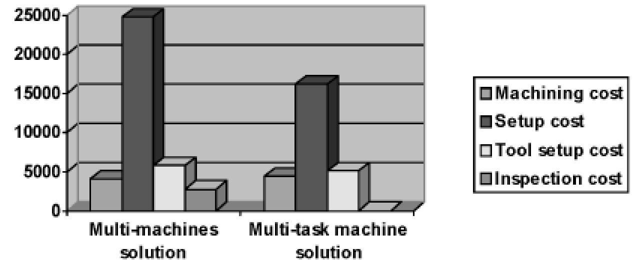

Fig. 5 Cost comparison between multi-machines and multi-tasking machine tool

4. Advanced features of multi-tasking machine tools

Multi-tasking machine tools were originally designed to integrate the turning and milling functions of machining centers. However, further development enabled the integration of special machining operations that were previously considered very difficult to integrate. Newer multi-tasking machine tools allow the integration of some special machining operations, such as: *deep boring with a long boring bar, deep hole milling with a special high-rigidity tool holder, taper drilling with a U-axis tool, hobbing of gears with an integrated shaft, grinding of turbine blades, turning with rotary round inserts*, etc.

Until now, special machines have been used for many deep boring applications because it is difficult to machine them with universal machines. Multi-tasking machine tools enable deep boring by long boring bar of up to 1000 mm. Figure 6 shows a detail from the workspace of a multi-tasking machine tool with a deep drilling tool.

The production of conical bore (conically shaped holes), e.g. in valve components, is very difficult because a good surface is required, which is necessary for the high tightness of the valve. The drilling of tapered holes cannot be done with a milling spindle, but can be done with a special CNC-controlled tool head with a “U” axis mounted in the machine spindle, Figure 7. A tool with a "U" axis has a steering axis in the radial direction of the tool spindle, so that the tip of the tool can be steered in the radial direction when the milling spindle rotates. With this method, it is possible to produce a complex internal taper or a curved surface with high accuracy.

Fig. 6 *Deep boring on multi-tasking machine tool (source: Yamazaki Mazak Co.)*

Fig. 7 *Boring by U-axis tool (source: D’andrea TA-C160)*

Hobbing of gears integrated into the shaft can also be performed on multi-tasking machine tools by synchronizing the rotation of the main spindle with the milling spindle, Figure 8. These gears can be found in many assemblies, e.g. in aircraft engines, construction machinery and the like. The production of gears is normally carried out on special machine tools.

Fig. 8 *Machine gears with multi-tasking machine tool (source: Yamazaki Mazak Co.)*

5. Hybrid multi-tasking machine tool

Metalworking processes can be divided into three categories. The first one is subtractive processes (machining, grinding, polishing, laser cutting and so on). The second one is shaping machining (casting, forging, stamping, injection molding and so on) and the third one is additive processing (Directed Energy Deposition - DED, Laser Metal Deposition - LMD, Powder Bed Fusion - PBF, Selective Laser Melting - SLM and so on).

Reducing manufacturing costs and overall processing time is critical for industrial systems to maintain a competitive advantage. Production should enable the achievement of high added value. The implementation of Industry 4.0 strategies includes, among other things, the hybridization of manufacturing processes. This is why the latest trend in the development of multi-tasking machine tools is moving precisely in the direction of hybridization. This means that different processing processes are combined in a hybrid production device based on multifunctional CNC machine tools, such as multi-axis machining centers for milling or turning.

The current hybridization of production processes involves the integration of additive manufacturing processes with cutting processes, i.e. subtractive processes in which material is removed from the preparation, together with automatic 3D scanning and dimensional control functions. Such hybrid multi-tasking machine tools are used for the production of solid parts from metal powder or for the application of special coatings in the production of multi-metal parts and the repair of worn or damaged products of high value.

A new hybrid manufacturing method (AM/CNC cutting) has developed very rapidly in recent years for many applications: the production of complex parts with high accuracy and good finish, the production of parts with hidden elements, the repair of worn parts in a single set-up and the production of parts from multiple materials using 3D printing. This method is particularly suitable for the production of small batches of difficult-to-process materials, such as alloys used in aviation, high-hardness materials used in the energy industry, or for mold making and medical products.

The algorithm for the hybrid process (AM+CNC cutting) is shown in Figure 9. Based on the 3D CAD model, the part is created using the previously transferred data in STL format and the CNC control program is generated with the selected CAM system. In the next step, the part roughly machined using the AM process is finished by CNC milling or polished using special tools.

Fig. 9 *General concept of technological integration of AM and cutting processes (source: Siemens)*

The main problem in developing the integration of AM and CNC machining is the installation of the AM module on a new or used CNC machine tool, without special modifications or after a certain finishing. One of the first hybrid multi-tasking machine tools was manufactured by Aero-Met Corp in 2004 for the production of the F-15 fighter jet. This machine integrated laser welding with a CNC milling machine. Figure 10 [4] shows tool magazine of the HSC hybrid turning and milling center.

One of the most practical applications of hybrid multitasking machining is the repair of large and complex parts, mainly for the aerospace industry. A special process based on laser cladding or selective laser melting is used for this purpose. This leads to considerable cost reductions, especially for high-quality components. In laser repair technologies, a certain volume of material is removed in the vicinity of the damage, then the missing material volume is refilled and the surface is finished by cutting and/or polishing. The repair of the blades is shown in Figure 11.

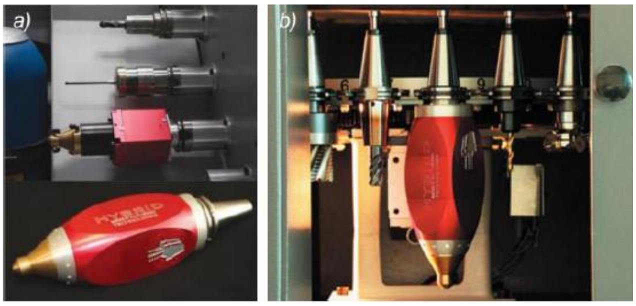

Fig. 10 *Tool magazine of the hybrid multi-tasking machine tool*

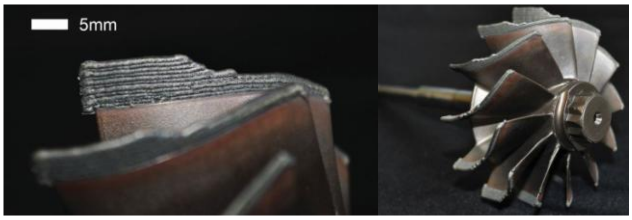

Fig. 11 *The repair of blades*

6. Conclusion

Industry 4.0 is changing the production environment. The integration of advanced sensors and IoT devices has revolutionized the architecture of machine tools by creating a highly connected and automated manufacturing environment. This enables real-time process monitoring and control, allowing workshops to optimize efficiency and reduce waste. Thanks to Industry 4.0, CNC machine tools are now able to self-diagnose problems and correct errors in the production process faster than humans can.

Multi-tasking machine tools are machines that combine multiple processes to reduce the number of operations required to produce a part. They are an important step in reducing part handling, clamping and unnecessary tooling. All of this leads to fewer human factor errors. The development of multi-tasking machining has intensified with the emergence of the Industry 4.0 concept. In almost all studies on Industry 4.0, additive technologies are cited as one of the pillars of Industry 4.0. This fact has also led to the development of hybrid multi-tasking machines. These machine tools are increasingly becoming a reality in the manufacturing environment.

7. References

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