Influence of technical-technological characteristics of workpieces on the choice of CNC machine tools

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The largest number of influences of the metal processing industry and the machine tool industry must be analyzed in defining the strategy, research and development of new products and technologies. The development of the industry and a large number of different products have conditioned certain requirements in terms of different structures of machining systems. One of the important conditions for the selection of CNC machine tools are the technical and technological characteristics of the workpieces. In this paper, prismatic workpieces will be considered. According to the technologies needed for the processing of a certain family of prismatic workpieces, it is necessary to define the structure of CNC machine tools. One of the ways to form the structure of CNC machine tools is from the appropriate library of standard machine modules. The goal is to increase productivity in production and reduce the number of machines, tools and accessories for their production.

Keywords: Workpiece, Machining system, CNC machine tools, Modules of machine tool

1. INTRODUCTION

Machining of workpieces on machine tools is achieved by the relative movement of the tool and the workpiece. The path of relative contact between the tool and the workpiece depends on the shape of the workpiece being machined.

The path of relative contact is composed of elementary translational and rotational movements, which are realized by rectilinear and circular movement of the working organs of the machine tool. Each trajectory of the relative contact of the tool and the workpiece can theoretically be realized by a maximum of six elementary movements:

- Three translational movements along orthogonal coordinate axes,
- Three circular motions around these coordinate axes.

For the operation of machine tools, in addition to the movements that form the trajectory of the relative contact of the tool and the workpiece, additional movements are often required. These movements are most often related to the manipulation of tools and workpieces [1].

Modern machine tools and multi-position special machines have one, two or more main movements, several auxiliary movements and several additional movements.

Therefore, the total number of elementary movements of the formation of forms and additional movements can reach more than ten of movements, such as transfer lines. These elementary movements are highly predetermined by the technologies and morphology of the work items for which the machine tool is selected or designed. Hence, the influence of workpiece and technologies on the elementary movements of the education of form and on the structure of kinematic connections is of decisive importance.

2. DEVELOPMENT OF MACHINE TOOLS

Previously, machine tools specialized in a particular production process or a set of several such processes. With the development that eliminated all technological shortcomings, there was a significant re-examination of functionality. A "machining centers" has been developed capable of providing several functions that have traditionally been performed by different groups of machines such as milling machines, drills, lathes, etc. With the development of such machining centers, and the ability to get to know the possibilities of machine tools by simply looking at the name, it has become a thing of the past. Although the names of processes such as scraping, final milling, etc. used to describe the process, the structure and appearance of the machines performing these operations can be completely different.

The main improvement of the machine tool came from the development of controllers that controlled functions such as movement, spindle, flow, fault diagnosis, coolant, tool changers, pallet changers, memory storage, etc. This almost eliminated the need for qualified machine operators and significantly reduced idle time in machine tools.

Many motion functions are integrated and controlled on a single CNC machine tool providing great flexibility, and the trend is to incorporate multiple functions. Technological advances have created a trend of "adding more features to an already complex machine tool for producing more complex components." This created the need for a systematic methodology for presenting current and future machine tools.

2.1. Application in industrial practice

Metal processing companies have a range of machine tools, from traditional lathes and milling machines to CNC machining centers, and perform the contracted work on these machines. Before they earn, they charge an hourly rate for the machine, the operator and the general cost of the job. The hourly rate for a machine depends on the price of the machine, so the rate charged by different companies may vary depending on which machine they intend to use for production.

Therefore, the method for quickly adjusting the capabilities of the machine tool, depending on the complexity of the component being processed, is basic for the customer and engineers for economical and high-quality production.

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Within special industrial sectors such as pharmaceutical, aerospace and food there is a group of specific workpieces. These workpieces have different weights, are machined outside the standard dimensions and have special characteristics.

A large number of characteristics present in such treatments cause high costs for their production. They are often produced once and with the help of code generated by CAD / CAM software [2].

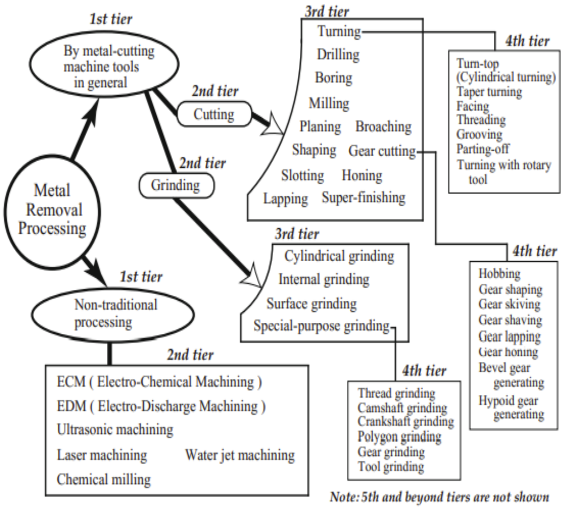


Figure 1: classification of different types of metal processing

Figure 1 shows the classification of basic types of metal processing

A study of the literature about machine tools identified the following basic points [3]:

• Advances in machining technology have reached a point where high-quality tools have been developed, coolants have been designed, control systems and controllers have been developed, technologies have been improved and better design methods have been applied. CNC machine tools capable of performing several processes that are traditionally performed on different machine tools have been developed. An analysis of some commercially available machine tools has indicated that there are machines that have widely different functions of movement and degrees of freedom.

• The block structure of the machine tool is divided into two parts as the main flow of forces and the flow of forces. This laid the foundations for the method of describing machine tools by an alphanumeric sequence.

• Shino and Ito presented the machine tool design methodology. They said the primary step was to provide a motion function in the block structure, which was then improved by structural design methods for mechanical properties. This shows that future machine tools can have more blocks that provide more complex motion functions. This was useful for developing alphanumeric code.

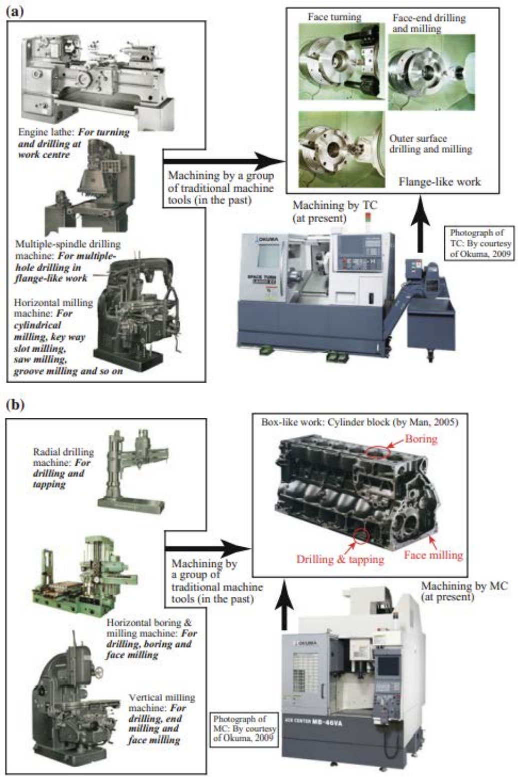


Figure 2: Integration of machining on traditional machine tools with machining centers (TC-turning centre, MC-machining centre)

Figure 2.A, B show that CNC machine tools can effectively replace various processing methods performed by a group of traditional machine tools. It is therefore natural that CNC machine tools now play a leading role in metalworking.

3. CHARACTERISTICS OF WORKPIECES

The basic division of workpieces is: cylindrical (axisymmetric) and prismatic. In this paper, will be considered prismatic workpieces due to their characteristics.

The processing of non-rotating (prismatic) workpieces is of special importance for any metal processing industry, because:

• they are of special importance for the functions of the machines in which they are installed,

• high percentage of the cost of machine structure waste on these parts (minimum 50%),

• production cycle and processing times are the longest.

Of the total number (100%) of prismatic workpieces, which appear in the metal processing industry, 35% belong to the group of plate-shaped objects and about 65% to the group of housing-shaped objects. Of the total number of prismatic parts, 80% do not exceed a volume of 650x650x650, which means that 80% of prismatic workpieces can be processed on machine tools with a working volume of 800x800x800 and smaller than these.

Prismatic workpieces can in principle be machined on three-coordinate drill-milling machines of different degrees of automation, with the proviso that workpieces with curved surfaces cannot be machined on machine tools with manual control [4].

Certainly, the results of workpiece processing are not the same, neither in terms of quality, productivity, nor in terms of price per workpiece. These and similar factors have a decisive influence on the orientation of work items on the available CNC machine tools, ie on the investment in new machines.

3.1. Characteristics of workpieces

Some of the basic characteristics of workpieces are:

• D - dimensional characteristics

The dimensions of the workpiece are directly related to the volume of the working space of the machine. In order to satisfy all the necessary processing operations, it is necessary that the workpiece corresponds to the working volume of the machine.

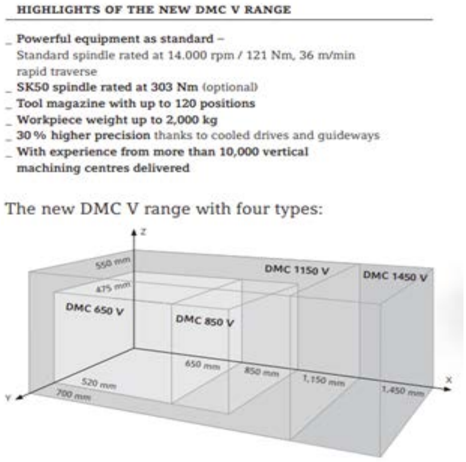


Figure 3: Dimensions of the workspace different types of machining centers from Deckel Maho DMC

• M - mass - weight

Workpiece classification by weight:

• light weight workpiece (up to 5 kg)
• medium weight workpiece (from 5 kg to 500 kg)
• high weight processing (up to several tons)

Some of the characteristics according to the working space of the machine is that the maximum workpiece weight for the DMC650 machine is 800 kg, and the maximum workpiece weight for the DMU 270 FD machine tool (5-axis milling machine) is 7 tons.

- M_t – Material

Some of the most common processing materials are: aluminum alloys, cast iron, copper alloys, magnesium alloys, insoluble alloys, stainless steels, carbon steels, titanium alloys.

Depending on the machining material and the tool material (high-speed steel or hard metal), machining parameters such as cutting speed, pitch, cutting forces, etc. are defined.

- K –Construction characteristics

In terms of construction characteristics, it can be considered what type of surfaces are being processed, whether they are flat surfaces or have cylindrical, conical depressions or protrusions, whether the surfaces are stepped, whether they have certain grooves or pockets, whether the surfaces are from the outside sides of the workpiece or also internal, which require tool movement (linear or contour machining in several axes).

- T - technological (types of processing)

According to the technical drawing of the treatment, the following may be required: rough and / or fine treatment of a surface. Depending on the required type of processing (extensive milling, face milling, groove milling, hole milling, thread cutting, ...), it is necessary to take into account the choice of machine and tools with appropriate parameters.

- Q - quality / measure accuracy

Processing accuracy includes:

• accuracy of measures
• surface shape accuracy, and
• the accuracy of the relationship between two or more surfaces.

The accuracy of the measures represents the degree of concordance achieved with the nominal measure.

The accuracy of the shape of the surface represents the degree of concordance of the treated surface with the corresponding geometric surface.

The accuracy of the mutual relation of surfaces is defined by the appropriate deviation from the given nominal position, such as the deviation from parallelism, directness, coaxiality of cylindrical surfaces, etc.

- O – processing operations (coarse, fine, ...)

For each machining operation, it is necessary to define whether it is rough or fine machining. The sequence of operations is also defined in order to make optimal use of available tools and processing modes.

The field of computer-aided modeling workpieces has developed a number of techniques for unambiguous three-dimensional representations of objects. Characteristics recognition is a sub-discipline of modeling that focuses on the design and application of algorithms for detecting production data from manufactured solid models to computer-aided design (CAD) systems [5].

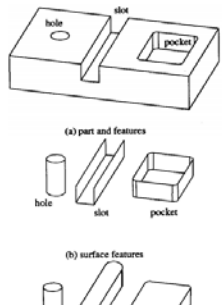


Figure 4: Basic shapes of surfaces on the workpiece

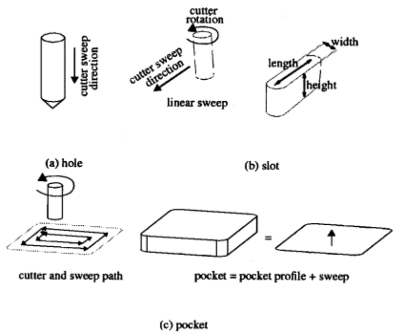


Figure 5: Procedure for obtaining surfaces during processing

Examples of this production information include functions such as holes, slots, pockets and other shapes that can be machined on modern CNC machine tools, Figures 4 and 5. Automated feature recognition has been an active research area in solid modeling for many years.

4. MODULAR DESIGN

The modular principle is a very popular method in the design of cars, diesel engines, household appliances, information devices, industrial equipment, etc. This trend can be considered as one of the great contributions of modular machine tool design to those working in other industries. Modular design can be classified into a significant number of variants, depending on the idea, goals and scope of application, areas of application, expected advantages, etc. In addition, the terminology of modular design itself has changed along with hierarchical changes in its meaning. Therefore, it is very difficult to present modular design in a simple sentence. Currently, the presence of modular design in the production sphere ranges from tools, templates and clamping accessories, through machine tools, to the production system [6].

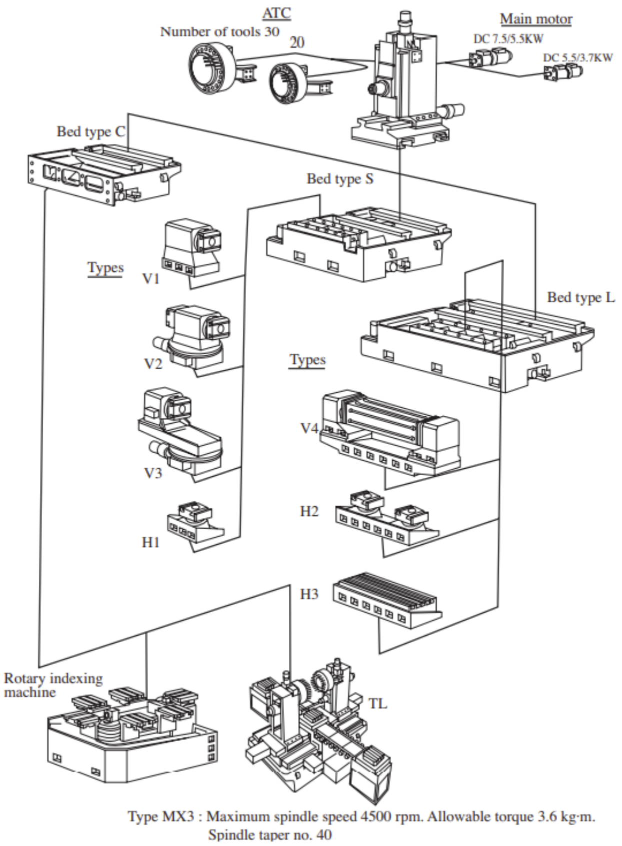


Figure 6: Modular design of the machining center (MC- machining center, courtesy of Ikegai Iron Works)

Figure 6 shows an advanced version of the MC-machining center of the Japanese company Ikegai Iron Works (type MX3)) in the early 1980s. As can be seen, modular design is preferably used to produce 10 variants, ranging from a flexible pallet-type FMC (flexible manufacturing cell), through flexible transfer lines FTL (flexible transfer line), to a five-axis processing machine. In this case, the leading modules are the pole, the stand, the worktable, the tool magazine, the main spindle, etc. This machine is a typical precursor to today's five-axis CNC machine tools.

Once the group of modules has been determined, a CNC machine tool with the required dimensional and performance specifications can be designed and manufactured as needed by selecting and combining the required modules from a predetermined group. In this case, the module must be standardized so that it has functionality or appropriate performance, including interchangeability with other modules. Figure 7 shows the hierarchical structure of a machining center (MC). For example, a machine consists of a unit assembly, a unit consists of functional assemblies, and a functional assembly is a combination of several parts - modules. Therefore, the question arises as to how to determine the module fully taking into account the hierarchical attributes of the product.

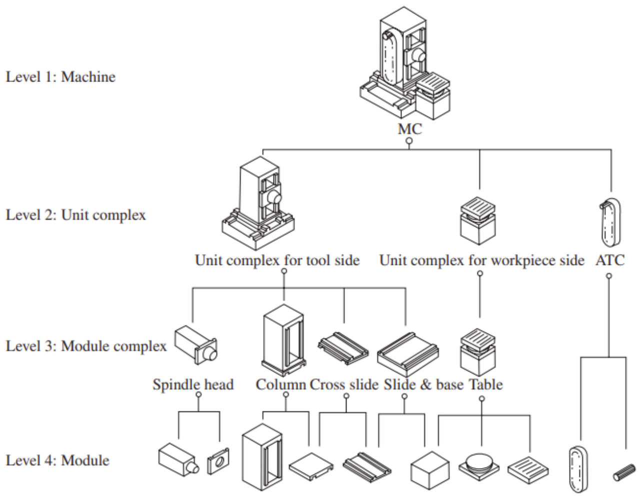


Figure 7: Modular structure of design machining center (MC- Machining center)

The following principles must be observed in modular design:

1. Modules must be replaceable without the use of measuring equipment.
2. The module must be self-contained with its own drive system, return voltage and lubrication systems or design accessories for easy expansion of such systems.
3. Each unit must have its own servo package with electronic connection to the digital input.
4. Modules must be usable in any orientation.
5. Modules must be replaceable within about half an hour.
6. The machining operations that are allowed in the first stage are scraping, drilling, grinding and milling.

It has been observed that modular design for conventional machine tools can provide economic benefit to the manufacturer and user, together with a wide range of choices according to production requirements.

4.1. Application of modular design for CNC machine tools

Modular design has been applied to CNC machine tools, with the aim of enabling machine flexibility from a hardware aspect. When the required machine tool flexibility is far greater than that possessed, the machine tools must be reconfigured to strengthen the machine flexibility by modular design, Figure 8.

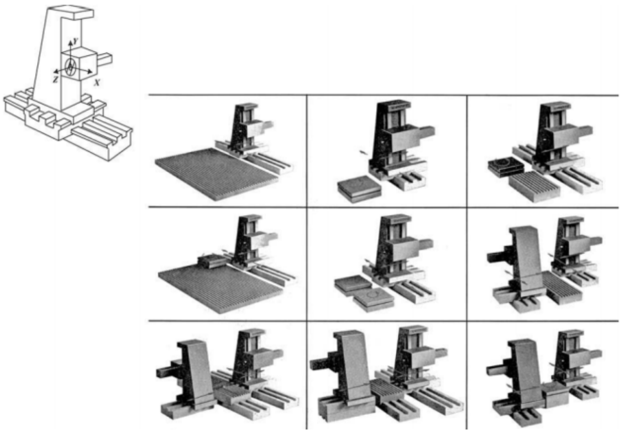


Figure 8: Horizontal machine tool with modular design (Scharmann Co.)

For a given family of parts, as shown in the first block in Figure 9, the processing characteristics for each part will be extracted as shown in the second block and compared with the processing characteristics library shown in the third block to find the desired motion modules shown in the fourth. block through matching the corresponding movements. Different types of workpieces will lead to different sets of modules shown in the fifth block [7].

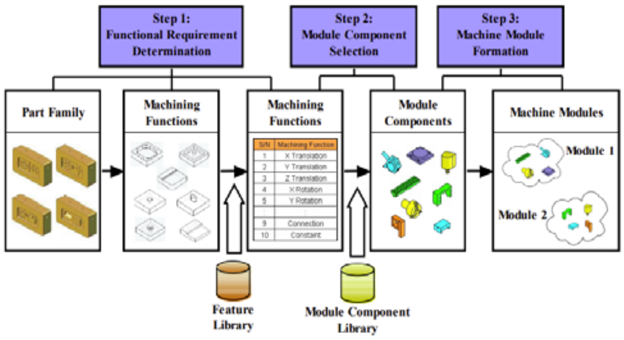


Figure 9. Diagram of module selection

As an illustrative example of the industrial application of mold making, Table 1 lists the processing characteristics that are allocated according to the STEP standard for a family of four given workpieces.

Part 1 includes five processing features: (i) two general pockets; (ii) 10 protrusions (and depressions) inside the pocket - cylindrical; (iii) two slots - rectangular profile; (iv) two blind holes - drilled; and (c) seven blind holes - cylindrical. Parts 2 and 3 contain six machining characteristics each, and part 4 contains four machining characteristics.

All these functions can be fitted with seven machining features (MF - machinihg features) as noted in Table 1: MF1— “General Pocket”; MF2— “Pocket bulges - cylindrical”; MF3— “Slot - rectangular profile”; MF4— “Blind hole - oppositely drilled”; MF5— “Blind hole - cylindrical”; MF6— “Bulge - general profile”; MF7— “Staircase”; MF8— “Rotated Profile - Removed Material Within Profile”.

Table 1: Machining features extraction

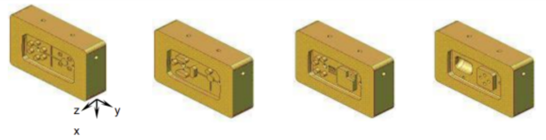
Part 1	Part 2	Part 3	Part 4
			
Machining Features: (1) General Pocket (2) (2) Boss within a Pocket—Cylindrical (10) (3) Slot—Rectangular Profile (2) (4) Blind Hole—Counter-Bored (2) (5) Blind Hole—Cylindrical (7)	Machining Features: (1) General Pocket (1) (2) Boss—General Profile (3) (3) Boss within a Pocket—Cylindrical (3) (4) Slot—Rectangular Profile (2) (5) Blind Hole—Counter-Bored (2) (6) Blind Hole—Cylindrical (7)	Machining Features: (1) General Pocket (1) (2) Boss—General Profile (1) (3) Boss within a Pocket—Cylindrical (5) (4) Step (1) (5) Blind Hole—Counter-Bored (2) (6) Blind Hole—Cylindrical (7)	Machining Features: (1) General Pocket (1) (2) Boss—General Profile (1) (3) Revolved Feature—Volume Removal (1) (4) Blind Hole—Cylindrical (14)

Table 2: Corresponding motion requirements

Machining Feature	Spindle Axis	Motion Requirement
MF1	z	x-Translation, y-Translation, z-Translation
MF2	z	x-Translation, y-Translation, z-Translation
MF3	z	x-Translation, y-Translation, z-Translation
MF4	z	z-Translation
MF5	z	z-Translation
MF6	z	x-Translation, y-Translation, z-Translation
MF7	z	x-Translation, y-Translation
MF8	y	z-Translation

Note: MF1—“General Pocket”; MF2—“Boss within a Pocket—Cylindrical”; MF3—“Slot—Rectangular Profile”; MF4—“Blind Hole—Counter-Bored”; MF5—“Blind Hole—Cylindrical”; MF6—“Boss—General Profile”; MF7—“Step”; MF8—“Revolved Feature—Volume Removal”.

Table 2 shows how these processing characteristics are related to the corresponding movement requirements. For example, MF1 (general pocket) is processed by placing the spindle in the z-axis and moving it in the x, y and z-axes. For MF2 to MF8, their movement requirements are detailed in Table 2.

5. CRITERIA FOR SELECTION OF THE MACHINE TOOL

The selection of workpieces for machining on CNC machine tools is often guided by the following criteria:

- Small and medium series with multiple repetitions,
- Complex geometry of workpieces with high processing requirements,
- High cost of production and long time of possible procurement or production in case of scrap,
- Work items with a long production cycle.

When describing the structural characteristics of CNC machine tools, the following are important [8]:

- position of the axis of the main working spindle,
- working stroke length (X, Y, Z),
- desk surfaces,
- maximum weight of the workpiece,
- positioning accuracy,
- installed power,
- speed and translational movements,
- time required to change tools,
- time required to change the work item,
- ways to change tools and work items and more.

6. CONCLUSION

All possible combinations of modules in the structural model of the CNC machine tool give many variant solutions, each of which is not adequate for realization from the production point of view. A large number of variant solutions are only theoretical possibilities, because the production of such structural models of CNC machine tools would be very complex, and the functional characteristics would not meet the necessary requirements in terms of the possibility of upgrading the automatic pallet change system. In addition, modularity would not be satisfied, as some structural models of CNC machine tools would be suitable only for machining smaller and lighter workpieces, and some only for machining large and heavy machine parts.

The optimal structural solution of the CNC machine tool must be adapted to the technical and technological requirements of the cutting process when processing prismatic workpieces.

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