*Design of Machines and Structures, Vol. 6, No. 2 (2016) pp. 37–45.*
*https://doi.org/10.32972/dms.2016.011*

# AUTOMATION OPTIONS OF SINGLE-PURPOSE MACHINES

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**Abstract:** The basic aim of this paper is to discuss the automation opportunities, difficulties, problems and possible solutions of the designing of single-purpose machines, which are widely applied. Another aim is to use the computer optimally when designing these types of machines and to reduce the time of the designing as much as it is possible.

***Keywords:*** *Single-purpose machine, designing, optimization, function contraction*

## 1. INTRODUCTION

In our speeded up world in the competition sphere, where we have to react to the demands of the market very quickly, it is indispensable to manage with the time. The company that replies the quickest to the market demands, can stay in competition. The earlier the reply arrives with the tender, the bigger the chance for the company to win a project. Before the company makes decisions they make financial calculations. In case of components required in smaller or bigger amount, it is necessary to decide, which type of machine worth more. There can be a lot of solutions but basically two of them are possible. One of them is to build a single-purpose machine to a certain problem or occupying CNC machines. There are less and less single-purpose machines used in production, because nowadays the application of CNC machines is advantageous even if there are small amount of workpieces. As well as due to the fact that the CNC machines are universal, they can be applied in the production of other components, too. But in case of single-purpose machines it is not true. There can be significant financial differences between the mentioned opportunities. Due to this, the leaders of the companies have to take a huge risk when they organise a project. It can result more difficulties that there is not enough time to think the decisions over. The prices of CNC machines are given, but in case of single-purpose machines we have to build the machines around the workpiece. The prices of single-purpose machines depend on the planning and the construction, so we have to plan the machine with good approximation to value the expected cost. Therefore more and more companies deal with automation options of single-purpose machines [1], [2].

In the following we will introduce an algorithm, which helps to make the designing some periods of single-purpose machines automatic so golden hours can be spared for companies.

## 2. PLANNING OF SINGLE-PURPOSE MACHINE

We can see the planning steps of single-purpose machines in *Figure 1.*

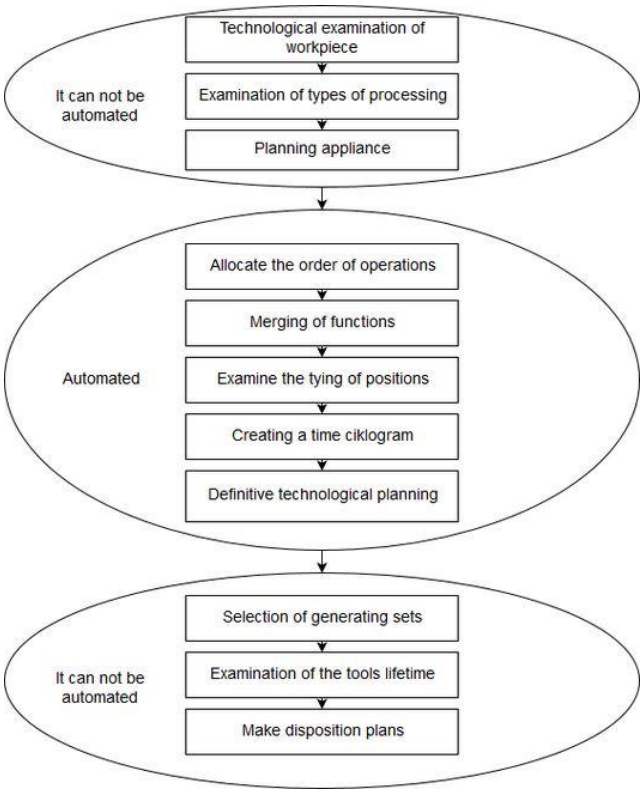



*Figure 1. Planning steps of single-purpose machines*

First and basic operation is to analyse the piece. Since we have to build the machines around the piece, we have to examine the attack directions that are needed to process and after that we have to decide where we can clamp the workpiece. It is important to examine what kind of processing is needed and what type of technology have to be used to finish machining and of course we also have to examine that we can keep the prescribed tolerance. The next step of the designing is merging of functions. Since the basic aim of single-purpose machine is to create a component as soon as possible, it is important to do serialization and collimation during the processing. The concentration regime of operational tools helps us. Based on this we distinguish first degree, second degree and third degree concentration [3]. Next we will show the characteristics of these concentrations.

## 2.1. Merging of functions

### *I: First degree spatial merging*

The aim of first degree spatial merging is to merge tools -which take effect from the same attack directions- to common axis of rotation. The result is the complex tool.

Conditions:

1. The order of finishing each surface cannot be changed as the result of the merging.
2. Technology compatibility: The revolution of tool edges, which are on the same axis of rotation are the same but the distance of the axis can change, and in this way there are different cutting speeds. The feeding speeds are the same too so we have to synchronise them.
3. By complex tools it is necessary to pay attention to chip removal, cooling, strength, the accurate settings of the edges and exchangeability.

### *II. Second degree spatial merging*

The aim of second degree spatial merging is to merge tools, group of tools -which take effect from the same attack directions- to common feeding unit. The result is the multi-spindle gear.

Conditions:

1. The order of finishing each surface cannot be changed as the result of the merging.
2. If the tools are on common gear they have the same feeding speed. Feeding speeds have to be synchronized. The revolution of the tool is $n_i$, the feed is $f_i$, so the feeding speed is $v_{ei} = n_i \cdot f_i$. It will work if the feeding speed of every tool is the same.
3. Both the rotational speed and the direction of rotation can be different.
4. It is not possible to merge the tools of surfaces which are in different processing phase within one gear.
5. Geometric compatibility: Tools – which are mounted in gear – have to fit. Distances of the axes have to be as big, that the bearings of the suitable strength spindles could fit. As well as, the necessary cutting performances have to be given to each tool.

### *III. Third degree spatial merging*

The aim of third degree spatial merging is to group operational tools around the workpiece and to shape common working space. Results of this merging are the positions of single-purpose machines and the version of positions. According to the merging the structure sketch of single-purpose machines can be realized and after that we can decide what kind of aggregate units have to use to build a single-purpose machine.

Conditions:

1. The order of finishing each surface cannot be changed as the result of the merging, but if there is not any technological limit it can be interchangeable the chronology of group tools which take effect from the same attack directions.
2. Do not disturb technologies in common working space and position!
3. There should not be significant differences among cutting performances otherwise there will be large differences among forces.
4. The processing units need enough place in positions in order to be carried out the changing of tools, the cleaning and the task of maintenance.
5. The single-purpose machine has to be repairable.

According to these geometric and machining theory consideration and of course the concentration regime of operational tools we can automate the merging of functions all we need is an universal code system – which expands every parameters of the workpiece – from the workpiece. Thereinafter we will examine the merging of functions from the viewpoint of bores.

### 2.2. Difficulties of function merging from the viewpoint of bores

The first problem is come from that the computer's algorithm has to recognise the bores on the technical drawing. Furthermore it has to decide, which way will be the best to drill a bore, from below or from above, how to merge more surfaces to processing or how will be enough place to the unit of processing. It has to recognise the axis of bores, that these axis are coincident or not, or axis have an intersection or not. If the axes are coincident, it has to be examined – knowing diameters – that which bore we have to start the processing with. If the axis has intersection in one plane, it has to take cognizance the depth of bore and it is allow the collimation or not. In case of the axis are skew it has to examine the depth and the diameter of bores and certainly examine that there are enough material between the bores. In case of processing more bores it has to make an order among the processing and it has to recognise which flow will be the next. If it is not working the tools can be broken. Because of the easier transparency we have to perform these requirements that the user will not have to give too much data.
Computers need codes and mathematical operations but the users need easy manoeuvrability, minimal energy input and of course easy-to-learn code system. Thereinafter there will be a proposal which satisfies these requirements.

## 3. OPERATION OF BORE RECOGNITION ALGORITHM

If there is not a model in 3D, the computer has not enough information to recognize the bores of the workpiece automatically. That is why we have to supply the bores with codes which have got enough information content for computer processing. Every type of processing [4] which can be perceived by technologist we have to

supply by a letter during the encoding. This letter will be referred to the nature of processing.

Letters of processing:

1. D: broaching,
2. E: chamfer,
3. F: drilling,
4. FB: enlargement of bore,
5. H: front countersink,
6. M: threading,
7. S: countersink.

Of course, during the processing the order is important, for example we cannot do broaching or threading while there is not any bore.

The order of precedence among the flows:

1. Drilling (F) if it suits the diameter requirements it can be merged with chamfer (E) and front countersink (H).
2. Enlargement of bore (FB), chamfer (E), and front countersink (H).
3. Countersink (S).
4. Broaching (D).
5. Threading (M).

Processing from the same level can be parallelised if there are not any geometric limits or conflicts.

Since we talk about bores and bore type of processing we have to define cylinders in the space. To this we have to use a universal coordinate system. This coordinate system can be taken every point by user, but the suggestion is assign the XY plane to the sectional images, assign the XZ plane to plan view and assign the YZ plane to the side view, as you can see in *Figure 2.* This kind of coordinate system definition can be used for all of the workpieces.

After that we can define spatial cylinders. According to [5] for defining a cylinder we need the centre of the cylinder (point C), need the direction vector of the cylinder axis (vector $\vec{w}$), furthermore need the r radius and the h height *(Figure 3).*

According to these we can give all points of the cylinders with the next formula:

$$P(\theta, t)=C+(s\cdot \cos\theta)\cdot \overrightarrow{e_x}+(s\cdot \sin\theta)\cdot \overrightarrow{e_y}+t\cdot \overrightarrow{e_z}. \quad (1)$$

Where $0\leq s \leq r$; $|t| \leq \frac{h}{2}$; $\theta \in [0,2\pi]$.

To the operation of algorithm we not need to give the centre of the cylinders just the starting point of the bores, after that the program by means of a constant multiplier changes the starting point of the bores to the centre point of the bores. Here is the constant multiplier:

$$Const = \frac{h}{2}\cdot |\vec{w}|. \quad (2)$$

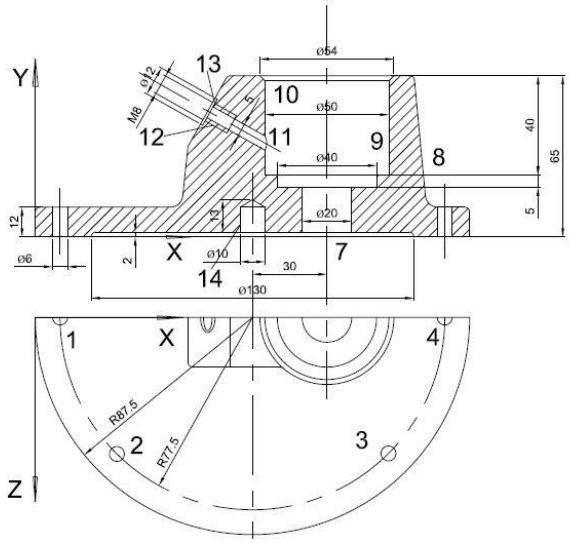



*Figure 2. Defining coordinate system*

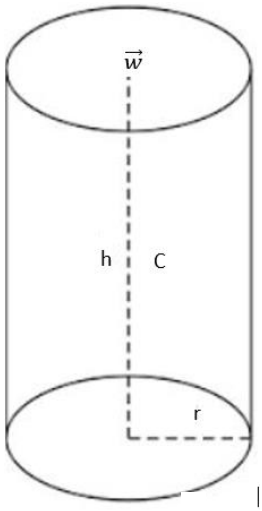



*Figure 3. Remarkable points and lines of a cylinder*

To give the direction vectors of the cylinders can be difficult. The first angle that we mark with θ is in XY plane. This angle is between the axis of bore in XY plane and the X axis. The other angle that we mark with γ is between the axis of bore and the XY plane. In *Figure 4* we can see how to take the angles.

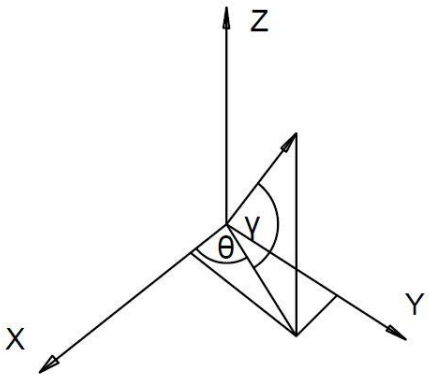



*Figure 4. Define the axis of cylinder*

The direction vector of the bore axis can be given with these angles. Here is the formula:

$$\vec{w}=(\cos\theta\cdot\vec{e}_x+\sin\theta\cdot\vec{e}_y)\cdot\cos\gamma+\sin\gamma\cdot\vec{e}_z. \quad (3)$$

So here is the code that the user should give in case of bore by the user:

$$A(F;C(x,y,z);\theta,\gamma;r;h). \quad (4)$$

The examination of cylinders (in this case bores) will start when we give two or more codes of bores to the program. The algorithm is the next in case of group of bores. First of all we have to count a vector $\vec{D}$, which is the difference of the centre points of the two cylinders:

$$\vec{D}=C_1-C_0. \quad (5)$$

After that we take the two direction vectors of the cylinders and make a vector multiplication. The result is a vector which is perpendicular to the two direction vectors of the cylinders. This vector will be important later because with the help of it the program will foist planes and examine if the cylinders cut each other, or not:

$$\vec{M}=\overrightarrow{w_0}\times\overrightarrow{w_1}. \quad (6)$$

Then we calculate the length of these vectors.

The main reason why we have to calculate the length of the vectors will be clear with understanding the next formula (7):

$$\left|\vec{a}\times\vec{b}\right|=|\vec{a}|\cdot\left|\vec{b}\right|\cdot\sin\alpha. \quad (7)$$

A multiplication is zero when one of their factor is zero. The two vector cannot be zero, because these are the direction vectors of the cylinders, so just the $\sin\alpha$ can

be zero. If the $\sin\alpha$ is zero the axis of cylinders are parallel. If it suits the requirements of diameter, the bores – and with the bores, processing too – can be merged. In other case the axis of cylinders are not parallel so other type of test is needed. In case of parallel there are two possibilities: firstly we have to examine the distance of the two bores. We have to add the radius of cylinders after that we have to subtract the centre distance of cylinders from the sum of radii. On the other hand the cylinders can cut each other because of the height. If there are not parallel we have to run a five-step test. These tests generate planes between the cylinders. If these planes cut the cylinders, the processing cannot be merged.

In case of merging bores, there is not enough to compliance to the geometric requirements. Thereinafter we will examine the bores from the viewpoint of machining theory.

We have to expand the main code with three new parameters. These parameters high percentage of it are given by manufacturers beside to their products. The three new parameters are cutting speed *($v_c$),* feedrate *($v_f$)* and the feeding force *($F_f$).* Here is the general shape of code which is expanded by these three parameters:

$$A(F;C(x,y,z);\theta,\gamma;r;h;v_c,v_f,F_f). \tag{8}$$

Conditions of technological compatibility in case of bores in one axis:

1. The maximum diameter of bores is 15 mm, the bore is bigger than this have to be drilled a much smaller-sized tool [4].
2. The difference from the optimal cutting speed cannot exceed ±21,5% in case of bores along one axis [4].
3. The lifetime of the tools have to be the same or multiple of each other.
4. The main drilling machine time have to be multiple of each other.

On the basis of consideration which is described above, we can see the encoding of the workpiece shown in *Figure 2.*

1 F,20,12,0,–90,0,6,12,330,3.5,300
2 F,97.5,12,134,–90,0,6,12,330,3.5,300
3 F,252.5,12,134,–90,0,6,12,330,3.5,300
4 F,330,12,0,–90,0,6,12,330,3.5,300
5 F,252.5,12,–134,–90,0,6,12,330,3.5,300
6 F,97.5,12,–134,–90,0,6,12,330,3.5,300
7 F,205,17,0,–90,0,10,17,416,6.1,450
8 F,205,22,0,–90,0,20,5,416,5.3,900
9 F,205,60,0,–90,0,25,40,416,4.7,1100
10 E,205,62,0,–90,0,27,2,416,4.41,1150
11 F,145,55,0,–30,0,2.5,15,416,7.4,250
12 M,145,55,0,–30,0,4,10,130,4.8,100
13 H,145,55,0,–30,0,6,15,416,6.2,300
14 F,175,0,0,90,0,5,13,416,6.1,300

## 4. SUMMARY

According to the geometric and cutting theories detailed and defined above, the computer can make a sequence plan and it can specify the numbers of serial or parallel processing in case of bores. The principle and the realisation can reduce the time of planning largely by missing or jumping some steps. Thereinafter this principle will be extended to the milling featured processing too. Furthermore, the end goal is that the computer would be able to offer the user a sequence of operations and optimal structures of single-purpose machines. It will help companies to save time during the planning phase.

## ACKNOWLEDGEMENT

The research work presented in this paper based on the result achieved within the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project. The project is financially supported by the European Union, and co-financed by the European Social Fund. Both financial supports are gratefully acknowledged.

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