Selected manufacturing difficulties encountered during setup of machining on CNC multi-axis linear automatic lathe and on CNC multi-spindle turning centers

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Abstract: *The article presents the observed manufacturing technology implementation difficulties in workshop practice, resulting from the construction and principles of operation on the DMG's SPRINT 32/5 CNC linear automatic lathe and on the Mazak's HQR 150 MSY and QTN 200 MS CNC turn - mill centers, and discusses possible rules for solving the production problems encountered. The article also discusses the principles of dividing the machining process and working steps on multi-spindle CNC turn - mill centers. It is worth to build a system supporting the selection of the sequence of treatments [1], taking into account the frequency of natural vibrations and stiffness obtained after each single machining operations.*
The article shows the method of verification of the selection of the machining planning method on CNC multi-spindle lathes.
KEYWORDS*: CNC, MULTI-AXIS, MULTI-SPINDLE, MACHINING, LINEAR AUTOMATIC LATHE*

1. Introduction

Machine tool selection and part machining method can be a complex technological issue. Depending on the shape, quantity, dimension tolerance, and the geometrical dependence of the machining features, the workpiece made on multi-spindle turning centers can be produced in various ways. If you can choose a machine tool for conducting of machining, it is worth analyzing the benefits of using a specific type of machine tool.

The number of degrees of freedom and the length of machining features affect the choice of machine tool and machining method. The article describe the conclusions from the implementation of the CNC machining by the Author in Radmor S.A., and in Mechanika Radmor Sp. z o.o. in Gdynia in Poland, on a multi-axis machine tool, the commissioning of which eliminated the use of conventional cam lathes from production. The differences in starting production on CNC multi-axis linear machines and on the CNC milling-turning centers, which was discussed in article [2], were described.

The workpieces shown in the article were made on machine tools:

- Mazak QTN 200 MS - one turret, two spindles CNC turning center
- Mazak HQR 150 MSY - two turrets, two spindles CNC turning center
- DMG Sprint 32/5 – CNC linear automatic lathe, slider and stationary rail with tools, two spindles and the workpiece performs a work movement in the axial of manufactured bar direction (in the spindle Z axis)

It is worth to build a system supporting the selection of the sequence of treatments [1], taking into account the frequency of natural vibrations and stiffness obtained after each single machining operations. One of the key issues is to carry out the machining in an economic manner and to ensure that the required dimensional and shape tolerances are achieved.

Before machining, the workpieces should be classified in terms of:
the number of workpieces performed in machining series, workpiece's shape, type, size and machining tolerance of machined features.

For machine tools with the possibility of simultaneous machining on both sides of the turned workpiece, it is possible to divide the machining in a way that allows maximum length of the external feature with a diameter different from that of the input bar with length greater than 3 times bar's diameter to perform on CNC multi-axis linear automatic lathes with dividing of machining for MAIN and SUB spindles and additional with regarding to the feature shape and dimensions between different kind of CNC centers type.

2. Description and characteristics of the dual-flow dissymmetrical low pressure steam turbine

Fig. 1 shows elements made by Autor on the DMG Sprint 32/5 CNC linear automatic lathe, characterized by various degrees of machining difficulty, the number of necessary tools to perform the machining and the requirement to apply the required machining strategy, including the machining strategy consisting in dividing the machining area into sections shorter than the length of the guiding part of the carbide guide bush.

Fig. 1. *Workpieces made on CNC turning centre*

Important principles of turning on CNC multi-spindle turning lathes:
1. After fixturing of the workpiece on a CNC multi-axis linear automatic lathe, the length of the protruding length of machined object from the face of the collet of the auxiliary SUB spindle should be as short as possible
2. The length of the turned step of the workpiece on the MAIN spindle, with a few passes of the tool, cannot be longer than the length of the leading part of the guide sleeve, for multi steps machining on the whole length (without dividing of machine feature on shorter machining lengths)
3. The turned workpiece's machining side requiring more machining tools is machined on the MAIN spindle
4. If the length of the part machined on the MAIN spindle is longer than the leading part of the guiding collet, but it is possible to process it with one pass, this machining is performed as the last machining operation on the MAIN spindle
5. If the length of the turned feature on the MAIN spindle isn't shorter than the length of the guiding part of the guide sleeve, it should be capable of turning during one pass
6. If the length of the outside turning feature machined on the MAIN spindle is longer than the leading part of the guiding collet, and it isn't possible to process it with one pass, because the depth of

cut is too large, this machining have to be performed with shorter length in Z-axis direction, than the length of machined feature is

7. For linear machines with a rigid guide sleeve (set on one diameter dimension), bars with the smallest possible cylindricity deviation should be used - a very important parameter for setup of machining

8. The length of the turned-milled workpiece that can be transported after machining with the conveyor belt is limited and is less than the length of the workable part described as maximum length of turning

9. The constant value of the rotational speed for individual tools (the same for machining the entire workpiece), if possible allows to shorten the machining time

10. When extending the bar onto the bumper, the amount of pressure force against the bumper should be reduced for smaller bar diameters

Fig. 2 shows workpieces with different machining features. The workpiece shown in Fig. 2a has turning features: outer diameter, faces, axial hole, slots. The workpiece shown in Fig. 2b has turning features: outer diameter, center and off-center holes, slot, faces.

Workpiece shown in Fig. 2c requires, during turning on CNC automatic linear lathe, conducting of turning with a very long guide of guiding bush, the length of which, even in a special version, is too short to perform machining of the feature in several passes along the entire length in the direction of the Z axis (in the workpiece's and spindle's Z axis).

The following symbols will be used throughout the rest of this article: MAIN - main spindle, SUB - auxiliary (second) spindle.

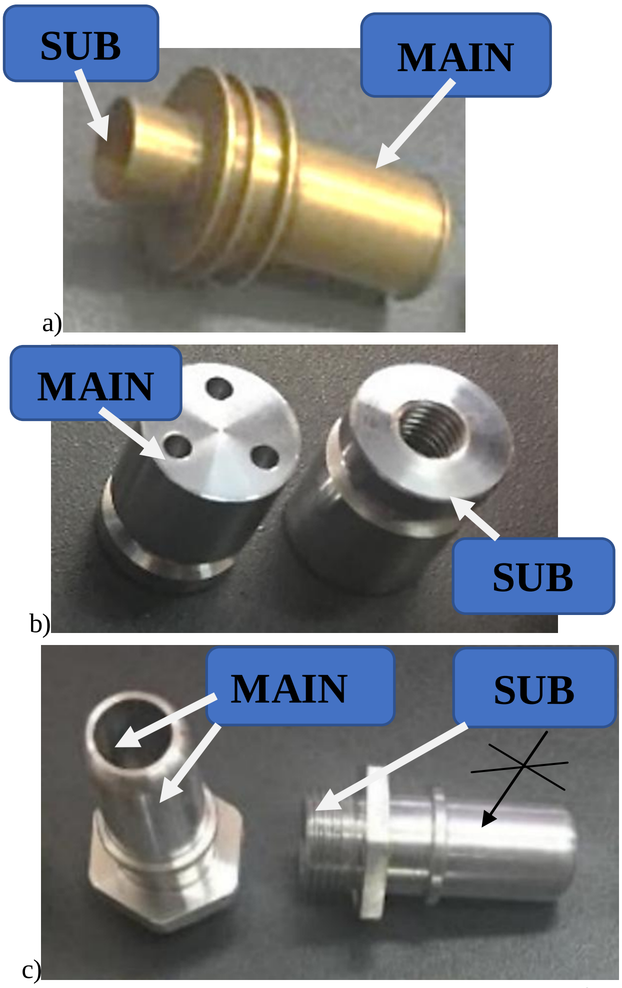


Fig. 2. Turned workpieces: a) there is interchangeability of the MAIN and SUB machining sides, b) interchangeability of machining possible only when the SUB has the Y axis, c) the milled feature requires driven tools

The individual workpieces shown in Fig. 2 represent a possible spectrum of items manufactured on CNC multi-spindle automatic lathes and on CNC multi-axis linear automatic lathes. Objects can be classified by weight and it can be assumed that Fig. 2a shows the workpiece of medium complexity and the most frequently made ones, Fig. 2b shows the objects that require the least amount of work to perform, while Fig. 2c shows the representative of the workpiece requiring the greatest amount of work, and the greatest amount of preparation time needing to start the machining on selected machine tool.

Figure 2c also shows the inability to process the indicated feature due to the inability to catch the workpiece for processing.

The most important thing regarding the issue of CNC turning linear automation lathe programming is verification of the possibility of guiding the bar through the carbide guide sleeve and the analysis of the possibility of symmetrically dividing the machining for both spindles MAIN and SUB that can be possible to simultaneously performing machining on both lathe's spindles.

Fig. 3 shows a sketch of the machining space of the DMG Sprint 32/5 machine tool.

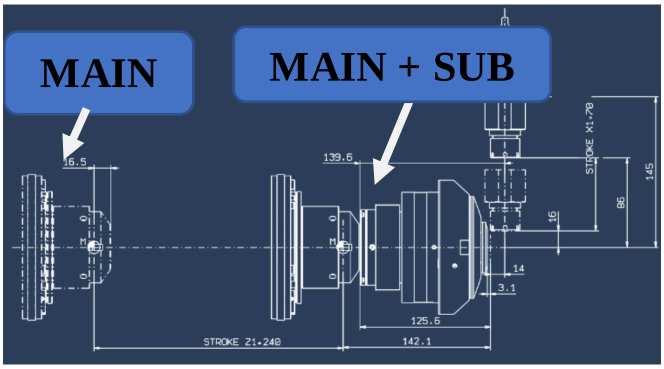


Fig. 3. *Working space of the DMG Sprint 32/5 linear automat*

Fig. 4 shows the 3D solid model of the Mazak's HQR 150MSY CNC multi-spindle lathe, which was implemented in the EdgeCAM software. The key issue before preparing of CNC program is to prepare the 3D solid model of a machine tools in a way to show the machining space with very high precision (no more than a few hundredths of a mm). Making a 3D solid of a CNC lathe with greater tolerance can cause a collision during machining. Attention should be clearly focused on the reliable preparation of the 3D machine tool body, especially of the machining space.

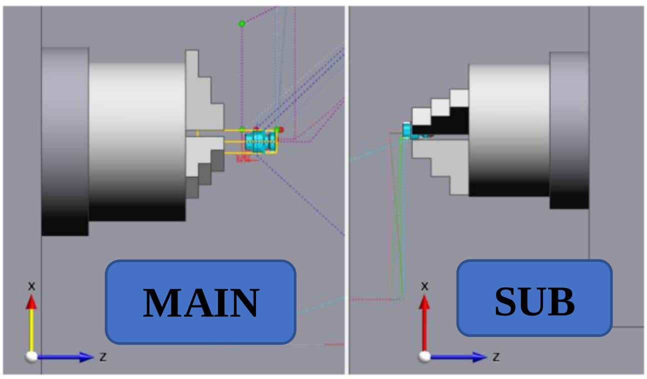


Fig. 4. *Machining space - view of the main spindle "MAIN" and the auxiliary spindle "SUB" of MAZAK HQR 150 MSY*

3. Preliminary analysis of the manufacturing method

When planning the machining process on a CNC multi-spindle turning center or on a CNC multi-axis automatic linear lathe, you should pay attention to several factors:

- Number of tools mounted in the MAIN spindle slide: C_1

- Number of tools mounted on the additional MAIN spindle holder: C_2
- Number of rotary tools for the MAIN spindle: C_3
- Number of rotary tools for SUB spindle: C_4
- Number of machining tools for the SUB spindle: C_5
- Total length of machined workpiece: L
- Length of the guide part of the guide sleeve in MAIN spindle: L_1
- Maximum length of insertion of the part into the SUB spindle: L_2
- Length of the part that can be ejected into the auto-feeder: L_3
- Length of the turning feature on the MAIN spindle: L_4
- Length of the turning feature on the SUB spindle: L_5
- Overhang of the part from the auxiliary SUB spindle: A
- Number of machining features for the MAIN spindle: X_1
- Number of machining features for the SUB spindle: Y_1
- Number of machining features requiring separate tools for machining features on the MAIN: X_2
- Number of machining features requiring separate tools to machine features on the
- SUB: Y_2

If is possible to manufacturing the workpiece, after checking $C_1 \div C_5$, X_1, X_2, Y_1 and Y_2 we should check further aspects:

If "A" is less than "L_3" it is possible to automatically collect machined workpieces by using a machined parts ejector and a conveyor belt.

Is there a machining feature length greater than the length of the guide part of the guide sleeve:
$Z_1 = 0$ NO (you can turn in traditional meaning of turning but with movement in Z direction of a machined bar)
$Z_1 = 1$ YES (you can turn only after dividing turning features on shorter length than the guiding part of guiding bush have)

Is there a turning feature length greater than the lead length of the guide sleeve and that requires turning in several passes:
$Z_2 = 0$ NO (you can turn on DMG SPRINT 32/5)
$Z_2 = 1$ YES (you can't turn on DMG SPRINT 32/5)

If $Z_1 = 1$ you can use Mazak's HQR 150MSY or QTN 200MS however, it should be remembered that in the case when the overhang of machined workpiece is longer than 3 diameters, it is necessary to support it with the tailstock of the lathe. The necessity for using of the tailstock will be when Z_2 parameter value is equal: Z_2=1.

4. Modal analysis - introduction

Analytical and numerical tests clearly show a change in the value of the natural frequency depending on the amount of material removed during turning process. On Fig. 5 shown simple sketch of turning process.

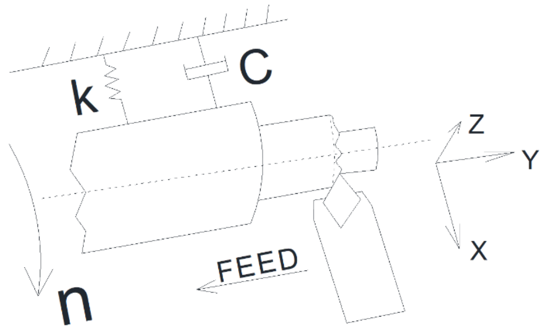


Fig. 5. Sketch of the turning process

Machining process, for example turning process, produces a machining force that is proportional to the chip thickness and chip width.

The machined tool used in turning process is stiff, but it is not infinitely stiff. The vibrating tool changes the chip thickness. Varying cutting forces due to varying chip's depth during turning produce vibrations of the turning tool. Variable forces cause vibrations and vibrations cause wavy surfaces, and than consequently wavy surfaces cause vibrations.
During turning, a very important phenomenon is the formation of self-excited vibrations, where, as we know, a slight change in parameters (the number of rotations) can drastically improve the course of the turning process. The knowledge of stability lobe diagrams and the problem of reduction or elimination of the formation of self-excited vibrations during the implementation of turning machining may determine the machining, e.g. in half the previously planned time value, with obtaining better parameters of the roughness profile of the machined surface (e.g. parameter Ra).

The time dependent chip thickness h(t) is determined as (formula 1):

$$h(t) = h_o + y(t - \mathrm{T}) - y(t) \qquad (1)$$

where:
T – time for one rotation
y(t) – positive value current vibration of cutting tool
y(t – T) - positive value previous vibration of cutting tool

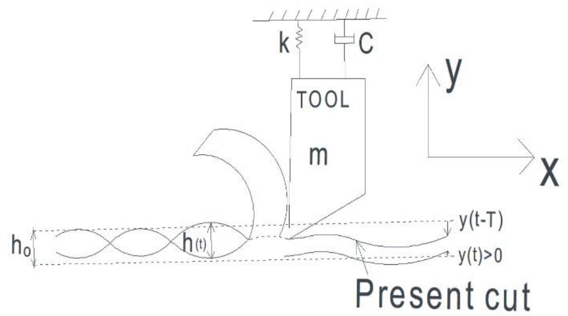


Fig. 6. *Sketch of the turning process (m – mass of the machining tool)*

Total cutting force received in turning process (Fig. 6) is described by formula 2.

$$F_n = k_s \cdot A = k_s \cdot b \cdot h_m \qquad (2)$$

where: b – width of chip

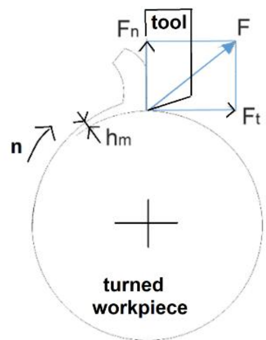


Fig. 7. *Sketch of the orthogonal turning operation*

Normal force F_n depends i.e. from the chip thickness h(t), and during turning (Fig. 7) the value of h(t) is changing its value (formula 3).

$$F_n = k_n \cdot b \cdot h(t) = k_n \cdot b \cdot (h_m + y(t-\tau) - y(t)) \qquad (3)$$

where: τ – time of one rotation

5. Modal analysis – numerical simulations

You can help with numerical finite element analysis FEA of turning process, which can help in finding, for example, the value of the natural frequency of a turned object. One possibility is to carry out several numerical analyzes for several production stages, after the turning operations of machining the turning features in a different sequence.

Characteristic data of the performed numerical FEA analysis are presented on Fig. 8.

Study Property	Value
Study name	Modal Study 1
Study Type	Normal Modes
Mesh Type	Tetrahedral
Iterative Solver	On
Number of modes	10
Frequency Range	Minimum: 0 Hz Maximum: 1e+04 Hz
NX Nastran Geometry Check	On
NX Nastran command line	
NX Nastran study options	
NX Nastran generated options	
NX Nastran default options	
Surface results only option	On

Aluminum, 6061-T6

Property	Value
Density	2712,000 kg/m^3
Coef. of Thermal Exp.	0,0000 /C
Thermal Conductivity	0,180 kW/m-C
Specific Heat	920,000 J/kg-C
Modulus of Elasticity	68947,570 MegaPa
Poisson's Ratio	0,330
Yield Stress	275,790 MegaPa
Ultimate Stress	310,264 MegaPa
Elongation %	0,000

Constraint Name	Constraint Type	Degrees of Freedom
Fixed 1	Fixed	FREE DOF: None

Mesh Information

Mesh type	Tetrahedral
Total number of bodies meshed	1
Total number of elements	55 449
Total number of nodes	82 269
Subjective mesh size (1-10)	10

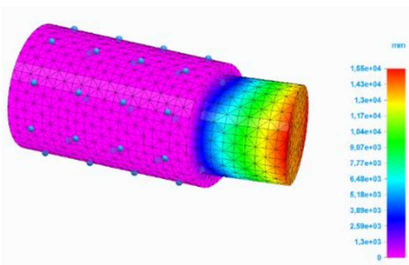
Fig. 8. *Input data for modal analysis performed in SolidEdge*

The weight and stiffness of a turned workpiece changes during machining and depending on the machining method.

If we know the mass, stiffness, and the initial vibration conditions of the turned workpiece, we can describe how the workpiece will behave during turning operation.

Displacement Results

Extent	Value	X	Y	Z
		Result component: Total Translation		
		Mode 1, 2,996e+04 Hz		
Minimum	0 mm	6,250 mm	10,825 mm	-18,810 mm
Maximum	1,55e+04 mm	1,951 mm	9,808 mm	0,000 mm
		Mode 2, 2,996e+04 Hz		
Minimum	0 mm	6,250 mm	10,825 mm	-18,810 mm
Maximum	1,55e+04 mm	-9,808 mm	1,951 mm	0,000 mm



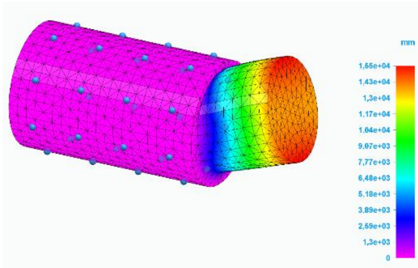


Fig. 9. *Natural frequency for the initial stage of turning*

Comparing the data shown in Fig. 9 and Fig. 10, it can be noticed that depending on the amount of material removed in turning process, different stiffnesses and different natural frequencies were obtained.

Displacement Results

Extent	Value	X	Y	Z
		Result component: Total Translation		
		Mode 1, 8,578e+03 Hz		
Minimum	0 mm	12,310 mm	-2,171 mm	-49,444 mm
Maximum	1,09e+04 mm	-3,701 mm	-9,290 mm	-0,000 mm
		Mode 2, 8,580e+03 Hz		
Minimum	0 mm	12,310 mm	-2,171 mm	-49,444 mm
Maximum	1,09e+04 mm	-9,076 mm	4,199 mm	-0,000 mm

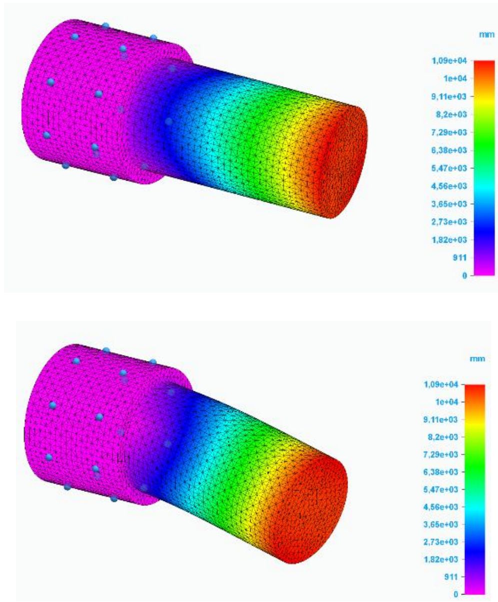


Fig. 10. *Natural frequency for the final stage of turning*

Different natural frequencies means different optimal value of machining parameters recommended for machining on turning centers.

7. Conclusions

In the case when it would be possible to machine the workpiece on different type of CNC lathes, for example on MAZAK QTN 200 MS (single-head, two-spindle machine), on the MAZAK HQR 150 MSY (two-head, two-spindle machine) but the FEA numerical simulations carried out will indicate that it is possible that the machining will not be stable (self-excited vibrations will develop), in this case it is worth to consider machining on e.g. CNC linear such as DMG SPRINT 32/5 multi-axis and multi-spindle linear lathe.

After each single machining and after each machining operation, the stiffness of the machined workpiece, and thus the natural frequency, changes.

It is worth to build a lathe system supporting the selection of the sequence of treatments, taking into account the frequency of natural vibrations for individual shapes and stiffness obtained after each single machining operations. Such a system could take into account, for example, what sequence of machining the features allows for machining with the greatest depth and the greatest feed, i.e. how to machine features successively so that the gradually changing stiffness of the workpiece would allow maintaining a high value of machining parameters as long as possible.

In subsequent tests, experimental research will be carried out for turning with a constant and with variable rotational speed.

8. References

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