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ARCHITECTURE OF THE CNC HORIZONTAL LATHES

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Abstract. This paper presents a synthesis of the most recently types of parallel and revolver lathes in modular conception. The basic constructive variants are analysed and presented, pointing out their structure from the point of view of kinematic couples rotation (*R*) and translation (*T*), axes *Z*, *X*, *Y*, *C*, *B* and others, and motion axes numerically controlled. On their basis each structure is given a structural formula that contains the symbols of the NC axes connected to the tool and workpiece motions. Thus, one can distinguish between lathes with and without the axes *C* and *Y*, with one ore two coaxial or parallel main spindles, with one or two turrets, with or without radial slides, etc. The 2D and 3D representations regarding the architecture of the analysed lathes, lead to the establishing of a code that is assigned to diverse constitutive modules (structure elements, slides, revolvers, tailstock, heads with angular positioning adjustable o two axes, adaptable steady rest, system for storing and transfer of workpieces and tools, clamping and driving devices for workpieces and tools, chip conveyers). The variants in modular conception enable a rapid change of the analyzed machine tool configuration, depending on technological necessities of the types and complexity of workpieces to be machined, specific requirement of the flexible fabrication.

Keywords: horizontal lathe, NC axes, generating/positioning motion, element, constructive assembly

1. Introduction

The analysis of the principles of modular conception of the CNC machine tools achieved in paper [1] points out exclusively for milling machine tools and milling machining centres numerous (tens of thousands) of possible variants resulted from he selective selection of minimum three of the eight basic modules, grouped in the machine structure in the *driving branch* and *workpiece setting branch* respectively.

It is noticeable the statistic analysis of the main technical characteristics of these machines achieved at that time considering 230 horizontal and 200 vertical machining centres. The data base constituted enabled the determination of tendencies in using the machining centre structures and also connections and interdependencies between the dimensional, functional, and structural characteristics. The paper proposes three complex calculation programs for structure analysis, synthesis, and draft representation of machining centre structures. Using them, ENIMS has developed a modular system of machining centres to shorten the production time and lower the costs of the machine tools.

A similar approach is presented in paper [8], in which the conceptual design of the milling machines with three axes is analysed. They are considered consisting of the basic modules, on which support a lot of types of milling machine could be obtained. For the configuration of the possible variants, the followings are taken in consideration: the models of the guiding long and short, library of parametric components, structuring the diverse type of machines in four classes depending on the fixing mode and design space constraining. Thus, 56832 sub-variants resulted depending on the main spindle positions (horizontal or vertical), existence or absence of a symmetry plan, possibility/impossibility of mirrored machines.

Also, the concept presents the generation analysis of machine variants on the basis of the mechanical model, static deformation analysis, and dynamic analysis achieved by means of a computer using the program ROBOTRAN and the analysis of clearance through which the possible interferences between components are removed for each position of the main spindle in the machine work space. For optimizing the machine variant generation, a genetic programme is proposed.

The paper [2] presents four groups of work machines (for conventional and non-conventional processing) established on the basis of the translation and rotation couples of the structure. For exemplification, some structures are analyzed, among them being milling machine structures for which the structural formula is indicated. It contains the NC axis notations: axes that supplies the workpiece and tool motions.

In the work [3] a structural configuration method for machine tools was described and applied to vertical machining centres. The approach uses a graph representation of the machine tool in which the nodes stand for joints (motions) and the links for structural components. The variants are generated as graphs and then some criteria of incompatibility and functionality of the whole assembly are applied. To the remaining graphs a set of optimization criteria is applied for obtaining the most suitable configurations to the functional and technological requirements.

Other approaches are presented in papers [9] and [10].

2. Structures of some lathes

2.1. Lathes with one main spindle

a. *Lathes with two NC axes.* This category is the most spread one, having possibilities of frontal (axis *X*), cylindrical (axis *Z*), conical or profiled by linear and/or circular interpolation and threading by cutter machining. Figure 1 emphasizes the rotary main motion (rotation couple *R*), with speed n_c executed by the workpiece *P* and feed motions (translation couples T_1 and T_2) executed by the tool (cutters, tools for hole processing) in radial direction (axis X) and longitudinal (axis Z) with speeds v_{fT} and v_{fL} respectively. The bed B_t is the structural element on which the head stock and the two slides assembly (longitudinal (*SL*) and transversal (*ST*)) are disposed. Joining two modular structures of this type leads to a new frontal lathe architecture with two parallel main spindle and two work supports (assemblies of slides *SL* and *ST*).

For workpieces with length shorter than their diameter (figure 2), the bed guides are radial (transversal), in inclined or horizontal plane, the lathe being named frontal lathe. On the bed guides there is the radial slide and on its guides the longitudinal slide is moving. In the majority of lathes, on this slide an assembly called turret is mounted with the axis of the toolholder disk horizontal or vertical.

For workpieces with the length greater than the diameter, the bed guides are longitudinal and situated in horizontal, inclined (figure 3) or vertical plane.

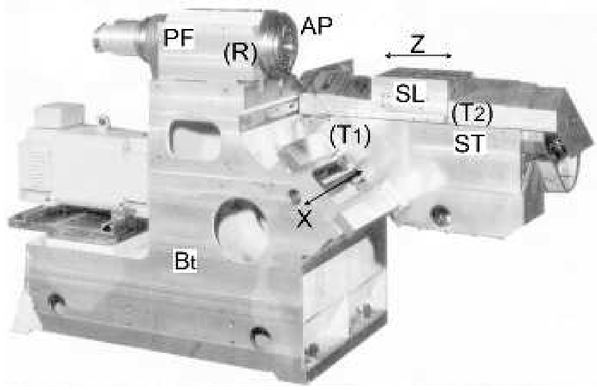

Figure 1. Frontal lathe with one working unit

Figure 2. Example of workpiece

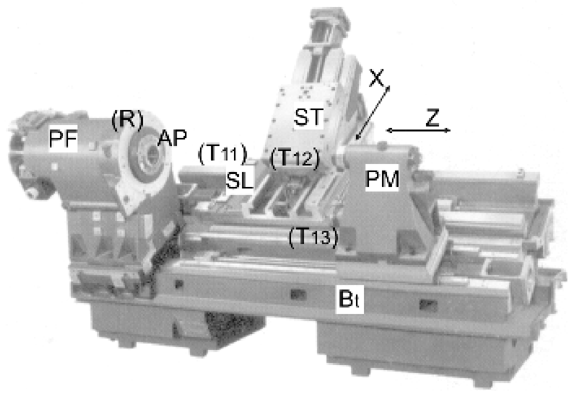

Figure 3. Turret lathe with one working unit

In many cases, the tool clamping is done between centres: a centre in the main spindle (*AP*) and tailstock (*PM*). The tailstock guides are parallel to those of the longitudinal slide (*SL*). On the guides of the longitudinal slide the transversal slide (*ST*) is moving, on which there is an assembly turret (not represented).

b. *Lathes with three NC axes*. The third NC axis (axis *C*) stands for the rotation motion of the main spindle regarded as feed/angular positioning motion used for achieving drilling, milling, and grinding operation with rotary tools in the turret.

Figures 4 and 5 show both the turning

possibilities, which requires the movements: main (n_c) and feed (axis X, Z), and also those of feed/positioning executed by the workpiece (axis C) for drilling, milling, and grinding in well determined angular positions. Also, it is possible to process cylindrical exterior and interior threads by turning with cutter.

Figure 4. Workpiece of bush

Figure 5. Flange type workpiece

In some lathes having the axes Z, X and Y, the axis Y is perpendicular to the plane generated by the other two axes.

Therefore, there are two variants of lathe architectures with three NC axes: *ZXC* and *ZXY*.

c. *Lathes with four NC axes*. These lathes have two turrets, one situated above and the other one below the mains spindle *AP* level (figure 6).

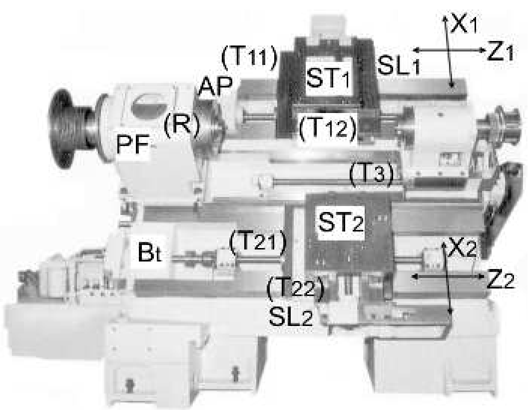

Figure 6. Lathe with two turrets

Each turret is mounted on a work support, constituted by the two slides, longitudinal ($SL_{1,2}$) and transversal ($ST_{1,2}$) that achieve the feed motions on the axes (X_1, Z_1) and (X_2, Z_2) in regard with the bed B_t. In these lathes, the assembly situated at the right end of the bed is a tailstock enabled with broach and live centre (rotary). Most actual lathes with such architecture have also an axis C.

Another mode of obtaining four NC axes has on the basis the architecture of the three NC axis lathes (X, Z, C) enabled with a work support that effectuates displacement in feed motion not only in horizontal or inclined plane (axes X, Z), but also on vertical direction (axis Y). The structural formula is *ZXYC*. Thus, one ensures the increase of the processing technological possibilities, e.g. for helical groves with variable depth. The mill (S) (figure 7) processes surfaces of the workpiece P fixed in the main spindle *AP* and in a live centre (not represented). The tool is driven in rotary motion by a kinematic chain situated in the structure of the turret (*CR*) fixed on the transversal slide, which together with the longitudinal slide *SL* forms a work support of the lathe. The toolhoder *Ps* is fixed on the toolhoder disk of the turret. It results two variants of lathes with four axes: $Z_1X_1Z_2X_2$ and *ZXYC*.

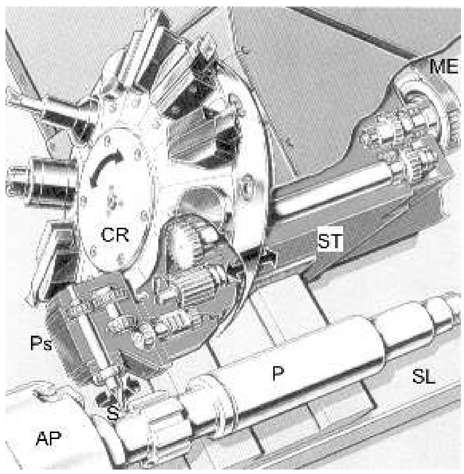

Figure 7. Turret assembly

d. *Lathes with five NC axes*. The fifth NC axis stands for the circular feed or angular positioning motion of the axis of the rotary tool in the turret (for lathes with one work support) about a horizontal axis, perpendicular to the main spindle axis.

Other lathes have the architecture with one work support and one of the structural formula: *ZXYCA*, *ZXYCB*, *ZXYAB*. The lathes with two work supports correspond to one of the formulas: $Z_1X_1Y_1Z_2X_2$, $Z_1X_1C_1Z_2X_2$.

e. *Lathes with six NC axes*. These lathes have on the basis the formula *ZXYCAB*. The turret has two NC rotary axes (A, B). For these lathes with two work supports, the structural formula could be: $Z_1X_1Y_1Z_2X_2Y_2$, in which each work support has three translation axes numerically controlled or $Z_1X_1Y_1CZ_2X_2$ in the lathes that have the rotary axis C of the main spindle. Other formulas could be: $Z_1X_1Y_1Z_2X_2C_2$, $Z_1X_1C_1Z_2X_2Y_2$, $Z_1X_1C_1Z_2X_2C_2$ (see figure 7 where on the bed, at the right end, it is positioned a second tailstock with main spindle), $Z_1X_1C_1B_1Z_2X_2$ and others. According to these formulas, one of the work supports has three translation axes numerically controlled, the other one only two.

Some lathes from this category have on the main work support (with transversal slide), instead a turret an assembly (figure 8) with NC angular positioning (*UPa*) and milling unit (UM). The tools are automatic fed in toolholder seats (for tool of cutter and rotary types) from a tool magazine adapted on the bed in the rear part of the headstock.

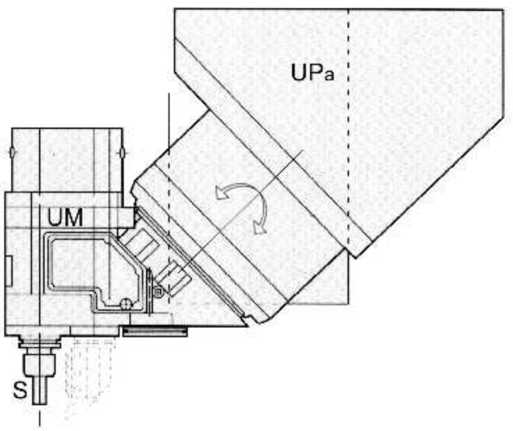

Figure 8. Work unit with angular positioning

f. *Lathes with seven NC axes*. They could be:

- with four axes on the first work support and three on the second one:

$Z_1X_1Y_1C_1Z_2X_2C_2$; $Z_1X_1Y_1C_1Z_2X_2Y_2$;
$Z_1X_1Y_1A_1Z_2X_2C_2$; $Z_1X_1Y_1A_1Z_2X_2Y_2$;
$Z_1X_1Y_1B_1Z_2X_2C_2$; $Z_1X_1Y_1B_1Z_2X_2Y_2$;

- with five axes on the first work support and two on the other one:

$Z_1X_1Y_1C_1A_1Z_2X_2$; $Z_1X_1Y_1C_1B_1Z_2X_2$;
$Z_1X_1Y_1A_1B_1Z_2X_2$; $Z_1X_1C_1A_1B_1Z_2X_2$.

g. *Lathes with eight NC axes*. They could be:

- with four axes at each work support:

$Z_1X_1Y_1C_1Z_2X_2Y_2C_2$; $Z_1X_1Y_1C_1Z_2X_2Y_2A_2$;
$Z_2X_2Y_1C_1Z_2X_2Y_2B_{2;}$ $Z_1X_1C_1A_1Z_2X_2Y_2C_2$;
$Z_1X_1C_1A_1Z_2X_2Y_2A_2$; $Z_1X_1C_1A_1Z_2X_2Y_2B_2$;
$Z_1X_1C_1A_1Z_2X_2C_2A_2$; $Z_1X_1C_1A_1Z_2X_2C_2B_2$;

- with five axes on the first work support and three on the other one:

$Z_1X_1Y_1C_1A_1Z_2X_2A_2$; $Z_1X_1Y_1C_1A_1Z_2X_2Y_2$;
$Z_1X_1Y_1C_1B_1Z_2X_2C_2$; $Z_1X_1Y_1C_1B_1Z_2X_2A_2$;
$Z_1X_1Y_1C_1B_1Z_2X_2B_2$; $Z_1X_1Y_1A_1B_1Z_2X_2Y_2$;
$Z_1X_1Y_1A_1B_1Z_2X_2C_2$; $Z_1X_1Y_1A_1B_1Z_2X_2A_2$;
$Z_1X_1Z_1A_1B_1Z_2X_2B_2$.

- with six axes on the first work support and two on the other one:

$Z_1X_1Y_1C_1A_1B_1Z_2X_2$.

h. *Lathes with nine NC axes* could be:

- with five axes on the first work support and four on the second one:

$Z_1X_1Y_1C_1A_1Z_2X_2Y_2C_2$;
$Z_1X_1Y_1C_1A_1Z_2X_2Y_2A_2$;
$Z_1X_1Y_1C_1A_1Z_2X_2Y_2B_{2.}$

- with six axes on the first work support and three on the second one:

$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2$; $Z_1X_1Y_1C_1A_1B_1Z_2X_2C_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2A_2$; $Z_1X_1Y_1C_1A_1B_1Z_2X_2B_2$.

i. *Lathes with ten NC axes* could be:

- with five axes on each work support:

$Z_1X_1Y_1C_1A_1Z_2X_2C_2A_2$;
$Z_1X_1Y_1C_1A_1Z_2X_2Y_2C_2B_2$;
$Z_1X_1Y_1C_1A_1Z_2X_2Y_2\,A_2B_2$.

- with six axes on the first work support and four on the other one:

$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2C_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2A_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2B_2$,
$Z_1X_1Y_1C_1A_1B_1Z_2X_2C_2A_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2C_2B_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2A_2B_2$.

j. *Lathes with eleven NC axes* could be:

- with six axes on the first work support and five on the other one:

$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2C_2A_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2C_2B_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2A_2B_2$;
$Z_1X_1Y_1C_1A_1B_1Z_2X_2C_2A_2B_2$.

k. *Lathes with twelve NC axes*. These could have the structural formula:

$Z_1X_1Y_1C_1A_1B_1Z_2X_2Y_2C_2A_2B_2$.

It is possible to machine the workpiece in the same clamping, at both ends removing taking it of the main spindle, rotation with 180^0 and clamping for machining at the other hand. The assembly of the second main spindle (coaxial to the first one), situated on the right side of the bed can move axially to the main spindle of the left side in order to clamp the workpiece machined al the first end and bring it to the right (the second clamping), in order to machine the other end.

The two main spindle, driven independently, have NC rotary motion (axes C_1 and C_2); each turret has two (X_1, Z_1), (X_2, Z_2) or three (X_1, Y_1, Z_1),

(X_2, Y_2, Z_2) NC translation axes. Eventually, one has two translation axes, the other one three rotary axes numerically controlled.

By bringing in a device for clamping with large diameter both in the front part and rear part of the main spindle, it becomes possible the machining of long individual blanks or from bar.

By inserting a NC rotary axis (C), it becomes possible the synchronization of the axes X and C, e.g. for polygonal milling, and also synchronization of axes Z and C, e.g. for milling threaded grooves. In both cases, a rotary tool is used (see figures 7 and 8).

2.2. Lathes with two main coaxial spindles

2.2.1. Lathes with two coaxial main spindles in opposition and stationary. The effectuated study has lead to the identification of the following structures:

a. *with four axes*: two translation axes on each support, with the formula $Z_1X_1Z_2X_2$;

b. *with five axes*: three in the first support and two on the second one, having the formulas

$Z_1X_1Y_1Z_2X_2$ or $Z_1X_1C_1Z_2X_2$.

2.2.2. Lathes with two coaxial main spindles in opposition and axial movable. If the main spindle from the left can move axially, by means of a broach or slide (figure 9), then the variants that can be obtained are of the types: $\alpha_{22}Z_3$, in which α_{22} is any of the previous lathe with two main spindles and two work supports, and $\alpha_{22}Z_3$ represents the results of the concatenation of one of these variants with the axis Z_3 representing the axis of the translation motion of the second main spindle.

Certainly, the number of degrees of freedom is with one unit grater than the number of the degrees of freedom of the variant α_{22}. For generalization, it is considered α_{ij} the assemblage of variants of lathes with i main spindles $i \in [1, 2]$ and j - number of work supports, $j \in [1, 2, 3]$.

2.2.3. Lathes with two coaxial main spindles in opposition and three work supports. In principle, the third work support can have up to six NC axes: three translations and three rotations. These are added to the other maximum twelve NC axes of the lathe with two coaxial main spindles in opposition and two work supports.

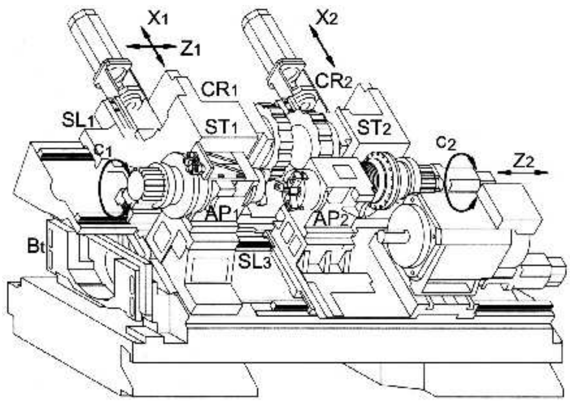

Figure 9. Turret lathe with two coaxial main spindles

The assemblage of lathes solutions of this type has as formula the result of concatenation of any formula of lathe with two coaxial main spindles in opposition and stationary and two work supports α_{22}, with any structural formula of lathe with one main spindle and one work support α_{11}:

$M_{32} = \alpha_{22}.\alpha_{11}$.

2.2.4. Lathes with two parallel main spindle in opposition and two work supports. For passing the workpiece between the two main spindles, one situated on the left side and the other one on the right side of the bed, it is necessary a radial displacement (axis X_3) for bringing the two main spindles in coaxial position and then a longitudinal displacement (axis Z_3) for achieving the workpiece transfer machined at one end form the left main spindle to the right one, in order to machine the other end of the workpiece.

The assemblage of solutions of the lathes of this type ahs as structural formula the result of concatenation of any structural formula of lathe with two main spindles in opposition and stationary with the assembly of motions on the two NC axes X_3 and Z_3:

$M_{22p} = M_{22}Z_3X_3$.

The number of NC axes could reach 14.

2.3. Automatic mono axis or multi axis lathes

These lathe categories are designated especially for machining the workpieces in production of short or middle series. The long individual blanks or long blanks from bar are used

The general structural formula has the form $Z_1Z_2...Z_m X_1X_2...X_n$.

In which m represents the number of slides with independent axial feed, and n - number of slides with independent radial feed. For exemplification, in figure 10 an automatic mono axis turret lathe enabled with four radial slides

($ST_{1,2,3,4}$) and a work unit with turret (*CR*) movable on the axes *Z* and *X*. For workpiece processing at the other end after cutback, the tools clamped and driven by the spindles AP_1 and AP_2 are used. The two spindles are moving axially (other axis *Z*).

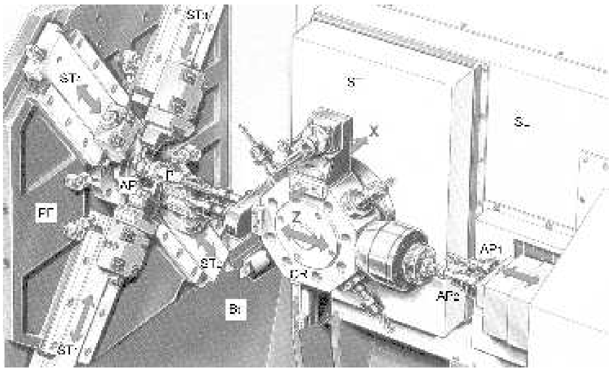

Figure 10. Automatic monoax turret lathe

From the effected analysis upon many automatic lathes it results that the number of main spindles does not influence directly the structural formula, but the number of slides with axial and radial feed.

3. Conclusions

In the paper, the possible variants of modular establishment of the NC horizontal lathes have been analysed. These lathes could have one or more main spindles, the second main spindle on the right side of the bed could be coaxial, stationary or axial moveable or parallel to the main spindle situated on the left side of the bed.

The number of the work supports could be one, two or three. Also, the lathe could have mobile supplementary devices for driving the grinding tool or local thermal treatments achieved by laser.

For each of these variants, the structural formulas have been deduced, fully respecting the standardized signification of the coordinate axes.

Some works in the field have been evaluated, they regarding the possible variants of modular structures used in configuration of the machining centres, having in view the extension of these works in the field of the NC horizontal lathes. Some of the presented formulas are a synthesis of the existent horizontal lathes, some of them being analysed only on the basis of prospects [11].

Other structural formulas represent variants yet non-existent but possible from the technical point of view. Among them, some may arise in the future, others of the type *ZY*..., in which the vertical slide (axis *Y*) is placed on the longitudinal one (axis *Z*), are less probable.

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