Classification of multi-axis machine tools

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Report no.: WPA 1007, March 1991.
BCR-90/012.

CONFIDENTIAL

Introduction

A survey of the different types of five axis CNC milling machines will be made in order to establish the origins and characteristics of their related errors. With this a basis for modelling the geometric structure can be achieved and type dependent finite stiffness effects can be pointed out.

The following classifications have been suggested:

PTB: Classification with respect to the most important errors. Within a certain class the machine tools should have the same type of significant errors.

Maho: Classical classification of milling machines [1]:
- -Bed type milling machine
- -Knee type milling machine

TUE: Classification with respect to the kinematic chain of the milling machine.

The underlying classification of different types of five axis milling machines is developed in order to simplify the identification of significant errors [2]. Therefore a separation is made between machine types with the same kind of errors (type dependant errors). The classification is based on the number of possible movements of the tool holder.

Classification

In general, milling machines have three perpendicular linear axes. In addition to these three linear axes, a five axis milling machine consists of two rotary axes with perpendicular axes of rotation. Also the spindle of a milling machine can be defined as a rotary axis. However, the spindle will not be included in this classification, since the errors introduced by the spindle are not machine type dependant.

Because rotary axes are available as an option, the three linear axes constitute the basic machine. In all cases the rotary axes will be be added to this basic machine and therefore they will not interfere with the kinematic chain of linear axes. For this reason a distinction is made between the basic machine and the additional rotary axes.

Basic machine

The basic machine has three perpendicular linear axes. These linear axes represent the kinematic chain of the basic machine. One end of this kinematic chain supports the tool, at the other end the workpiece can be placed. The base of the machine is situated within this kinematic chain. As measurements mostly are referred to the base of a machine, a distinction between two chains is made:

- A - chain: this chain supports the tool;
- B - chain: this chain supports the workpiece.

In figure 1 an example is depicted of a milling machine with its kinematic chain representation.

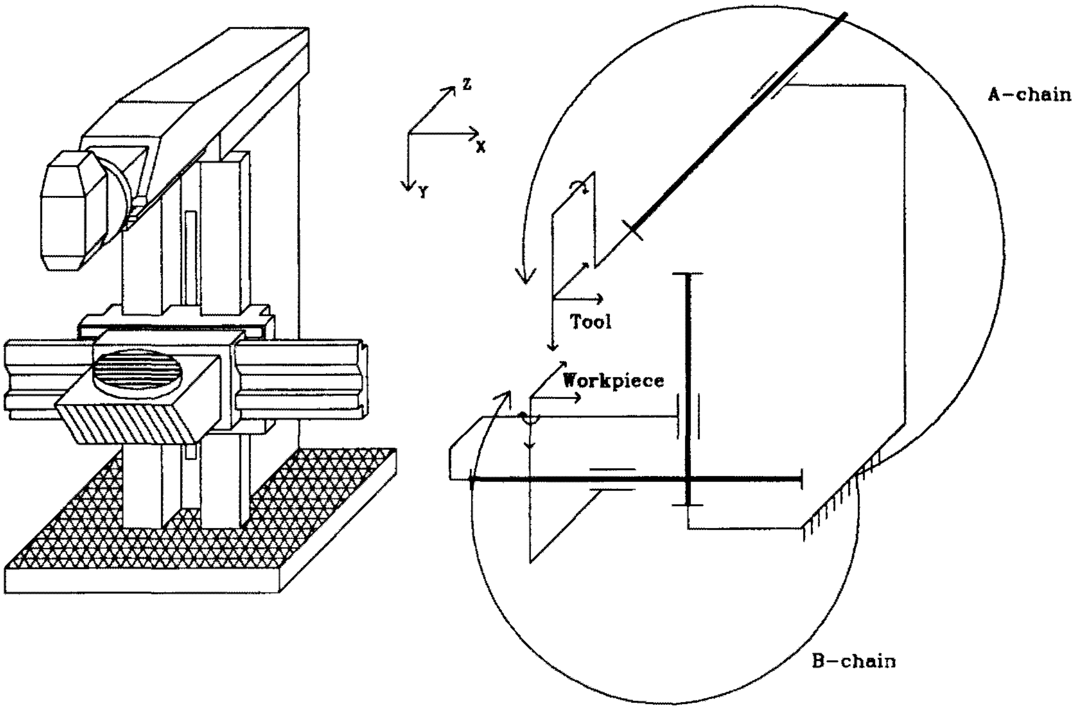

Fig. 1 Example of A- and B-chain in a knee-type milling machine.

In the ISO 841 standard [3] the nomenclature for the axes of motion is defined. In normal cases the axis of rotation of the tool is designated as the Z-axis. However, some modern machine tools are equipped with a swivelling tool holder, which allows to mill in a horizontal as well as in a vertical plane. Then applying the ISO standard to these types of milling machines leads to different viewpoints. It appears the last kinematic axis can be designated as the Z-axis as well as the Y-axis. To avoid problems with the nomenclature, the axes are not named X, Y or Z but indicated as horizontal (H) and vertical (V) axes of motion.

As a machine consists of three axes, four classes can be discriminated with a different number of axes present in a particular chain. Within these classes two groups are distinguished, where the construction of the machine causes another type dependent error structure.

In table 1 the resulting classification is presented. This table gives an overview of the different types of milling machines and their specific errors. In figure 2 some examples are depicted of the in table 1 presented classes.

<table>
<tr><th colspan="2">Number of axes in:</th><th rowspan="2">Classification</th><th rowspan="2">Some of the class dependent errors during traverse of the axis without process forces</th><th rowspan="2">Examples of machine types (Fig. 2)</th></tr>
<tr><th>A-Chain</th><th>B-Chain</th></tr>
<tr><td>0</td><td>3</td><td></td><td></td><td>None</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">2</td><td>Class IA
B-Chain: V → H
A-Chain: H</td><td>Bending of:
Table guide = F(Table, Weight/Load)
Ram = F(Ram)</td><td>Knee-type milling machine</td></tr>
<tr><td>Class IB
B-Chain: H → H
A-Chain: V</td><td>Bending of:
Table guide = F(Table, Weight/Load)</td><td>Fixed-bridge milling machine</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">1</td><td>Class IIA:
B-Chain: H
A-Chain: V → H</td><td>Bending of:
Table guide = F(Table, Weight/Load)
Column = F(Ram, Vertical slide)
Ram = F(Ram)</td><td>Fixed-column milling machine</td></tr>
<tr><td>Class IIB:
B-Chain: H
A-Chain: H → V</td><td>Bending of:
Table guide = F(Table, Weight/Load)
Column/bridge = F(Ram guide)</td><td>Fixed-bridge or travelling column machine</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">0</td><td>Class IIIA:
A-Chain: H → H → V</td><td>Bending of:
Bridge guide = F(Bridge)
Bridge = F(Ram guide)</td><td>Travelling bridge milling machine</td></tr>
<tr><td>Class IIIB:
A-Chain: H → V → H</td><td>Bending of:
Column guide = F(Column)
Column = F(Vertical slide, Ram)
Ram = F(Ram)</td><td>Travelling column milling machine</td></tr>
</table>

→ : Sequence in kinematic chain
H : Horizontal axis of motion
V : Vertical axis of motion

F(E): Function of position of element

Table 1 Classification of basic machine types.

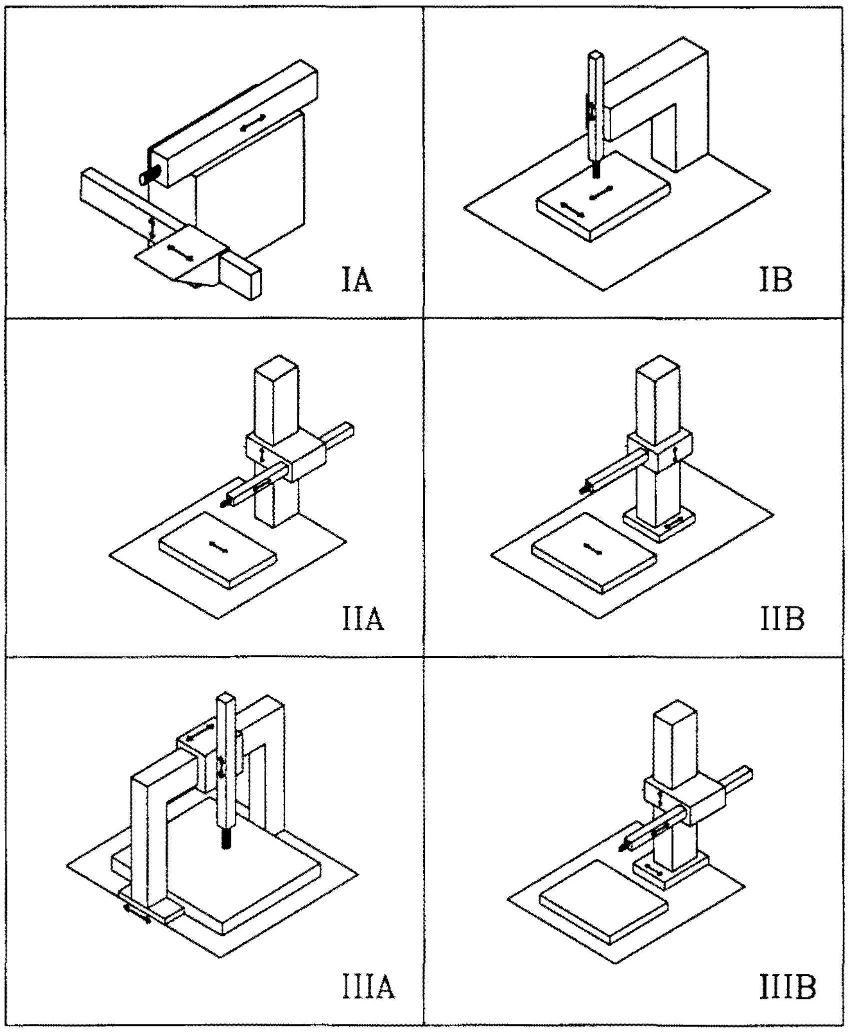

Fig. 2 Examples of milling machines of table 1.

Rotary axes

Apart from three linear axes, a five axis milling machine consists of two rotary axes with perpendicular axes of rotation. Taking two rotary axes it is possible to distinguish three classes with a different number of rotary axes present in a chain. In the next table this classification is shown.

Number of rotary elements in:		Classification
A-Chain	B-Chain	
0	2	Class 1 Workpiece table can rotate about vertical axis and swivel about horizontal axis
1	1	Class 2 Workpiece table can rotate about vertical/horizontal axis and tool holder can swivel about horizontal axis
2	0	Class 3: Tool holder can swivel about both horizontal and vertical axis

Example

The Maho 700S is a five axis milling machine with three perpendicular linear axes and two rotary axes with perpendicular axes of rotation (Fig. 3).

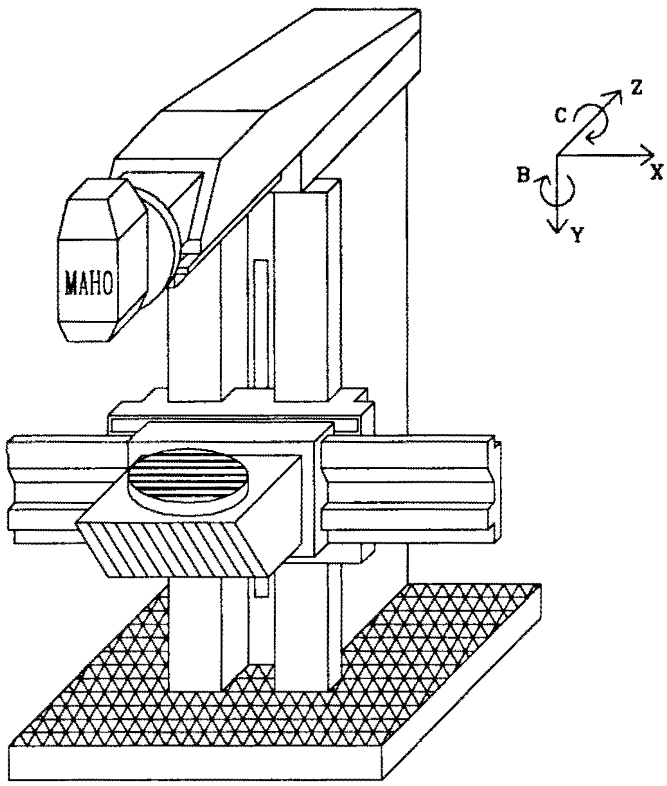

Fig. 3 A five axis milling machine (Maho 700S).

The basic machine, which consists of three linear axes, has one linear axis between the tool and the base (A-chain) and two linear axes between the workpiece and the base (B-chain). As the B-chain contains the vertical axis, this basic machine can be classified as Class IA. Both the kinematic A- and B-Chain contain a rotary element. Therefore the whole milling machine can be classified as Class IA,2.

Conclusion

With the described classification a distinction can be made between different types of five axis milling machines that manifest the same kind of errors (i.e. type dependent errors). With the knowledge of the type dependent errors the definition of a calibration setup and the error budget of the machine are significantly simplified.
As the classification distinguishes between different number of axes present in the A- and B-chain, it becomes less difficult to model the geometric error structure of the milling machine by using this classification.

Literature

[1] A list of the most important type dependent geometrical and thermic errors of machine tools, Maho AG, BCR-90/006, June 1990.

[2] Draft Standard ASME B5 TC52, June 1990.

[3] ISO 841:
Numerical control of machines - Axis and motion nomenclature.
ISO International standard, First edition, July 1974.