A

SEMINAR ON

Multi-Functional Machine Tool

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CONTENTS

1. Introduction

- **The fundamental functions of machine tools are to transform the raw materials with given mechanical properties to the finished parts with required geometry, dimensions and surface quality.**
- **As the demands are increasing to produce parts with higher quality at reduced cost, the machine tools are required to have higher machining accuracy and speed.**
- **As the production lot size becomes smaller, a single part with complicated geometry has to be machined without a trial cut.**
- **In order to meet such requirements, the machine tools are expected to have multiple functions with modular and reconfigurable design architectures**
- **The turning centers and machining centers are typical machine tools of such multi-functional machine tools.**

POSSIBLE PROCESS INTEGRATION OF MULTI-FUNCTIONAL MACHINES.

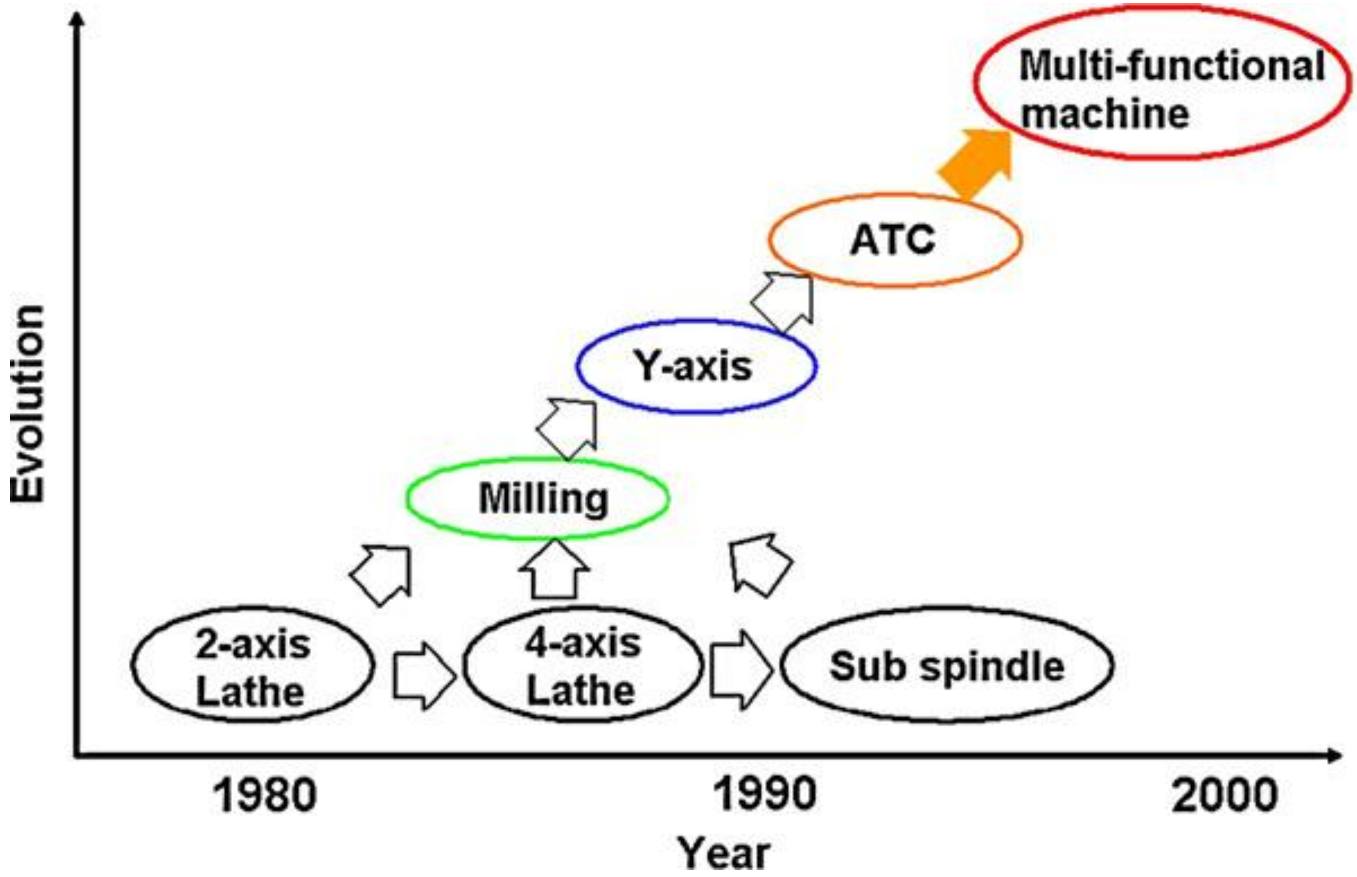
Cutting	Turning Milling Drilling Gear cutting Planning
Grinding	Surface grinding Cylindrical grinding Internal grinding
Forming	Forming Burnishing
Heat treatment	Laser sintering Laser softening
EDM	Electrodischarge machining
Measurement	On machine measurement
Handling	Parts handling

2. Historical review

2.1. Multi-functional turning machines

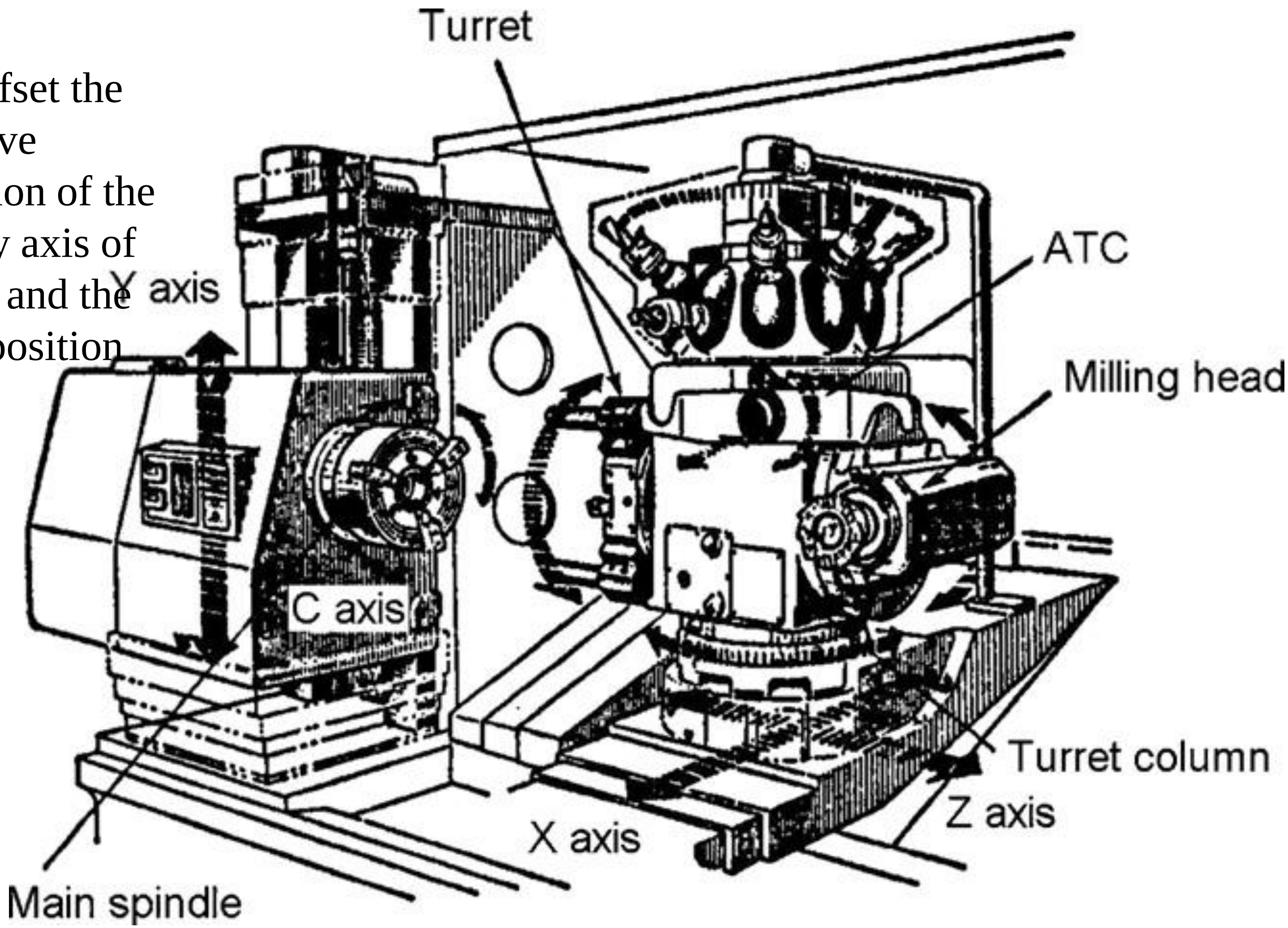
- **The boring machine developed by John Wilkinson and the lathe developed by Henry Maudslay**
- **In order to increase the productivity of the turning machine, the multi-axis automatic turning machine was developed**
- **These can perform several turning operations simultaneously on one machine equipped with multiple spindles.**
- **The turret was also developed so that multiple turning operations are possible.**
- **As simultaneous multi-axis control became possible with the advances in NC technology**

EVOLUTION OF MULTI-FUNCTIONAL MACHINE

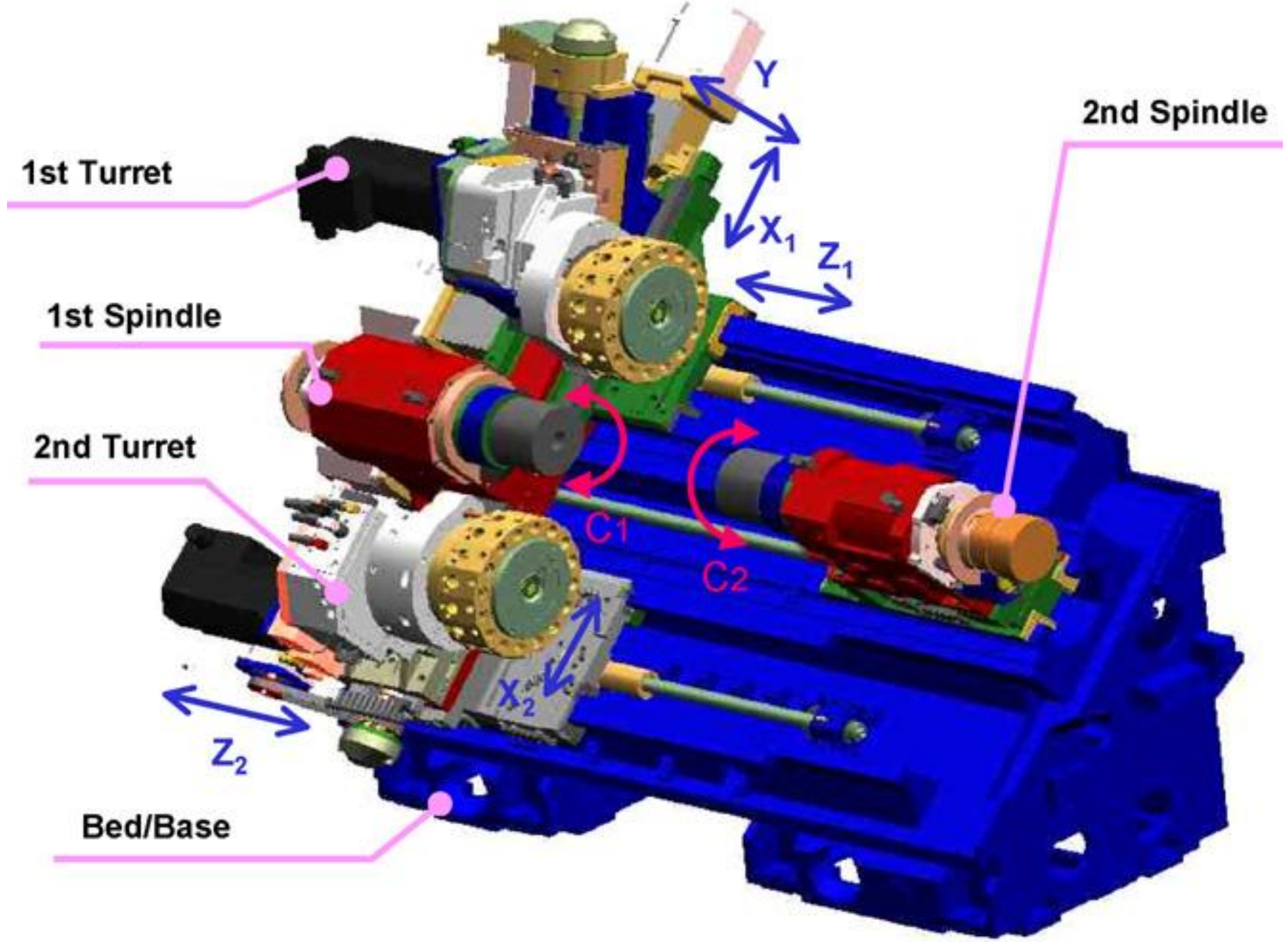


An example of an early TC developed in 1974

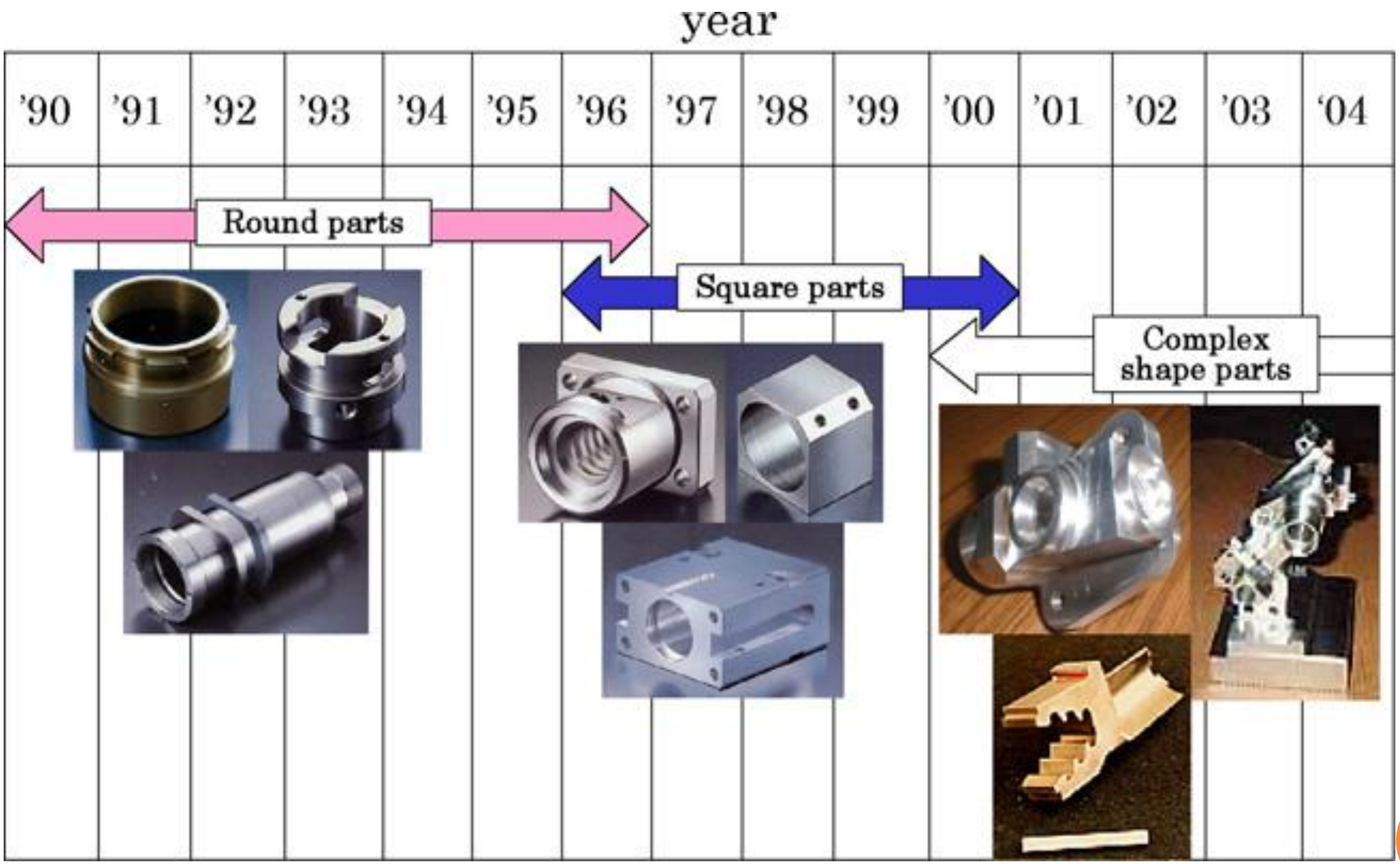
To offset the relative position of the rotary axis of work and the tool position



SAMPLE CONFIGURATION OF RECENT MULTI-FUNCTIONAL MACHINE TOOL.



EVOLUTION OF PARTS MACHINED BY TURNING MACHINES.



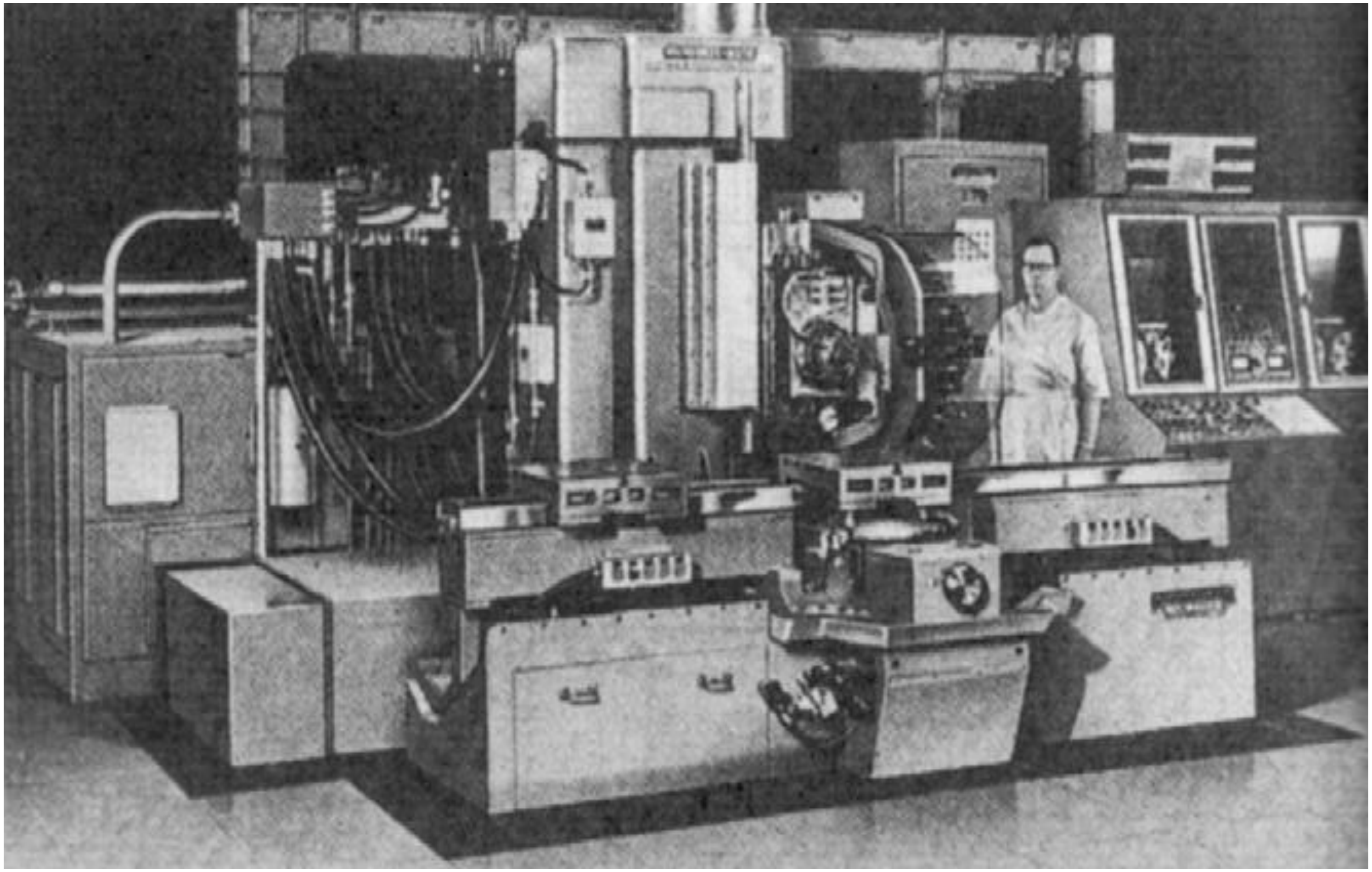
2.2. MULTI-FUNCTIONAL MILLING MACHINES

- **It was initially mainly used to machine flat surfaces & later expanded to 2D and 3D surfaces.**

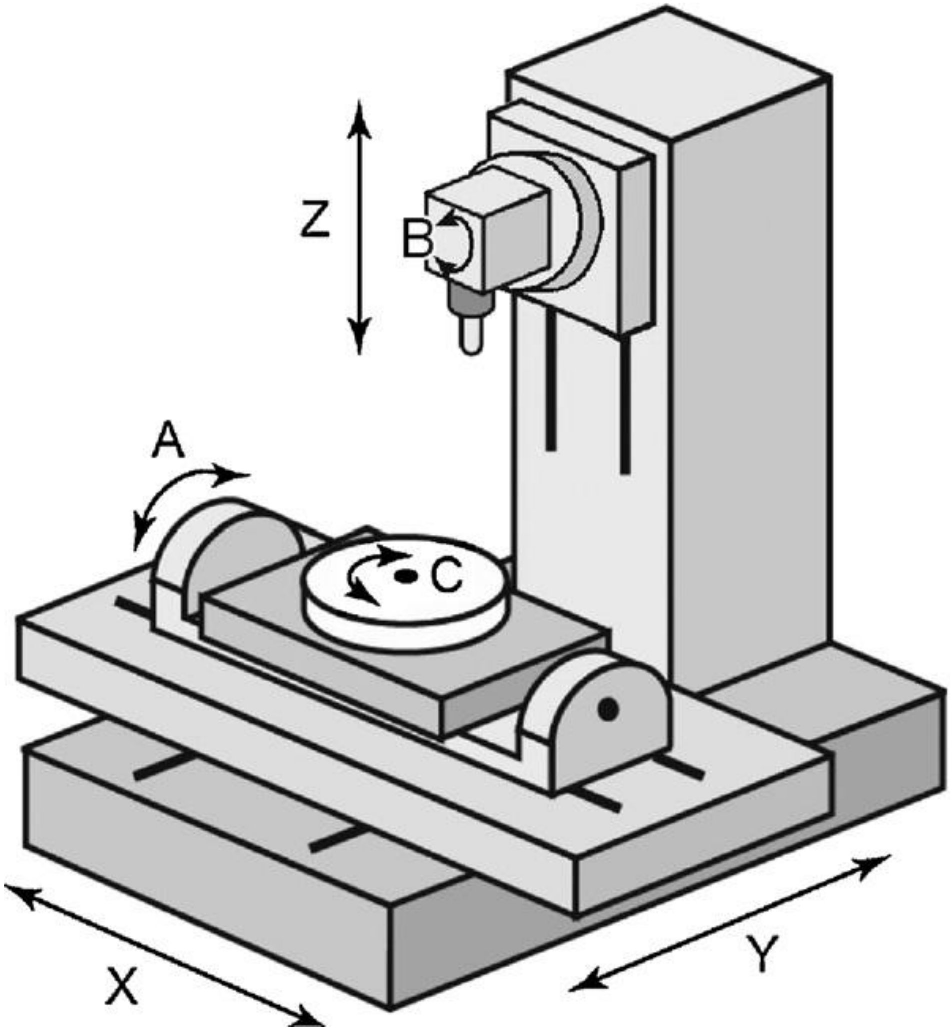
- **The first NC (Numerical controlled) machine tool developed by John T. Parsons in 1952 was a 3-axis milling machine.**

- **The first MC (Machining center) named Milwaukee-Matic was developed by Kearney and Trecker in 1958.**

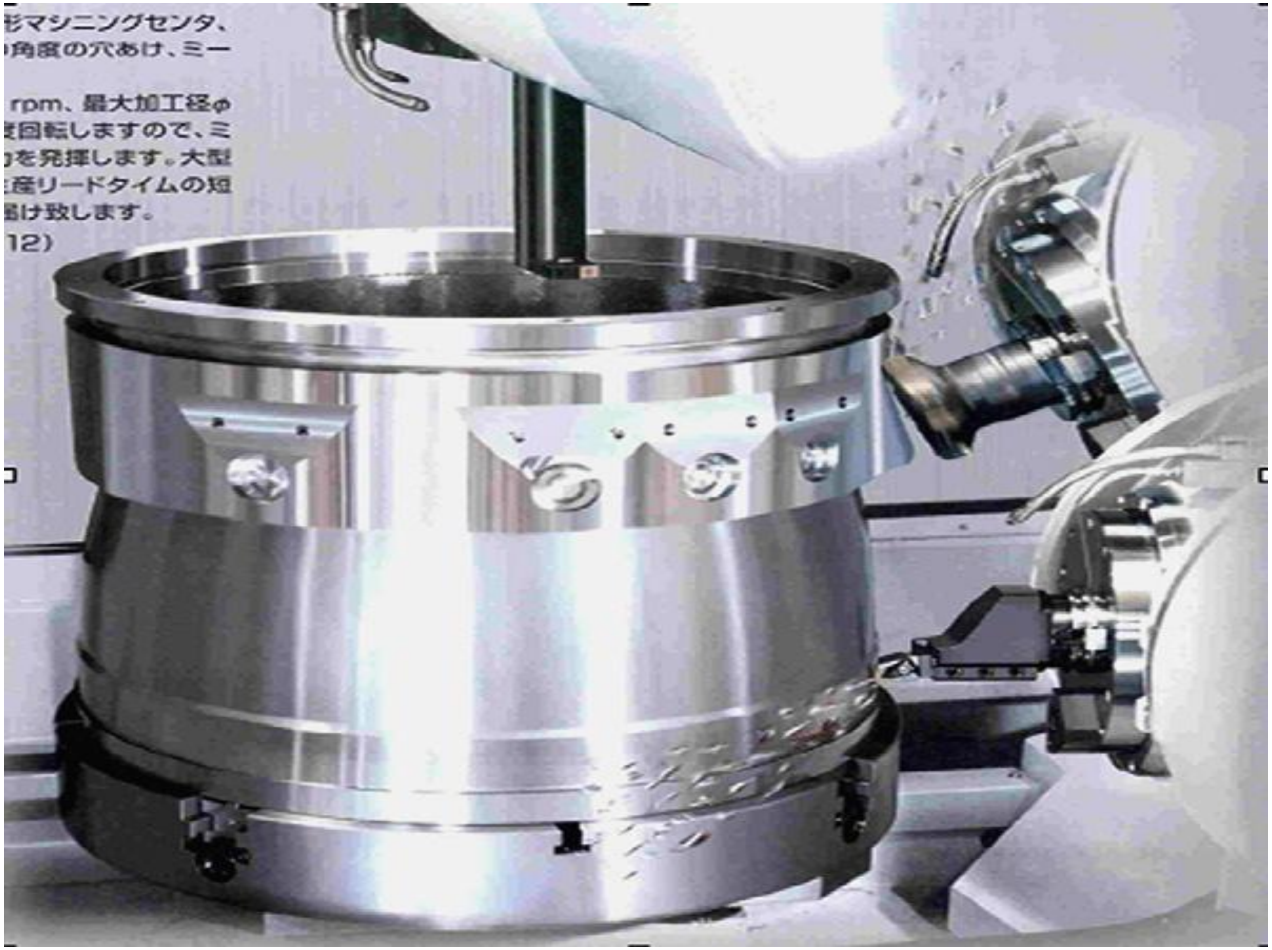
Milwaukee-Matic Model II developed by Kerney and Trecker in 1958.



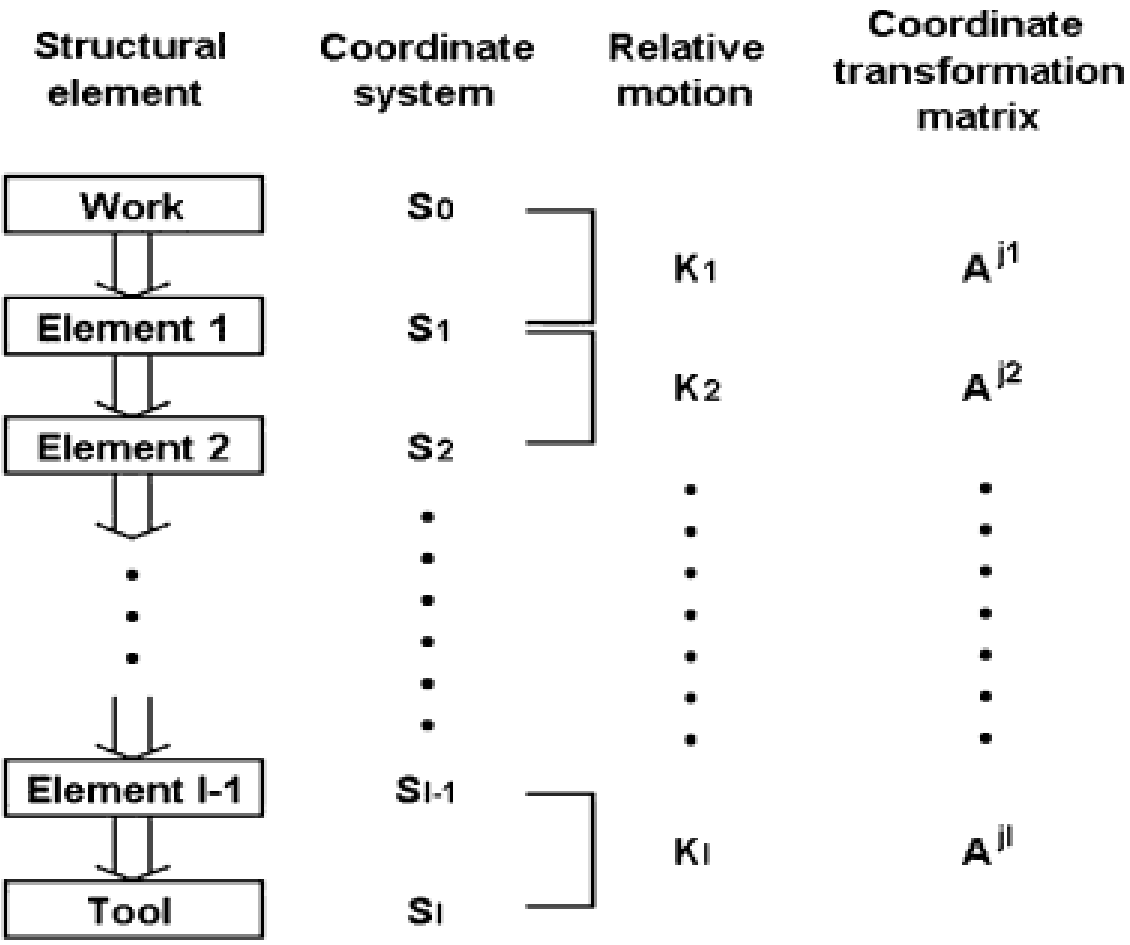
Typical configuration of MC with added rotary axes.



AN EXAMPLE OF SIMULTANEOUS MILLING AND TURNING ON ONE MACHINE



3. Design principle

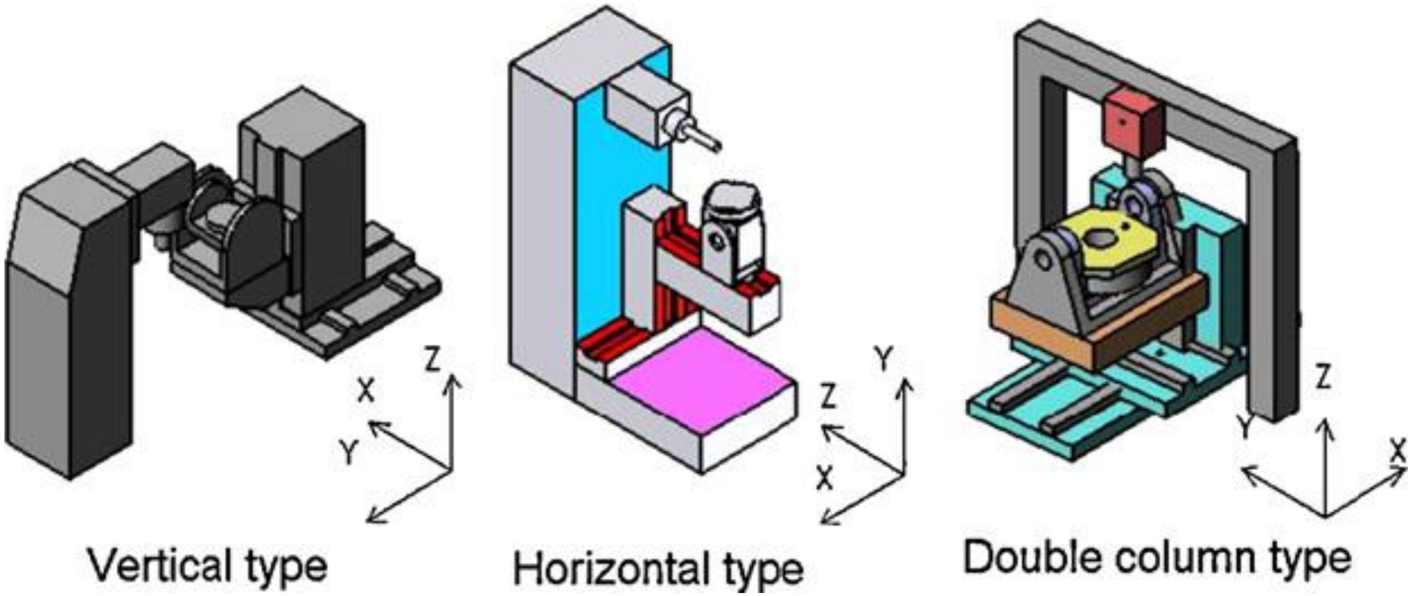


Mathematical model of machine tool (Inasaki).

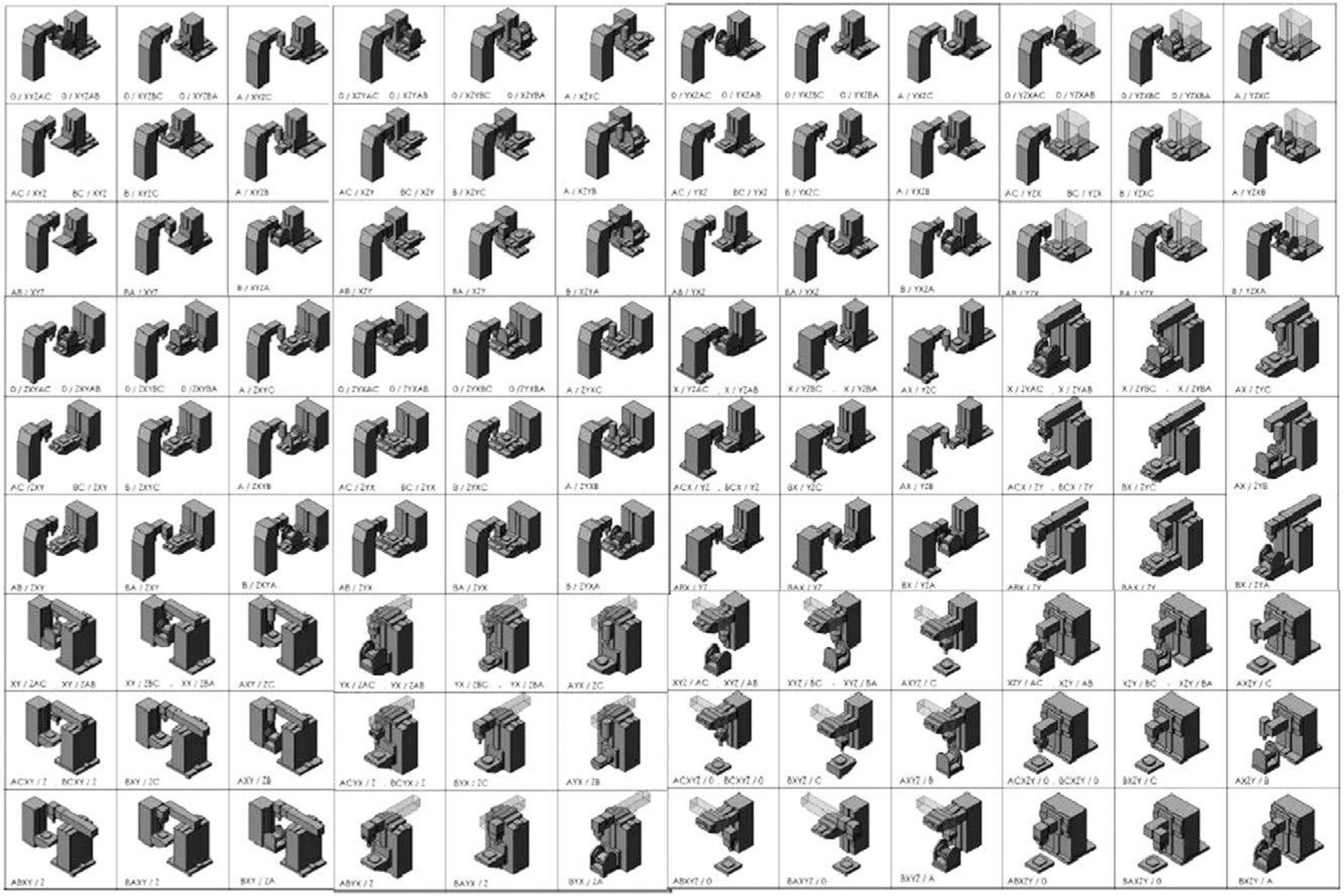
Coordinate transformation matrices.

	Relative motion	Coordinate transformation matrix
Linear motion X-Axis	1	$A^1 = \begin{pmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$
Y-Axis	2	$A^2 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$
Z-Axis	3	$A^3 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{pmatrix}$
Rotary motion A-Axis	4	$A^4 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\varphi & -\sin\varphi & 0 \\ 0 & \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$
B-Axis	5	$A^5 = \begin{pmatrix} \cos\psi & 0 & \sin\psi & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\psi & 0 & \cos\varphi & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$
C-Axis	6	$A^6 = \begin{pmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

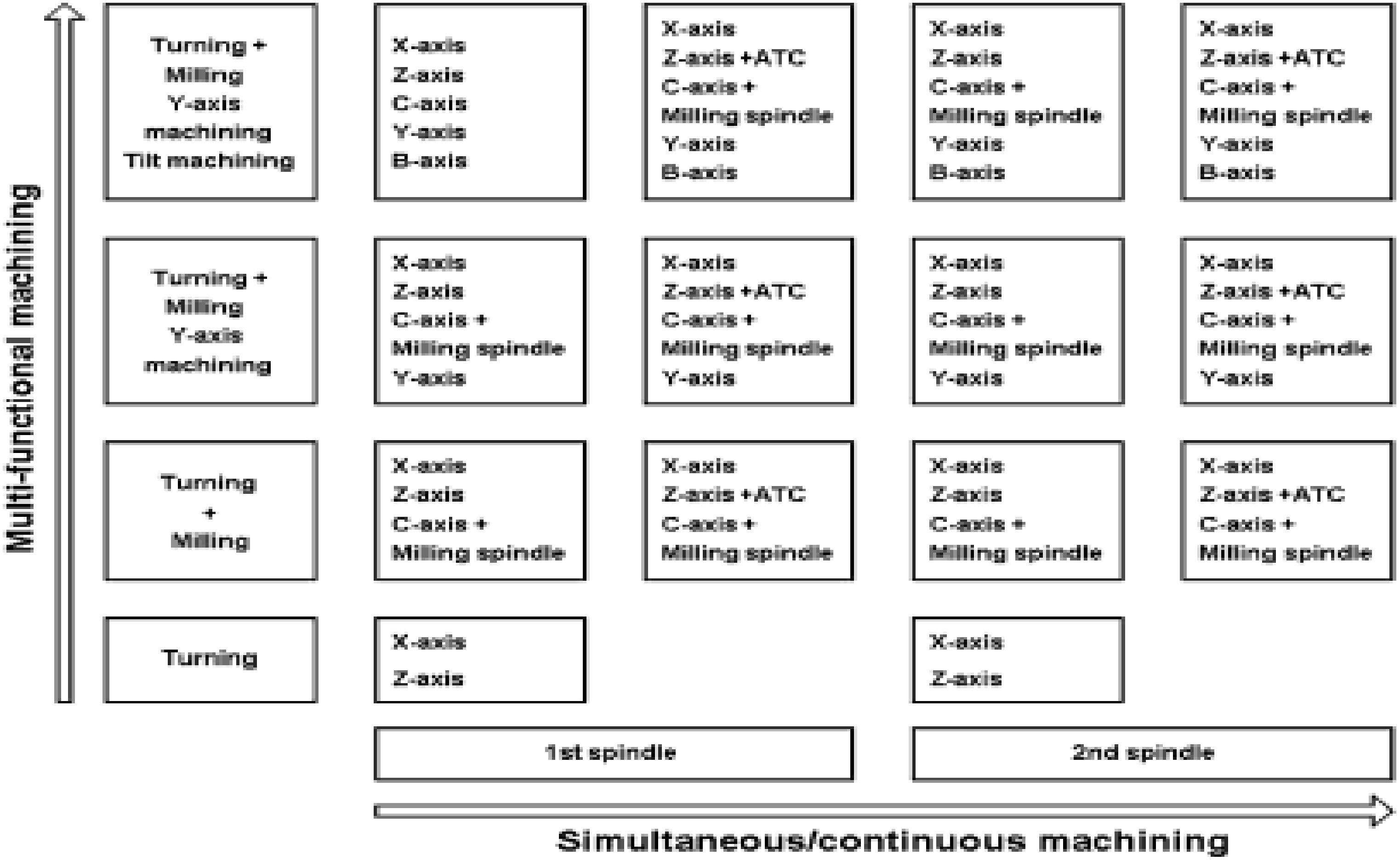
THREE POSSIBLE CONFIGURATIONS OF MACHINE STRUCTURE.



Possible configurations of vertical MC.



POSSIBLE COMBINATION OF MULTI-FUNCTIONAL MACHINE



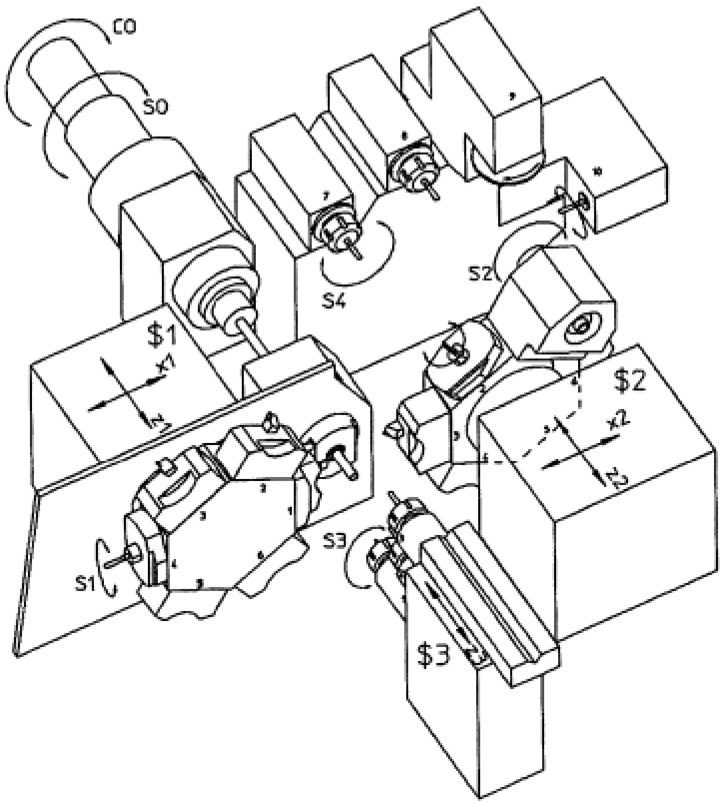
But the actual structure of the machine is determined by accuracy,rigidity,thermal deformation property and ease of manufacturing.

4. Examples and practical applications

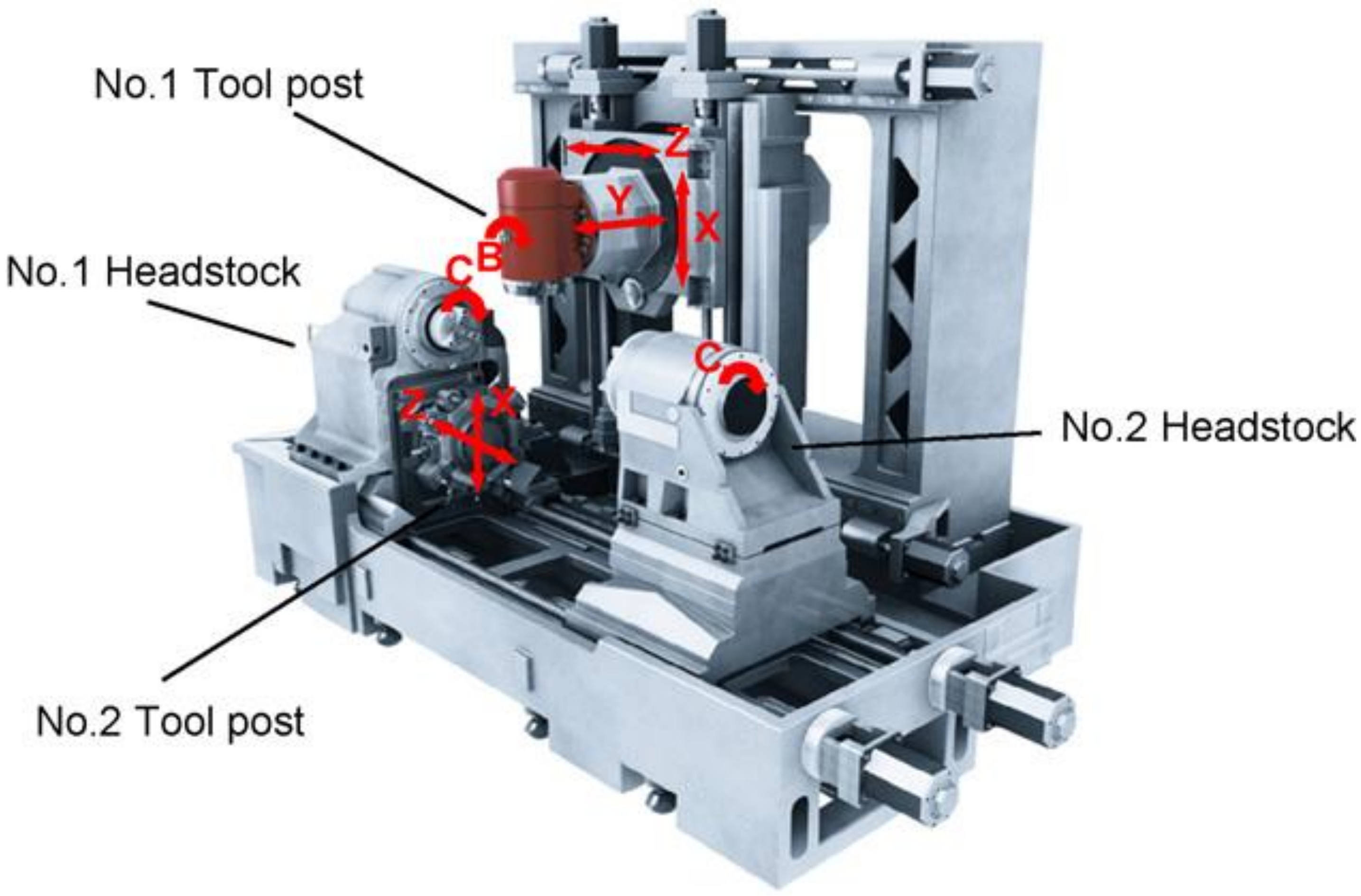
4.1. Multi-functional turning machines

- **The aero space, automotive and other mechanical industries as well as machining of dies and molds.**
- **The turning machine based multi-functional machine tools are mainly used to machine parts, with complicated geometry, efficiently.**

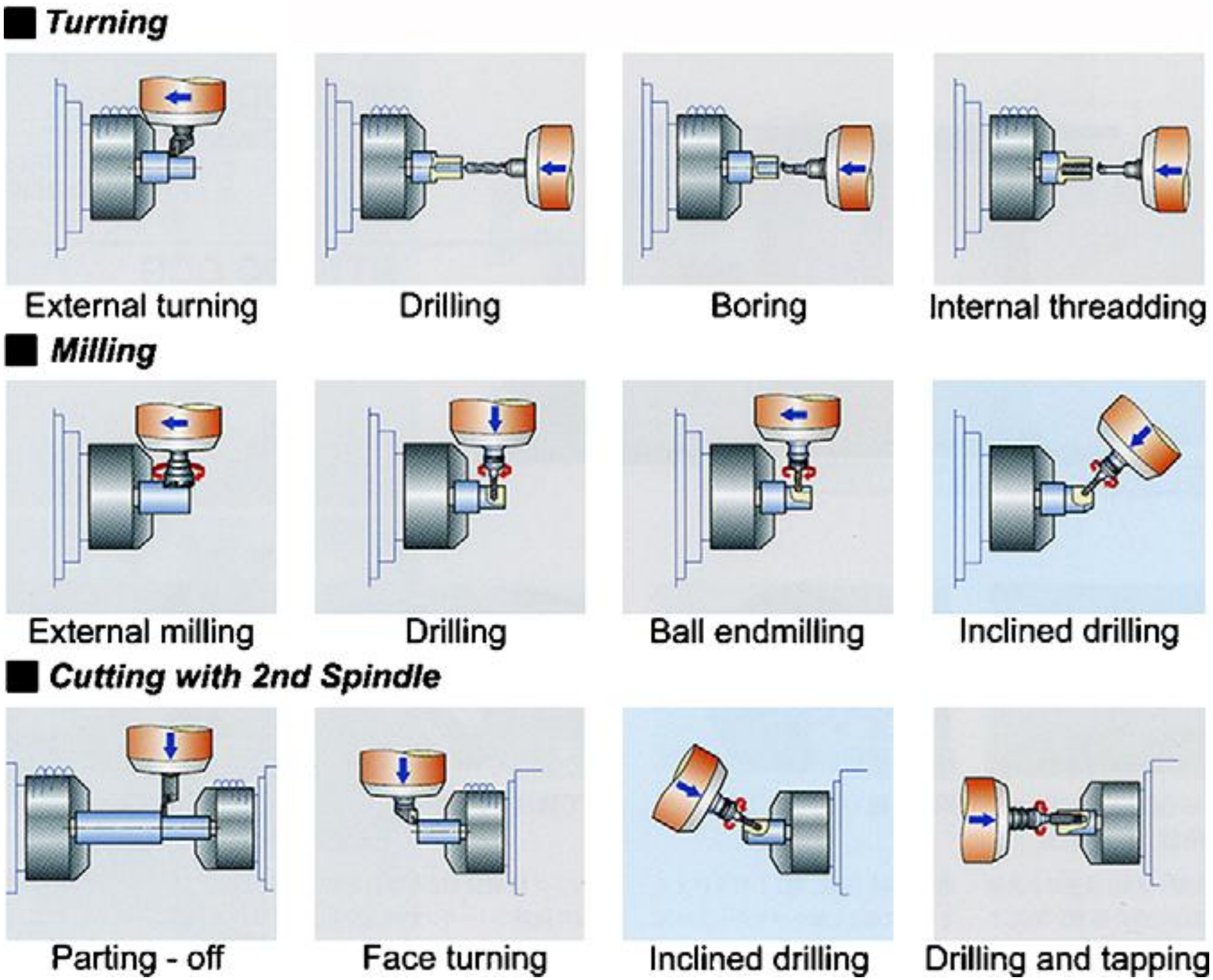
AN EXAMPLE OF HIGH PRODUCTIVITY, HIGH FLEXIBILITY CNC TURNING CENTER.



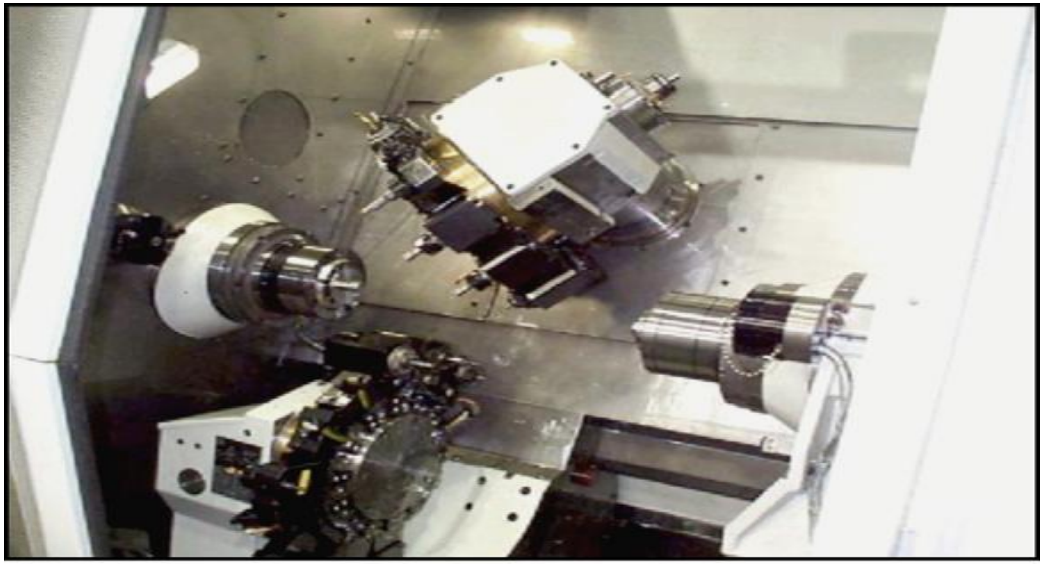
An example of combined multi-axis machine tool



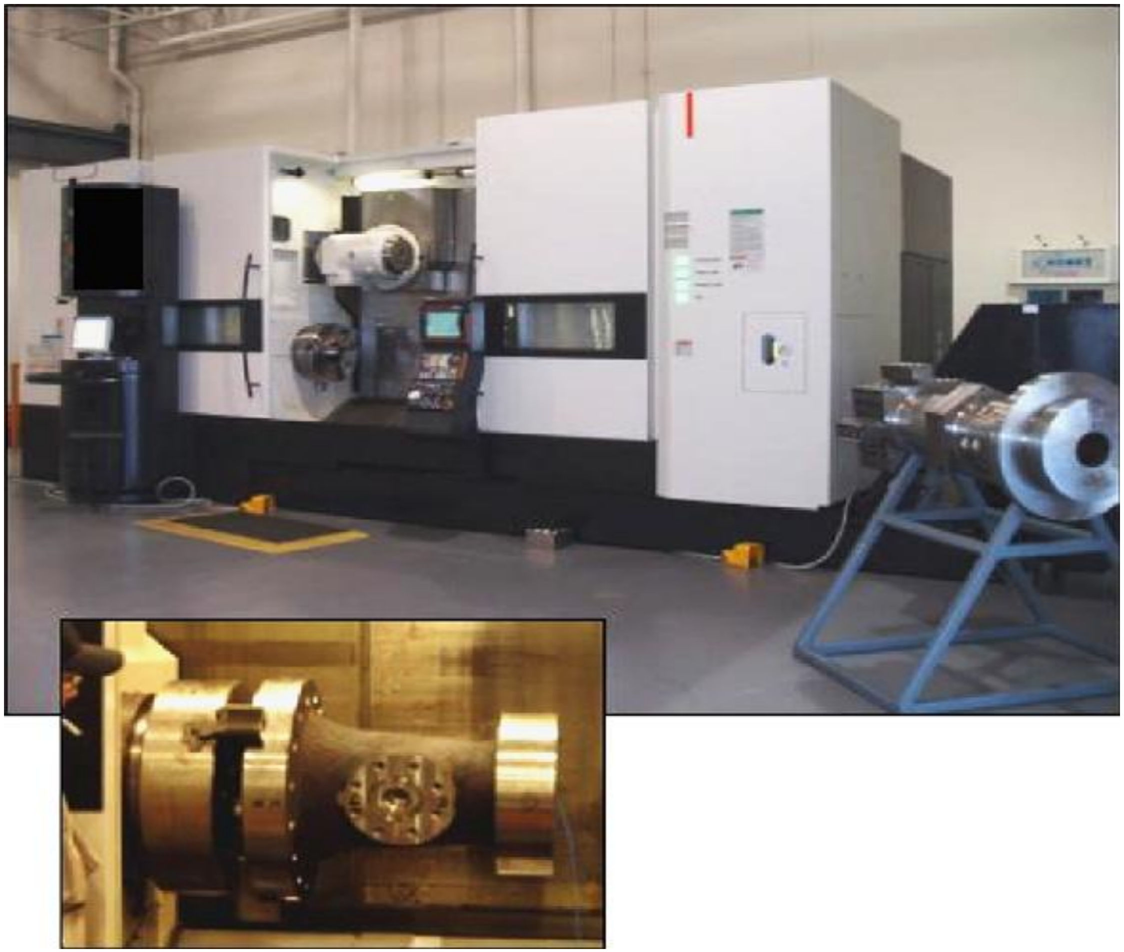
Feasible machining operations of combined multi-axis machine tool.



Special 9-axis control mill/turn lathe and gas turbine fuel nozzle machined.



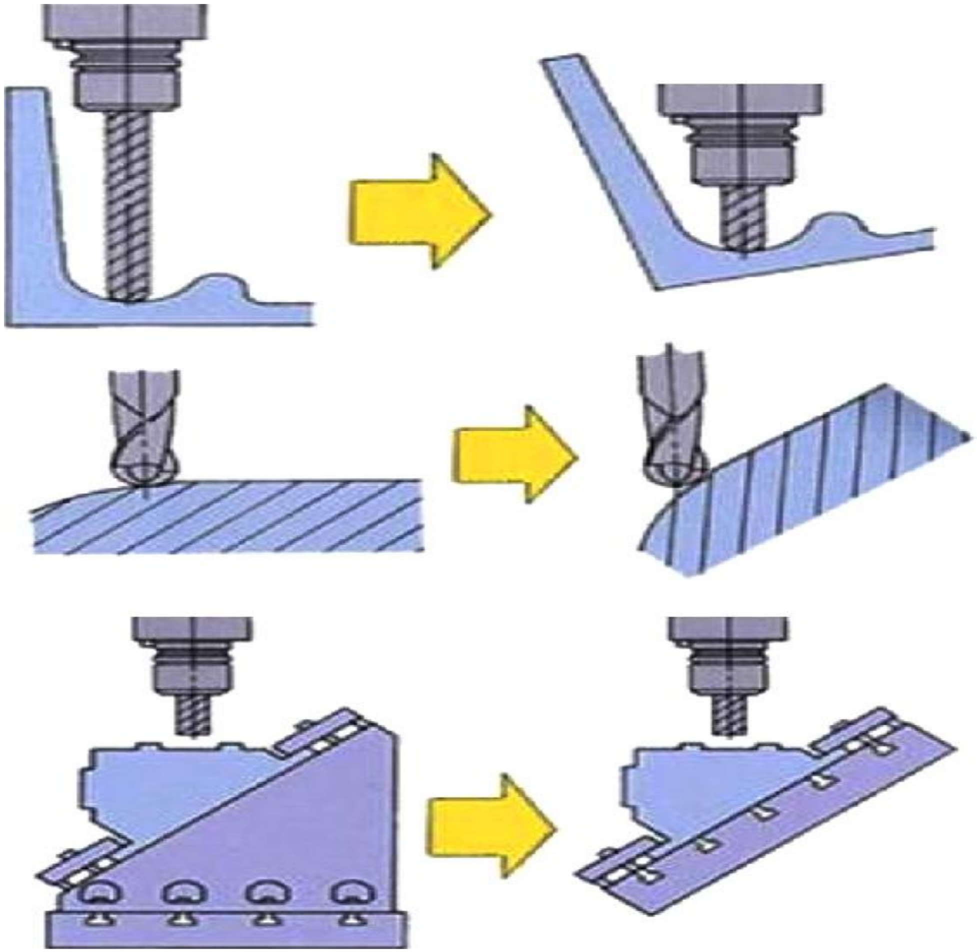
HEAVY DUTY MULTI-PURPOSE 5-AXIS MILL/TURN MACHINE



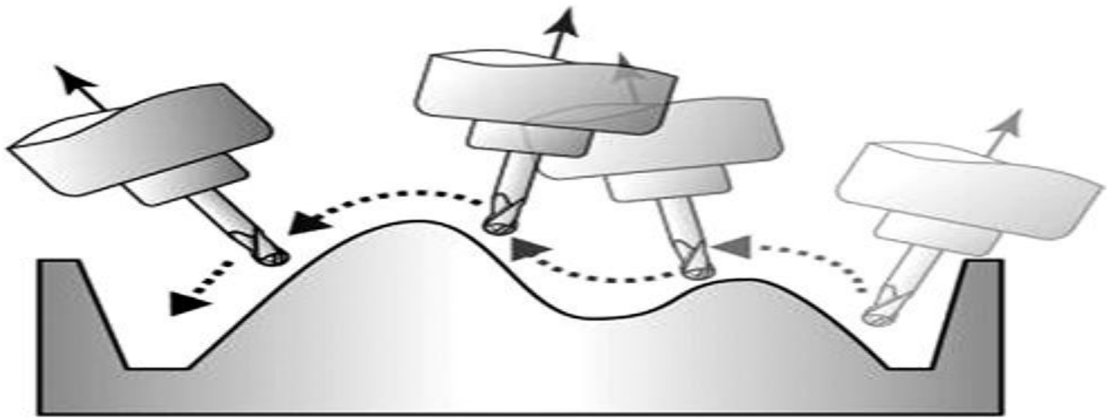
4.2. Multi-functional milling machines

- **The 5-axis MC is widely used to machine dies and molds.**
- **5-axis control is not necessarily used in many cases, but a simultaneous 3-axes control cut with additional off-line 2-axis control for the work posture change is applied.**
- **The prime advantage of this method is simplicity of the Programming.**

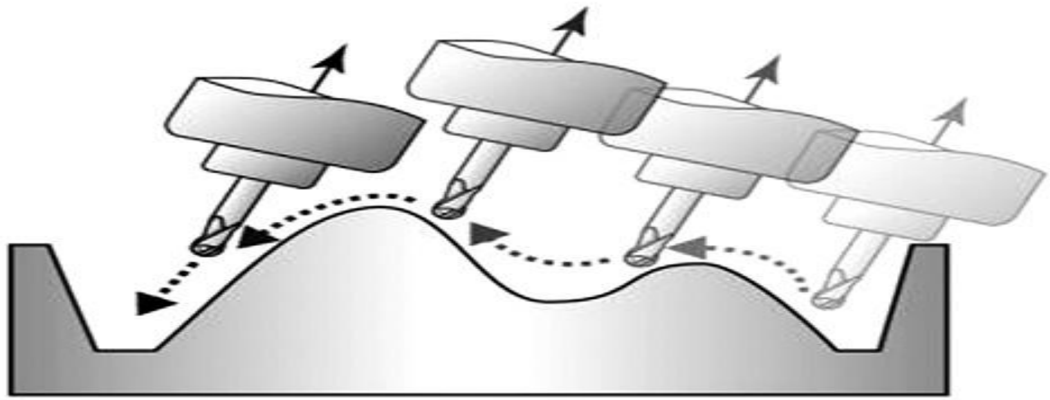
ADVANTAGES OF 3 + 2 AXIS CONTROL MACHINING.



COMPARISON BETWEEN 5-AXIS CONTROL AND 3 + 2 AXIS CONTROL.

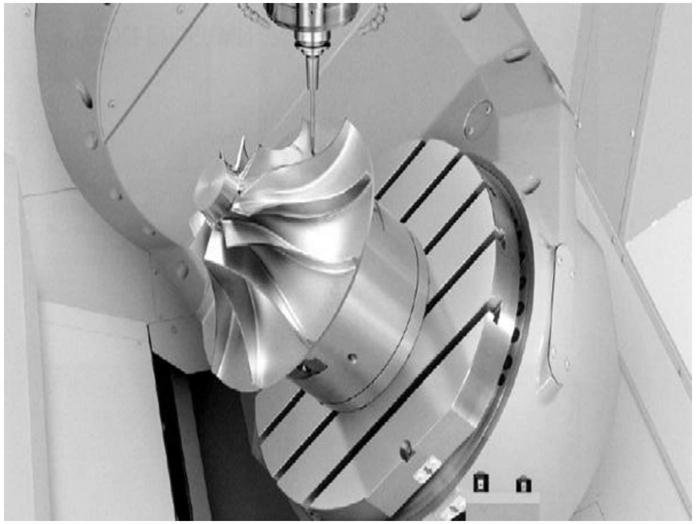


(a) 5-axis control

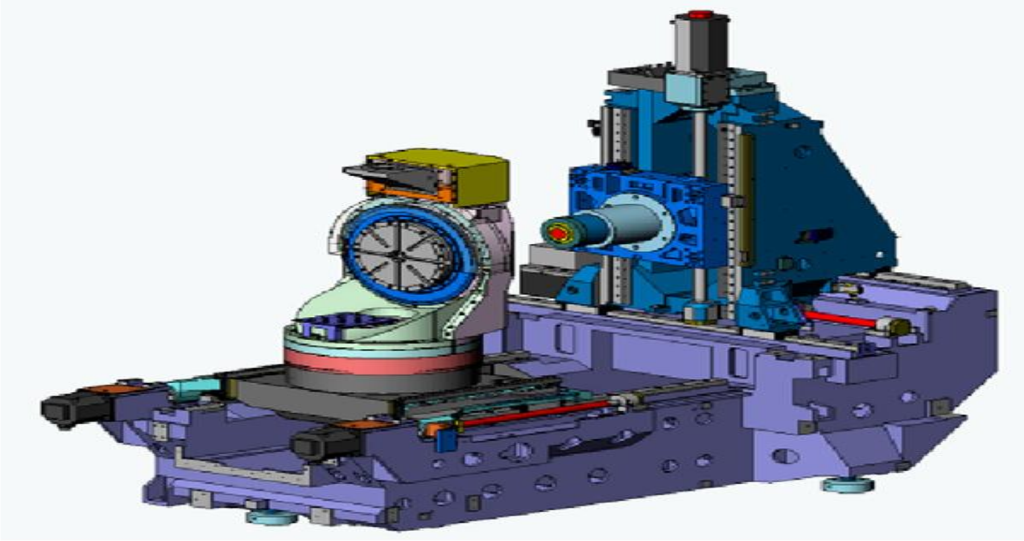


(b) 3+2 axis control

EXAMPLE OF 5-AXIS MC MACHINED PART



Machining of impeller



A machined compressor or turbine part

for jet engines made of titanium alloy.

5.Key components and supporting technologies

- **Feed drive**
- **Rotary drive**
- **High speed spindle**
- **CAM software**
- **Control technology**
- **Cutting technology**
- **NC program verification and collision avoidance**

Feed drive :-

Mechanism of motion generation.

Motor	Transformation mechanism	Motion
Servo motor	Rotary to linear transformation mechanism (ball screw, etc.)	Linear motion
Linear motor	–	Linear motion
Servo motor	Speed reduction mechanism (worm gear, etc.)	Rotary motion
Direct drive motor	—	Rotary motion

Rotary drive :-

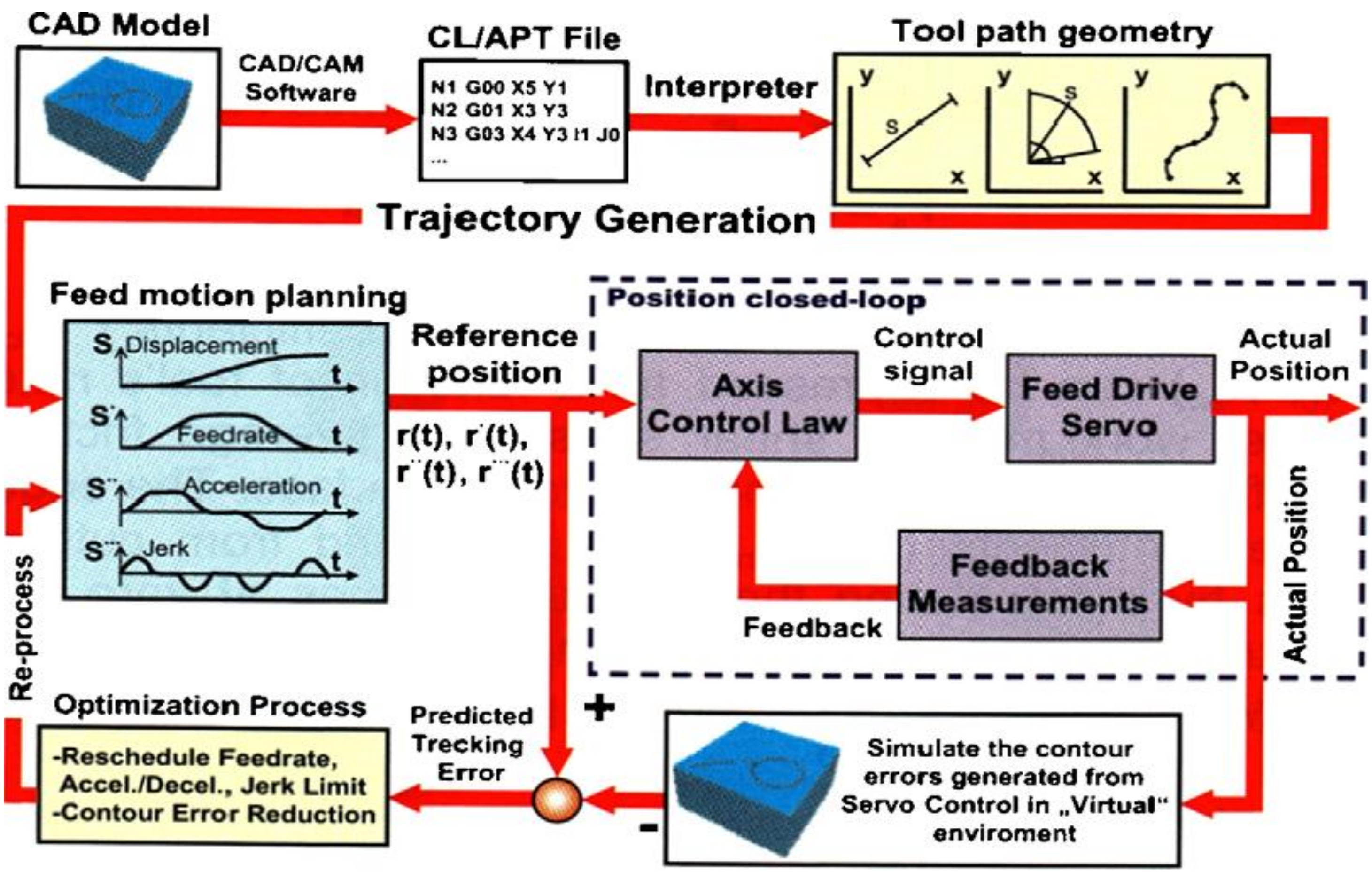
Functions and specifications of rotary axis.

	Indexing	Contouring	Turning
Rotational speed (min^{-1})	Medium up to 100	Low up to 50	High 500 or more
Rated torque	Low	Medium	High
Torque ripple		As low as possible	As low as possible

High speed spindle :-

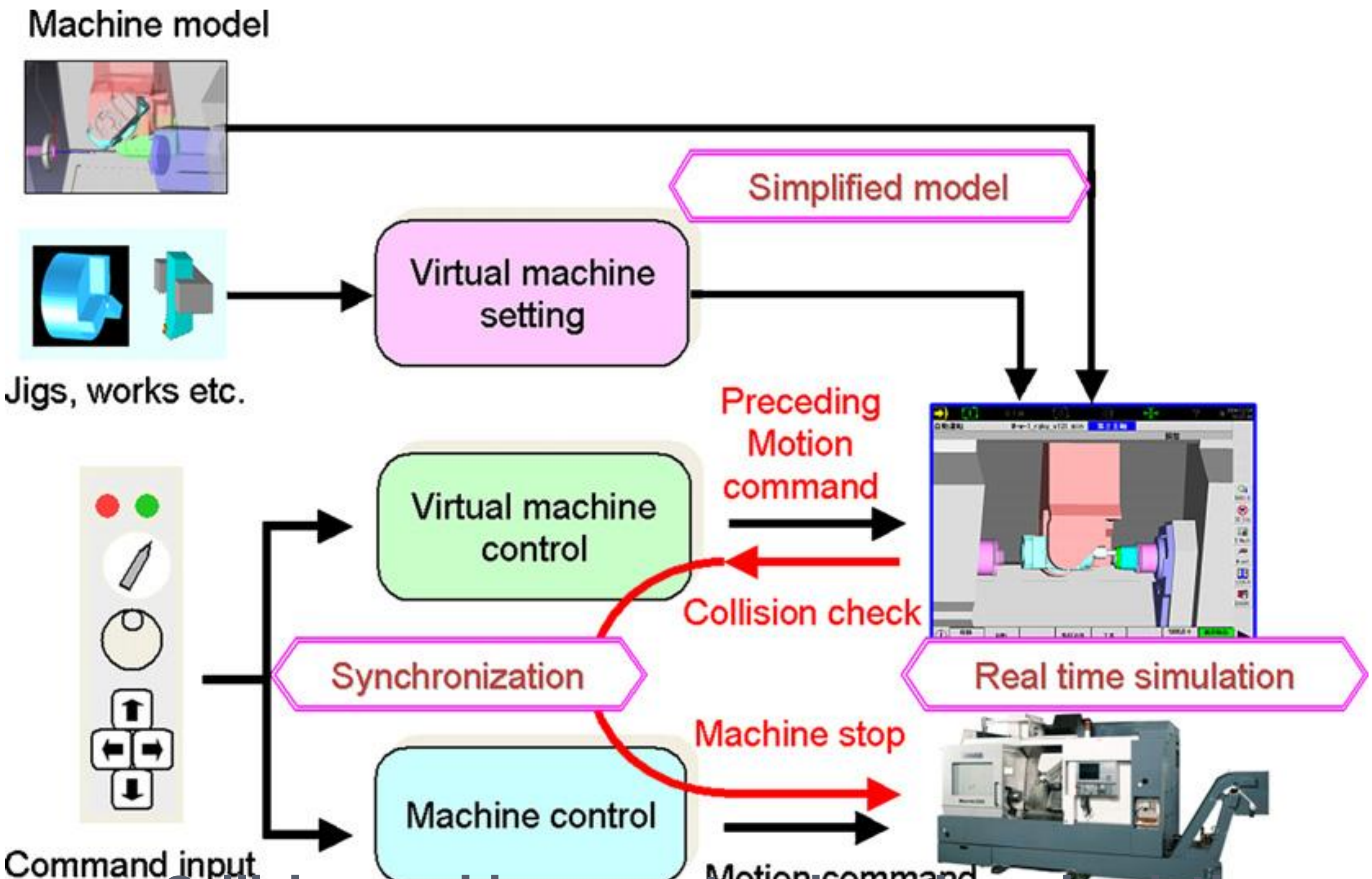
High speed machining centers are currently equipped with high speed spindles with maximum rotational speeds of 20,000–30,000 /min. Some special machine spindles have a maximum rotational speed up to 100,000 /min.

Control technology



Virtual model of trajectory generation and axes control.

NC PROGRAM VERIFICATION AND COLLISION AVOIDANCE

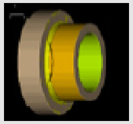
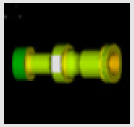
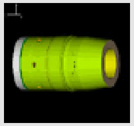


Collision avoidance system based on simulation

6.ASSESSMENT OF MULTI-FUNCTIONAL MACHINE TOOLS

- **<u>Evaluation of geometrical and motion accuracy</u>:-**
  - In the past, the motion errors of individual axis, such as those of linear motion or rotary motion were measured independently to evaluate the accuracy of a machine tool.
  - Now a well-known double-ball bar technique, proposed by Bryan, has been widely applied to evaluate the motion accuracy of machine tools. This technique calibrate parameter errors like backlash, positioning error, squareness,parallelism, etc.
- **<u>Economical justification</u>:-**

Required machining time and productivity increase of new machine.

Machine type	2-Axis lathe	Multi-axis turning machine	4-Axis lathe
Machine price	6.5 Million yen	18 Million yen	19.25 Million yen
Sample work			
Machining time of existing machine (T_{Wl})	188 s	727 s	970 s
Required machining time of new machine (T_{Wm})	123 s	559 s	843 s
Required productivity increase (T_{Wl}/T_{Wm})	1.5 times	1.3 times	1.15 times

7.Conclusions

- Effort must be devoted to develop a scientific methodology to design new multi-functional machine tools as their demand is still increasing in order to machine complicated and difficult parts at higher speed with higher accuracy.

- The control technology is the key issue to run the multifunctional machine tools effectively and accurately.

- The virtual machine tool technology is expected to play an important role to support advancement of the collision free tool path and simultaneous control of multiple drives.

- CAM software and the supporting technologies, such as NC programming and collision avoidance, are important from the practical point of view, and further efforts are needed to develop these technologies.
- The technology to measure and evaluate the motion error of the multi-functional machine tools. As the number of axes of simultaneous control increases, it becomes extremely difficult to measure the motion error of the machine, especially when the linear and rotary motions are combined. Further research in this field is also needed.

8.References

- Altan T, Lilly B, Yen YC (2001) Manufacturing of Dies and Molds. Annals of theCIRP 50(2):405–423.
- Altintas Y, Brecher C, Weck M, Witt S (2005) Virtual Machine Tool. Annals of the CIRP 54(2):651–704.
- Boer CR, Petitti M, Lombardi F, Simon J-P (1990) A CAPP/CAM Expert Systemfor a High Productivity, High Flexibility CNC Turning Center. Annals of the CIRP 39(1):481–483.
- Inasaki I (1994) Theory of Generation Motions for Machine Tools. Transactions of JSME Series C 60(574):1891–1895.
- Inasaki I, Kishinami K, Sakamoto S, Takeuchi Y, Tanaka F (1997) Shape Generation Theory of Machine Tools. Yokendo Press.
- Nakaminami M, Tokuma T, Moriwaki M, Nakamoto K (2007) Optimal Structure Design Methodology for Compound Multiaxis Machine Tools. I. Analysis of Requirements and Specifications. International Journal of Automation Technology1(2):78–86.
- Saito A, Miyakawa M, Tsutsumi M (2001) Evaluation Method of Positional and Geometric Deviations Using Simultaneous 4-axis Controlled Technique in 5-axis Machining Center. Journal of JSPE 67(2):306–310.
- Sato M (2006) Design and Performance of 5-axis Machines in Japan. Proceedingsof the 12th International Conference on Machine Tool Engineer's, 167–189.
- Woodbury RS (1972) Studies in the History of Machine Tools. MIT Press.