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Predictive Research into Desirable Features of Machine Tools in the Year 2015 and Beyond - Private Viewpoints and Assertion -

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ABSTRACT

This paper describes firstly a prediction for desirable features of the machine tool in the year 2015 and beyond, and then delineates something definite in relation to some representative machine tools, which could be realised in very near future. The paper depicts furthermore another aspect of future machine tools, i.e., innovative structural designs. In addition, author asserts the importance of grass root-like knowledge, when predicting the desirable feature of machine tools in future together with showing some evidences.

Key Words: Predictive research, Machine tools, Marked products, Innovative structural design, Grass root-like technologies

1. INTRODUCTION

It is not a " Myth " that the production technology can produce the wealth for the society, and duly we have believed that the kernel of the production is deeply relied on the machine tool. Although having so far been and being palyed the primary roles in the production sphere, which appears to develop almost daily in order that the nation can be positioned in the leading-edge, the machine tool technology has been believed as to be in fully mature states by people and by also even a certain number of machine tool engineers.

This belief can be supported by various evidences in part; however, the machine tool technology should be enhanced, when intending to establish more healthy, comfortable and enjoyable society hereafter. In fact, there have been a considerable number of predictive researches into the production environments in the year 2015 and beyond [1]. By contrast to the production environment, i.e., production system, related organisation and concerns, there have been no predictive researches into machine tools in future. Actually, an only exception is the research conducted by CECIMO from 1996 to 1999 by localising it within Europe region. Unfortunately, the research is in confidentiality*.

In consideration of the importance of machine tools as represented with " Mother Machine ", thus, this paper firstly shows a first-hand view of desirable features of the machine tool in the year 2015 and beyond,which has been produced on the basis of literature survey and on-the-spot investigation including author's own viewpoint and assertion. Then, the paper delineates some future perspectives of representative machine tools together with innovative designs for the body structure possible from the material and configuration.

In addition, the paper touches on the general problems inhabiting the predictive research and to seek a clue to solve such problems, author asserts the dire necessities of observing the developing speed of the grass root-like technology, and shows some typical examples.

2. FIRST-HAND VIEW OF DESIRABLE FEATURES

In the predictive research, the primary concerns are to understand correctly the art-of-present, and also to rationally determine the allowable prerequisite including underlying hypotheses. Table 1 shows, thus, some key

* Based on a private letter of Mr. Vannieu dated 18th October, 2000

terms regarding the present environment surrounding the machine tool, and Figs. 1 and 2 are some first-hand views of the changing trends of the production system together with suggesting the machine tools necessry and inevitable to realise such production systems.

In full consideration of these primary concerns as well as past and present perspectives of machine tools, author can suggest the future perspective of machine tools as shown in Table 2, simultaneously implying when the corresponding machine will become available. In addition, the expectable machine is allocated in closer relation to both the due industries and production systems.

As can be seen, the machine tool could be diversified to a larger extent, and to crystalise some ideas, the quick note will be given below.

(1) The system machine especially compatible with the island automation like the FML (Flexible Machining Line) proposed by Fritz Werner Co. may often be operated together with the traditional machine tool (machine tool of manual operation type) in order to secure the worker's motivation and to promote the technology inheritance.

(2) The information-driven type is tentatively definded as a machine tool tightly integrating with the necessary software package in accordance with the manufacturing requirements to guarantee the ease of operation. The machine would duly be an enabler of manufacturing rationalisation of small- and medium-sized enterprise (SME). For instance, the software package consists preferably of information for the form-generating movement, daily production control, tele-maintenance, cost accounting and operational mannual for unskilled worker. This machine will be available in very near future.

(3) The culture- and mindset-harmonised (region- and racial trait-harmonised) machine tool is designed to leverage the technological and social attributes, and in certain cases, to emphasise the social attributes, depending on the manufacturing requirements in wider scope. This machine will be available in near future as already delineated elsewhere [2].

(4) The ultra-precision machine tool with heavy processing will be available in a very near future to support the forthcoming information society as already proven by its important roles of producing the cooling module frame of the large-sized computer, polygon mirror for laser printer, non-axissymmetrical lens for CD player and so on.

(5) The machine for nano-precison processing will be spot-lighted in the year 2015 and beyond with the due advance of the science, although the required number of machines is not so many.

In due cpourse, Table 2 can not cover all the foresight. For instance, the TL (Transfer Line) and FML can, for the time being, facilitate the production of the motorcar industry, where the FML is of island automation type. In this case, the quinaxial NC machine tool could be applicable to the FML as a core machine.

As clarified already by the predictive research into the production environment in future [1], the most serious problems not having been solved are the estimation of the developing speed of the core technologies for the due engineering subject and also the authentic prediction of the available technologies at the discussing time.

This is also the allowable rule in the machine tool technology and one of the remedies appears to observe what is underway in the garss root-like technology. In Chapter 5, thus, such information will be quickly touched on.

3. REPRESENTATIVE MACHINE TOOLS WITH CHRONOLOGIC EVOLUTION

Notwithstanding the type and kind, the two remarkable trends, i.e., compactness and process integration, are now underway in the machine tool sphere. Table 3 shows some design remedies for the compactness, which can be, in part, realised by the reduction of floor space and two-face maintenance free configuration. Actually, the compactness can facilitate the improvement of cost performance, i.e., value-adding amount per floor space. Fig. 3 shows furthermore the eccentric-boring method. As can be seen, this method can be carried out by synchronising the self-rotational to eccentric rotational movements of main spindle, and as a result, it is possible to realise various turning methods using less number of cutting tools.

3.1 For the Tine Being - MC of Line Type, Diesinking Machine and Multiple-function Integrated Machine

3.1.1 MC of Line Type and Diesinking Machine

The thriving market sectors for MC are those related to the motorcar and die moulding industries and importantly at burning issue of MC including the diesinking machine is the simultaneous realisation of both the higher-speed and higher-accuracy in machining. In fact, in both the MC of line type and the diesinking machine, the idle time has been minimised as far as possible, and thus a facing problem is to reduce more machining time.

The MC of line type has, in genral, been enhanced its performance specifications by increasing spindle speed and table travelling speed. For instance, both are 20,000 r.p.m. and 50 m/min. in maximum, respectively. In die mould manufacturing, furthermore, a machine based on the novel design can show marked effect on the reduction of the machining time as shown, for example, in Fig. 4. In addition, the diesinking machine is allowed to machine

the new materials, e.g., graphite and porous ceramics, and duly the machine is requested to be capable of higher-speed machining.

In relation to these trends, an interesting proposal is a " Box-in-Box " body structure shown in Fig. 5 , which has been believed as to be firstly invented by Huller Hille Co for its typical product series, i.e., MC of " Specht 500T type ", to fulfil the requirements to the MC of line type and diesinking machine, i.e., those of higher rigidity with light-weight. In addition, the headstock can be driven by the linear motor or ball screw.

3.1.2 Multiple-function Integrated Machine - System Machine Converted to Conventional Machining Purposes

With growing importance of more rationalisation in manufacturing, the system machine, i.e., machine tool compatible with flexible manufacturing, was invented around the end of 1970's. In retrospect, the system machine has been developed in two-pronged direction: one is of multiple-machining method integrated type and another is of system-function integrated type.

With the modernisation of FMC to rationalise flexible manufacturing and also increasing number of the installation of FMC in the small- and medium-sized enterprise, the system machine has been well-configured within the three-dimensional space, rsulting in an innovative variant, i.e., compact MC or TC with higher functionality and performance [3].

In the system machine, another relevant issue is to enable the machine to be adaptable to machining with one-workpiece set. Fig. 6 shows a developing history of system machines, and an apparent underway trend is recently to deploy to the conventional purpose use within a short time, which is commisioned to the MC and TC of present, because the system machine has, in principle, more advantageous dimensional and performance specifications than conventional machine tools. To deepen the understanding, Fig. 7 shows a classification of system machines at present and of these some variants are becoming those for conventional use.

Although there are a considerable number of variants like that with auxiliary headstock, the multiple-function integrated machine can primarily be classified into (a) one-spindle and twin-turret, (b) twin-spindle (axially opposite allocation) and one-turret and (c) twin-spindle (axially opposite allocation) and twin-turret types, commonly having the holistic machining functions for turning and milling to a various extent together with remaining the functionality compatible with flexible manufacturing [4]. Fig. 8 shows a multiple-function integrated machine and from it we can perceive how the form-generating function is ramified. For instance, the machine can perform 6-face cutting and work hand-off operation while spindle rotating.

3.2 In Very Near Future - Ultra-precision Machine Tools for Mass-production (with Heavy Machining Capability)

We are now in the information-driven society and this social trend may be duly accelerated in the 21st century. Such a trend can be represented by a key term, i.e., " Commodities-like Information Devices ". In other words, people in the human society are requested to have certain knowledge about how to use " Commodities-like Information Devices ", e.g., personal computer, laser printer, copying machine and CD player, to spend the comfortable daily life. In contrast, such information devices should be produced cheaper than ever before in order that all people can obtain them without any difficulties. This results in the urgent development of the ultra-precision machine tool facilitating the mass-production.

Based on the common sense so far, the ultra-precision machine tool can facilitate a kind of production or one-off production with light processing force and duly the ultra-precision component is expensive. With the advent of the new manufacturing requirement, a new innovative machine should be geminately developed; however, there have been a very few trials, for instance, that for producing the scanning lens for laser printer shown in Fig. 9. The machine with 4-axis NC control can produce the lens having non-axissymmetric aspheric surface modified from the basic toroidal surface, resulting in the amazing reduction of production cost. In fact, the production cost has, in case of polygon mirror for the laser printer, been reduced from 100,000 ~ 200,000 Yen per piece to 300~500 Yen per piece by employing ultr-precision turning instead of lapping and polishing; however, the facing problem should be to reduce the cost up to 1/10 of that of present.

To deepen the further understanding, Table 4 shows some relationships between the ultra-precision component and the available machine, and as can be easily imagined, we must develop a mass-production technology for these components, and for further convenience, cutting tools possible to apply to such machining requirements are shown in Table 5 together with the present machining objectives. In short, the mass-production of the ultra-precision component appears to be realised with the advent of the new tool material. In addition, we must be aware of it that the prosthetic devices, e.g., artificial hip joint and die for artificial teeth, are furthermore included within the group of ultra-precision components.

4. INNOVATIVE DESIGN FOR BODY STRUCTURE

Although not having been applied yet to the machine tool, an innovative bearing called " CARB " of SKF-make is at a crucial point in the bearing engineering. This bearing can be realised by fusing the benefitial features of the cylindrical, spherical and needle roller bearings. For instance, the roller is of toroidal curve type without the retainer, resulting in higher load carrying capacity and long durability [5]. On this extension, there are now some trials to provide certain functions with race of bearing by contriving the shape and size of the race, e.g., lower friction force together with higher damping.

These evidences imply the future possiblity of designing the machine tool structure with self-functionality. More specifically, some innovative technologies will be available for the structural design in future, e.g., those using the new material and multiple-function integrated component to realise light-weighted compact structure.

4.1 Application of New Materials

In retrospect, the nickel-grey cast iron of monolithic type was used as a raw material for the bed of engine lathe in1940's, where the guideway was made of nickel cast iron and in contrast the bed body itself was made of grey cast iron. Actually, the designer aimed at the improvement of the wear resistance characteristics.

Thereafter, the machine tool manufacturer has been, in certain cases, very keen to employ this technique, and the most successful application has been credited to the Hitachi Seiki in the late 1990's. The Hitachi Seiki has called it as " Hardened Steel-fusion Structure " and as can be seen from Fig. 10, the desirable raw material for the base can be produced by the cast-in-place method. In addition, when referring to the amazing evolution of new materials, e.g., ceramics and FRP shown in Table 6, the designer can expect to use a material having the directional orientation in its stiffnes and damping capacity in very near future. Intuitively, a machine tool consisting of " Body Structure with Functionality " using " Functional Materials " will be realised. For instance, a connecting mechanism of the table with the driving system will be compactly designed using the material having strong directional orientation in travelling axis only.

4.2 Innovative Structural Configuration

In this context, the manufacturer has been very keen to produce the machine of parallel link mechanism type, although remaining a serious problem in relation to the position determination of joints even when reducing the freedom of movement. Apart from such well-broadcasting topical machine, the most outstanding concept is the NC vertical turning machine of " Hanging Spindle Type " and it would be credited to the Index Co. in 1996. Following that of Index Co., the Niles-Simmons and Hitachi Seiki have produced similar machines [6]. The machine can be characterised by the (1) pick-up-spindle, (2)wide accessibility of turret head and (3) column built-in tool magazine, resulting in the compact integration of the function together with better swarf disposability. Fig. 11 shows a schematic view of an NC lathe of Hitachi Seiki-make, and, for instance, the work loading and unloading cycle time is 15 sec.

4.3 Advanced Modular Design

The machine tool will be evolved, developed and deployed to a various extent as shown already in Table 2, and in accordance with these developments, it could be obvious that the modular design increases its importance. In full consideration of especially growing importance of both the multiple-function integrated machine and the culture- and mindset-harmonised machine, furthermore, author assert it that the modular design should be progressively modified by incorporating the following modules.

(1) Region- cultural- and mindset-harmonised module, e.g., indigenously available module. This module is for the machine tool designed to be compatible with the supply chain of world class. For example, a product consisting, in part, of region-available modules with cheap price and low quality should be realised to quickly respond to the regional manufacturing requirement, provided that the product quality itself is maintained in the mediocre standard or, in the most preferable case, in the highest standard.

(2) Modules compatible with LCA (Life Cycle Assessment). These modules facilitate the design of the machine tool, which can be well-harmonised to the natural environment, and there are primarily two representative modules: one is for recirculation and another is for up-to-date of function and performance of the product within its whole life. In the latter case, the manufacturer could provide the module and in turn the user would exchange the due module to maintain the product quality in constant.

5. IMPORTANCE OF GRASS ROOT-LIKE SUPPORTING TECHNOLOGIES

To have gotten the reliable prediction, another necessity is to grasp correctly the facing grass root-like problems of each engineering attribute together with its historical background. Intuitively, it is very difficult to depict a whole feature of machine tools by gathering and combining future possibilities of each engineering attribute; however, the first-ever survey for grass root-like technologies could reinforce the reliability of and be somewhat helpful to correctly interprete the prediction,

which has been stated beforehand. In addition, the grass root-like engineering konwledge are surely imformative to scrutinise the predictive research together with indicating the essential features of the machine tool.

Table 7 shows the facing grass root-like research and development subjects when diesinking machine, turning machine and MC with higher rotational speed are on work. It is, for example, noteworthy that the machining space will be in misty and foggy condition with the increase of the main spindle speed, and thus author can assert the following. In an MC with software package, for example, its NC should have a function for virtual visualisation of the machining space on the basis of the information obtained from an advanced in-process sensor. In contrast, some core subjects in the NC technology sphere have been suggested as shown in Table 8. As will be clear from the suggestion, at burning issue is to provide a function for " Ease of Operation ". In short, we can, as shown in this example, expect to have more reliable prediction with holistic effect by adding the information obtained from the grass root-like knowledge.

Table 9 shows thus some core engineering problems in relation to the guideway. As can be seen, there are multifarious problems to be solved; however, we have, in fact, become acquainted these from the old day. Dare to say, it is very difficult to find out a newly arisen problem in accordance with the advance of the machine tool except that of how to increase the damping capacity for travelling direction in the rolling guideway.

To this end, we must touch on the upmost typical grass root-like subject, which is in closer relation to the chuck and cutting tool. As shown in Table 10, it is noticed that the cutting tool is enhanced its performance by improving the matrix material, and that the fixture is designed to cope with higher-speed cutting.

6. CONCLUDING REMARKS

This paper has described a foresight of machine tools in the year 2015 and beyond when taking into consideration of technological, economic and social environments possible on that occasion. The paper has also included author's assertion. It can thus be considered that the paper can give something definite to related people; however, we must furthermore examine the influence of growing aged society on the machine tool technology and primary concerns meticulously.

In fact, it has been reported elsewhere that the population of the aged people between 65 and 84 years old at already industrialised nations will become triple at 2050 as compared with that of present. This implies that the nation will face to the acute shortage of young operator of the machine tool, simultaneously requesting the aged people to become a new source of work forces. Within an engineering context, thus, the machine tool should, for instance, be designed to ensure the ease of use for aged people. It can in turn be emphasised that the dire necessity is to depict what is a desirable machine tool within the aged society in a further predictive research.

Finnaly, author would like to assert that the machine tool can be claimed to be in continuing development for ever as " Mother Machines ", even when the society will be drastically changed.

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Increasing variety of people's requirements and shorter product life

Growing importance of LCA, recyclability and disposability

Necessity of paying special attention to cultural issue

Growing importance of customised product

Rapid growing of industry and enhancing of technology in Korea and Taiwan

Multiple-polarisation of R & D

Table 1 Environments surrounding machine tools

FUTURE PERSPECTIVES OF PRODUCTION SYSTEMS

DULY EXPECTABLE INDUSTRIES IN FUTURE

	Traditional	Traditional & highly automatised	Highly automatised Autonomous/ Intelligent		Human/environment harmonised	Multiple-nation co-operative (Including thought model-based type)
Home appliances	Diesinking machine	MC of higher speed cutting type		Information-driven/simple functionality (High productivity/precision processing)		Culture & mindset harmonised type
Motor car	Diesinking machine		MC of line type Super high speed heavy grinding machine with large flexibility		System machine compatible with island automation	
Aircraft/ space(Railway carriage)		System machine compatible with island automation		Information-driven/specified functionality (High productivity/precision processing)	In very near future	In near future
Computer/ peripheral equipments Information devices	Diesinking machine		Ultra-precision/mass-production (heavy processing) type			Culture & mindset harmonised type
Precision instruments	Nano-precision(less blur & silky -spot)	In 2015 and beyond				

Table 2 Future perspectives of machine tools

Ikegai Iron Works/Vertical MC	L-shape column-base unit complex Simplification of driving system Compact peripheral equipments Process integration
Hitachi Seiki/ TC	Avoidance of belt drive to minimise maintenance frequency Tailstock base travelling system (without travelling quill) Compact turret head and control panel Bed built-in lubricant tank

Table 3 Remedies for compact structural design

ULTRA-PRECISION (DIAMOND) TURNING MACHINE/DIAMOND FACE TURNING MACHINE

MAGNETIC DISC, ROLL FOR COPYING MACHINE, Mo PARABOLIC MIRROR

ASPHERIC TURNING AND GRINDING MACHINE

Al-ALLOY OPTICAL LENS, MIRRORS FOR HIGH-POWER LASER, INJECTION MOULDING DIE FOR LENS (SINTERED ALLOY), MIRROR OF ASTRONOMICAL TELESCOPE

SLICING MACHINE/MULTIPLE-BLADE SLICING MACHINE

Si WAFER (LAPPING MACHINE), $Al_2O_3 \cdot TiC$ HEAD

(DIAMOND) GRINDING / POLISHING

OPTICAL FIBER CONNECTOR, X-RAY OPTICS (Rmax 1~3 nm : manual polishing),

Table 4 Ultra-precision components and available machine tools

PCBN (Polycrystalline Cubic Boron Nitride)

Whirling of hardened steel ball bearing screw Plastic injection mould die

PCD (Polycrystalline Diamond)

Face milling of engine blocks made of dissimilar materials (Al engine block with cast iron cylinder liners

CBN-CERAMIC COMPOSITE

Finish turning of heat treated hardened gear (H_{RC} 62)

Table 5 Composite cutting tools available for mass-production

Materials		**Purpose of utilisation**	**Application areas**
Ceramics	Al_2O_3 series ZrO_2 SiC Si_3N_4	Wear resistance, Heat resistance, Material stability	Guide way, Main spindle, Bearing
FRP	GF type CF Alamid fiber	High strength Light-weight	Rotating components with ultra-high speed, e.g., main spindle, chuck and tool holder

Note : Disadvantages of the ceramics and FRP are its brittleness and high cost respectively

Table 6 Alternative new materials

Diesinking machine	Width variation of cutter marks between upward and downward cutter travelling - How to improve roundness of tip Breakage of motor rotor - Maximum spindle speed: 50,000 r.p.m.
Turning machine	Pitching of table caused by eccentric rotation of ball screw, although using hydrostatic coupling between tabel and ball nut - When eccentric rotation caused by bending of ball screw is 0.5 μ m, pitching error arisen is 1/100 μ m
MC	Noise problem caused by intermittent pass of oil-air in bearing - in main spindle of 40,000 r.p.m. in maximum speed, rolling element prevents continuous oil-air flow at certain interval Advanced in-process recognition of cutting state under misty and foggy environment - 70,000 r.p.m. in main spindle speed(magnetic bearing); 70m/min. in feed speed(linear motor) Use of Boron cutting tools to machine workpiece (SCM420) hardened up to H_{RC} 60

Table 7 (a)

MC and Turning Centre	Design methodology of panel cover Loosening shrinkage fit of rotor in built-in-motor Slideway materials applicable to up to 24m/min. in sliding speed - Based on long-standing experience, slideway is available up to 20m/min. in sliding speed Software package (Operational planning+ Daily production control+Daily accountancy+ Tele-maintenance)

Table 7(b) Grass root-like R & D subjects in diesinking machine, turning machine and MC with higher spindle speed

Machine tool industry	MC Turning machine	Unification of NC language, codes and operation method Common use of application software
	Turning machine	High-speed servo mechanism Machining technology for difficult-to-machine and high hardness materials
	Grinding machine	Standardisation of PC type NC
Machine tool-related industry	Function for ease of operation Monitoring system for healthy condition Standardisation of NC language Interchangeable data structure	

Table 8 Core subjects to be solved in NC technology

Guiding method/ Guideway structure	Guiding method and structural configuration for high accuracy and rigidity-[Ex] Damping capacity for travelling direction in rolling guideway Optimised structure for hybrid guideway Thermal deformation of slideway Enhancement of slideway characteristics - Oil groove and lubrication/New machining method/Uniform interface pressure distribution
Guideway accuracy	Change of table posture-[Ex]Floating by lubricant/ Table posture change at movement transition Higher accuracy-[Ex]Gib configuration and adjustment/Control of pitching and yawing in vertical guideway
Materials	Galling preventation Evaluation method of Turcite bonded guideway Application of ceramic guideway
Others	Total comparative evaluation among sliding, hydrostatic and rolling guideways/Estimation method for life and aging/Development of innovative wiper

Table 9 Technological subjects for guideway of NC machine tools

Bite shank with reinforcing stem made of sintered carbide
Hybrid end mill - cutting edge at flute:CBN/cutting edge around chisel:sintered carbide
Sintered carbide drill with varying grain size - outer layer:larger grain size with higher hardness central area:smaller grain size with larger toughness
Curved long slot milling with torocoidal form generating movement
Face milling cutter for higher-speed - remedies for fracture of cutter body and slip-away of throw-away blade
Chuck with swivelling jaw

Table 10 Grass root-like improvements in cutting tools and fixtures

Note: In machining of Al alloy work with the diamond tools, the cutting speed and feed speed are 5,000m/min. and 15,000mm/min., respectively.

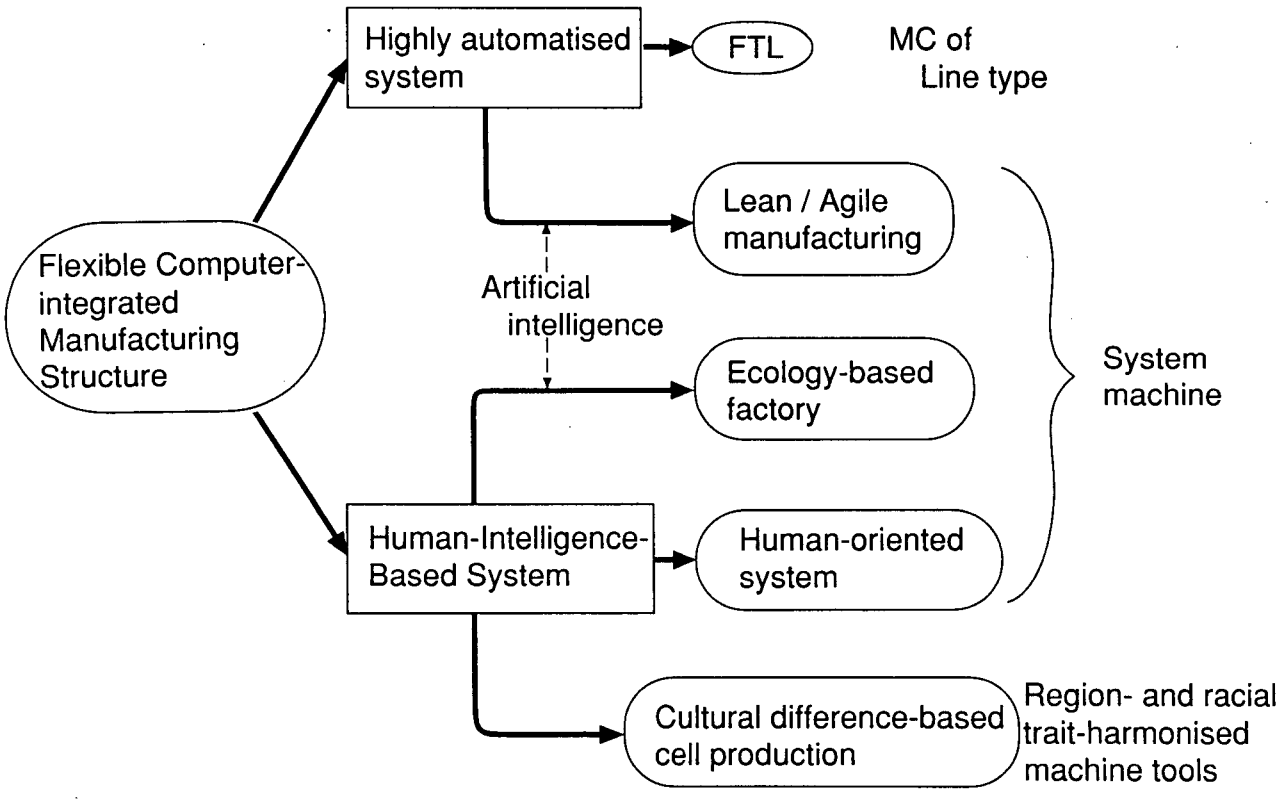


Fig. 1 Expectable production systems in future and related machine tools

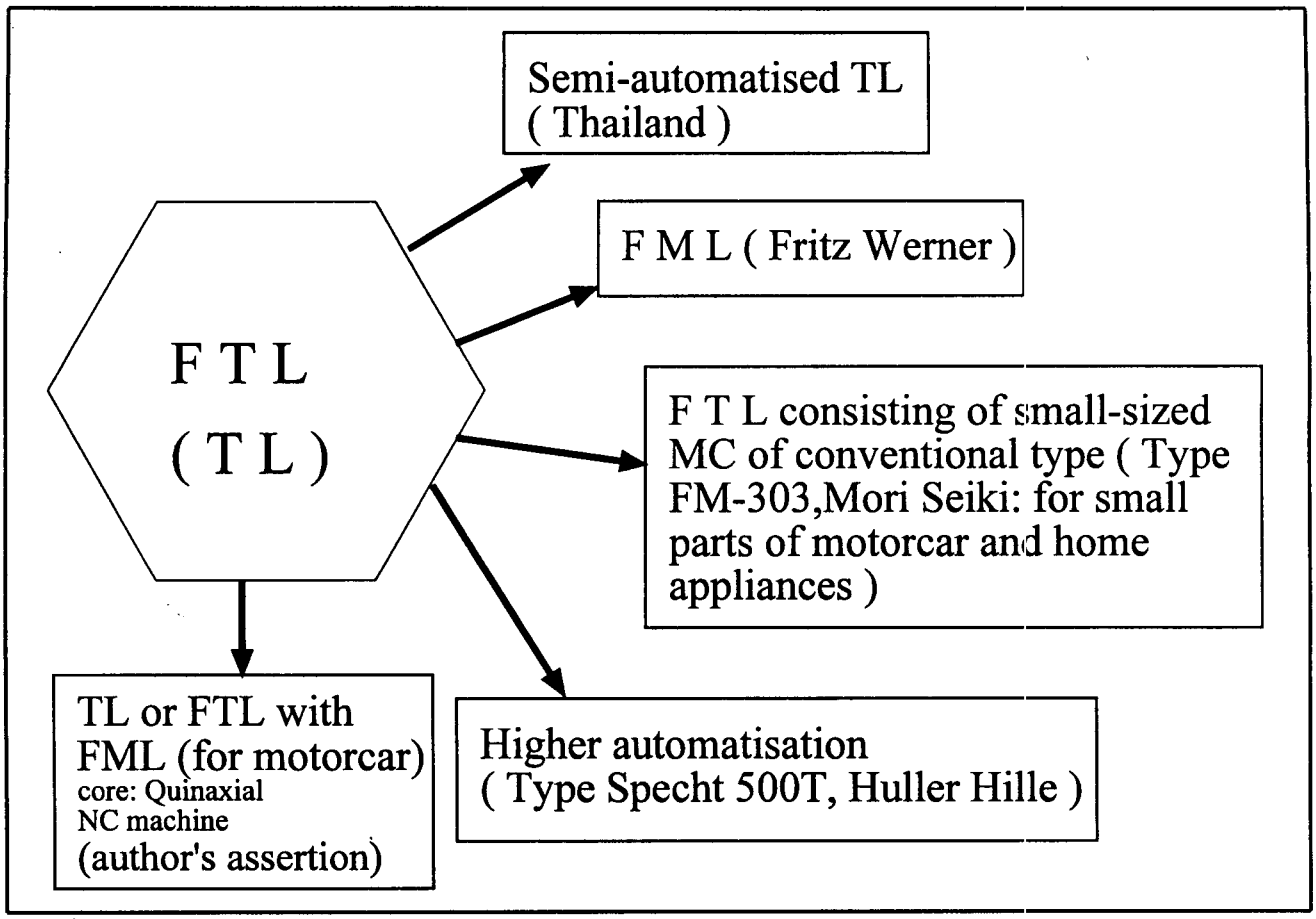


Fig. 2 Changing trends of FTL and related machine tools

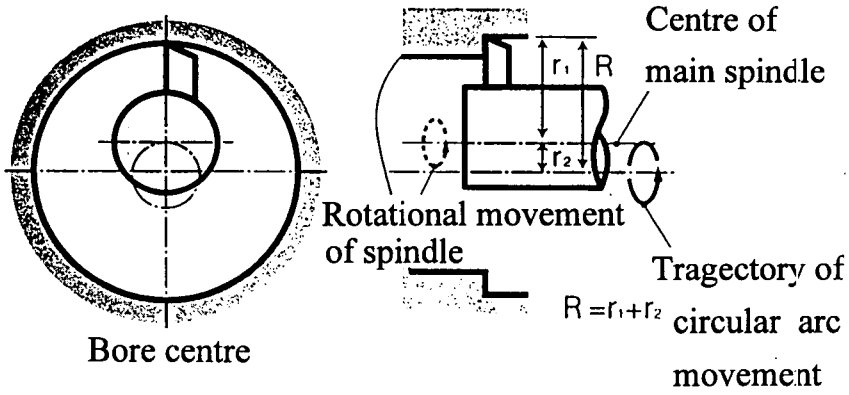


Fig. 3 Schematic view of eccentric-boring

(Type: NX76, Toshiba Machine)

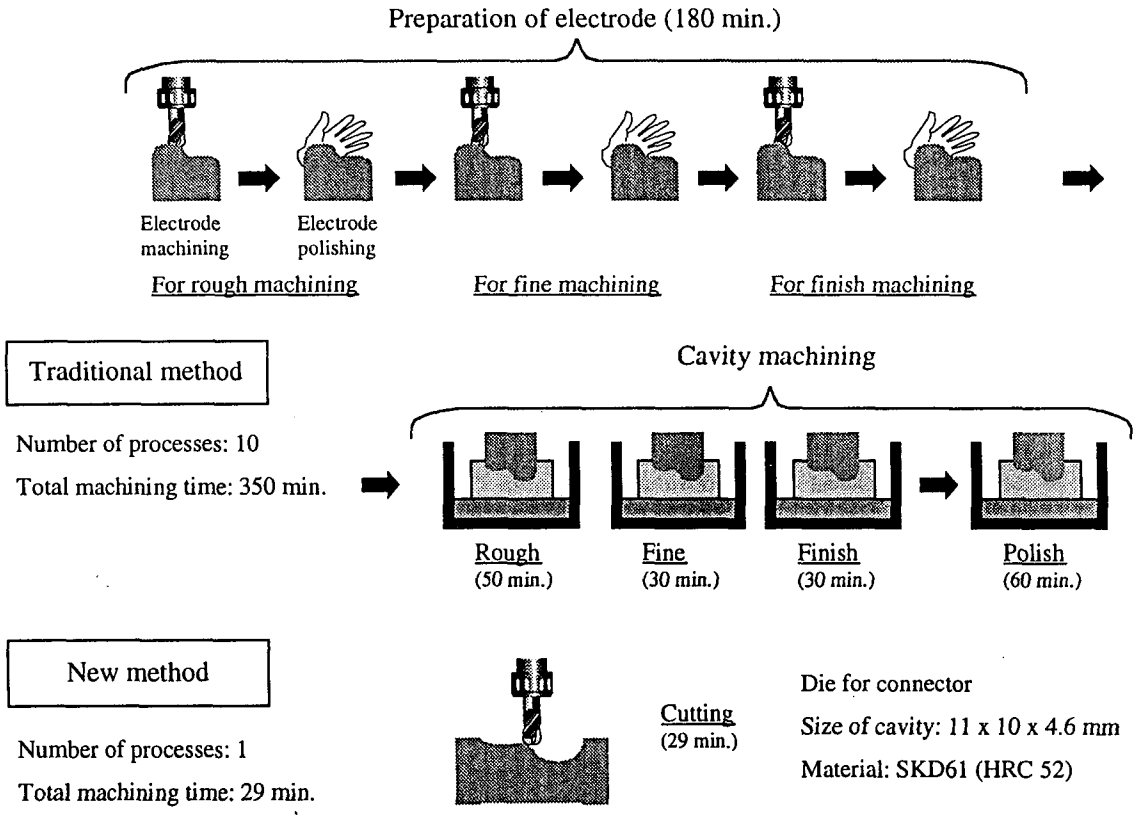
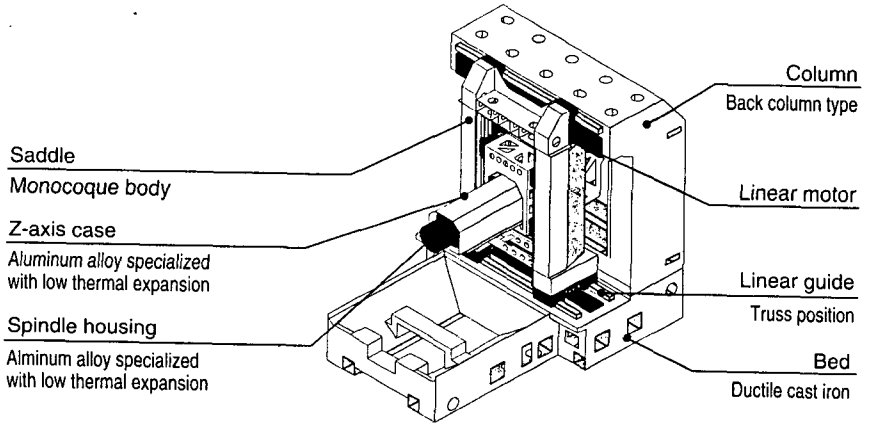


Fig. 4 Sample machining by " Hyper 5 "

(By the courtesy of Makino Milling Machine Co.)



Main spindle of built-in-motor: Maximum speed 20,000 r.p.m., starting time 1.2 sec.
Linear motor travelling for headstock career: Maximum speed 80 m/min.
Spindle quill: Al alloy of lower thermal expansion type

Fig. 5 Box-in-box body structure

(Linea M of Toyoda Machine Tool Mfg.)

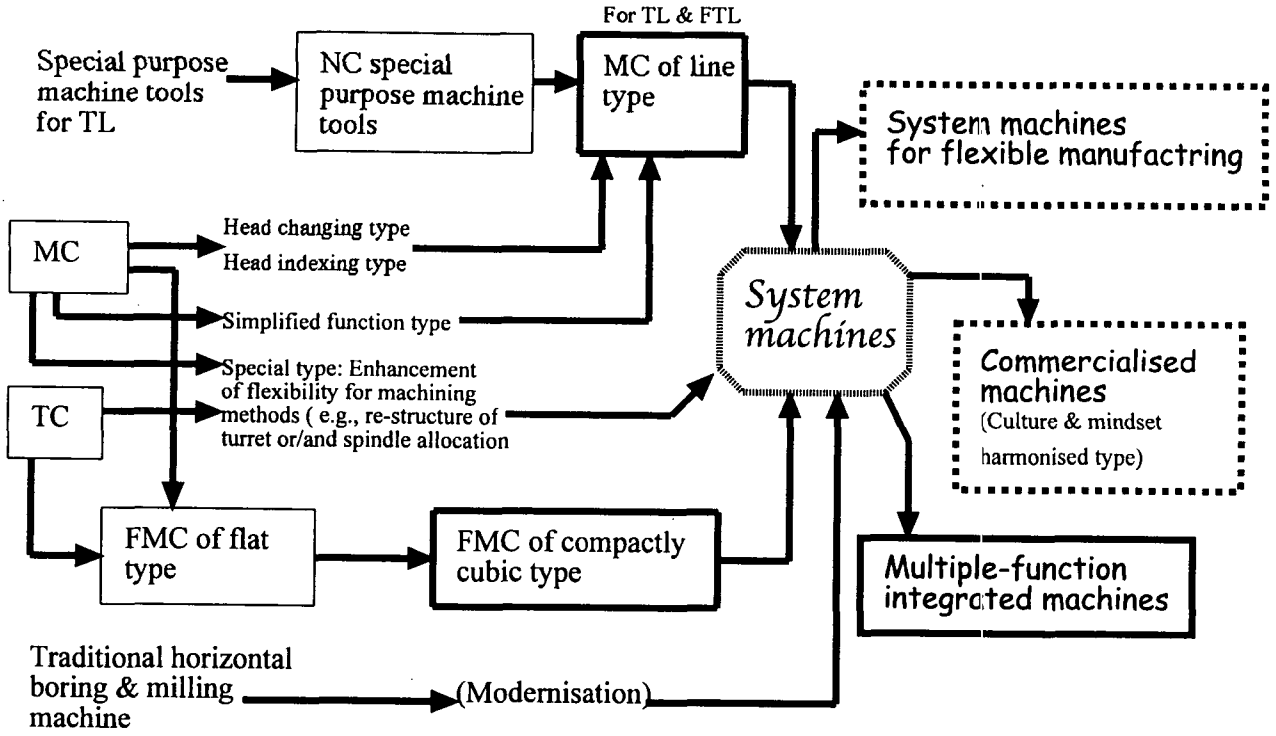


Fig. 6 Developing history of system machines

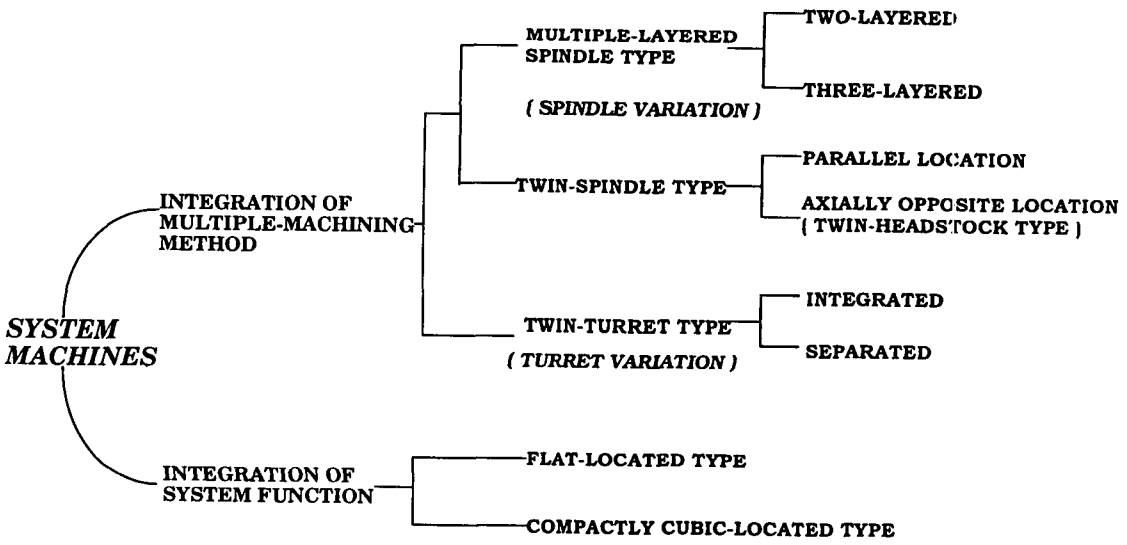


Fig. 7 A classification of system machines at present

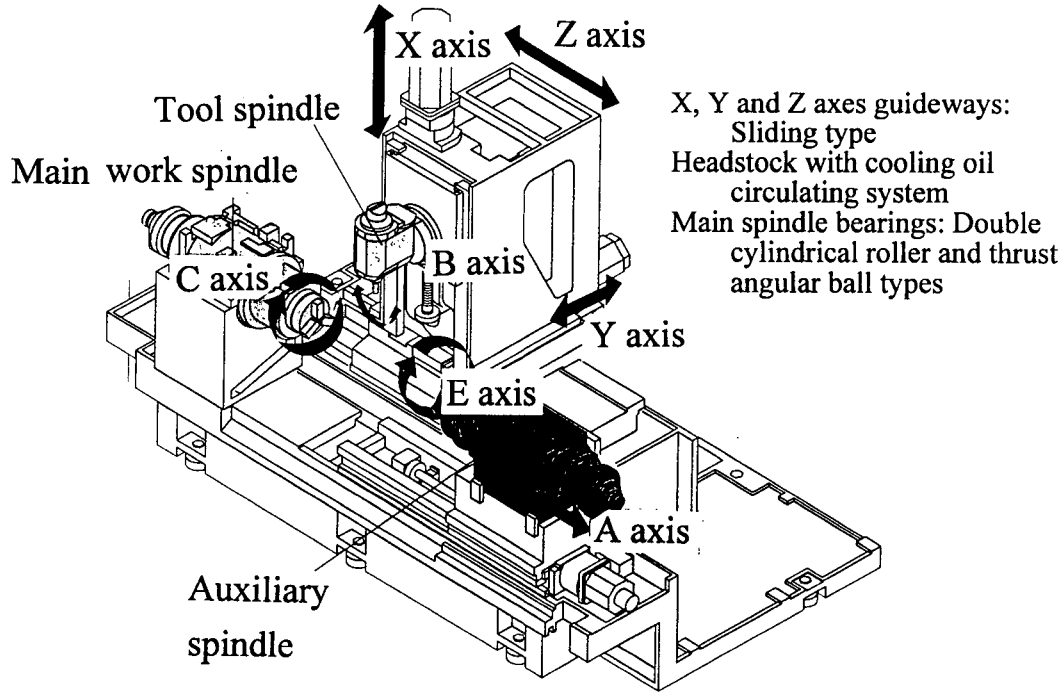
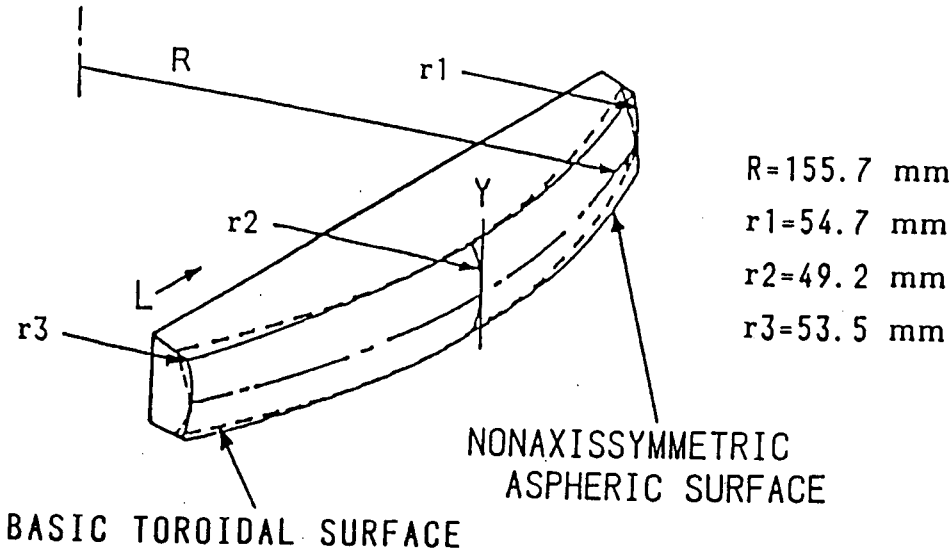


Fig. 8 Complex Machine of production type
(Tsugami: TMA type)



Transmissivity: more than 98 %

Fig. 9 Shape and size of scanning lens

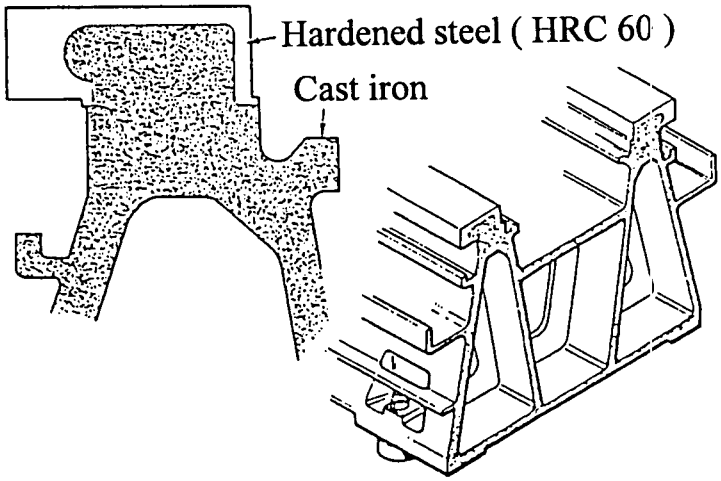
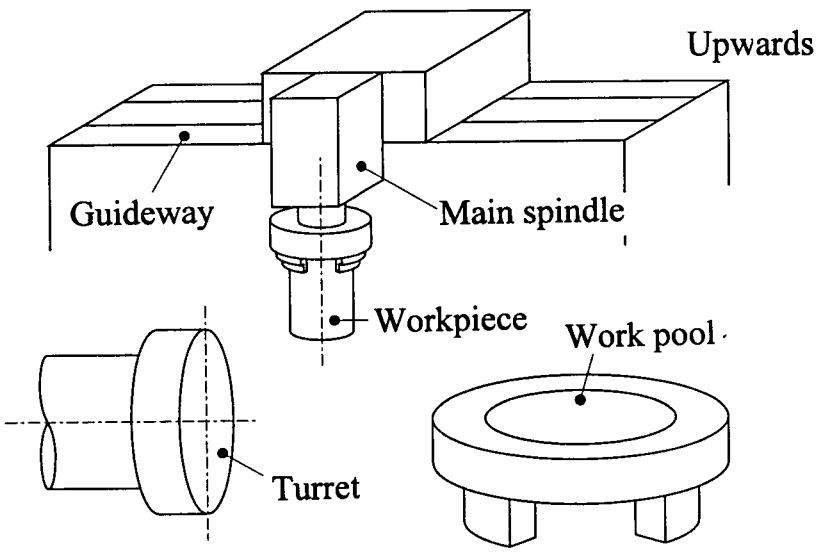


Fig. 10 Guideway of cast-in-place type



Main Motor Output: 7.5 kW

Work Diameter in Max.: 400 mm

Downwards

Fig. 11 NC vertical lathe of hanging spindle

(Type: CS 20, Hitachi Seiki Co.)