

Chapter 2

Choosing Guide in Form-Generating Movement and New Approaches to Machining Technology—Correlation Diagramme Among Machining Method—Tools—Attachments—Machine Kinds

In discussing the machining technology, a facing crucial issue is to establish a choosing guide for the machining method, when providing us with the part drawing. For such a purpose, we must conduct the meticulous investigation into the mutual correlation among a group of the structural body components allocated around the machining space (hereafter, call it “*Structural Configuration Entities*”), attachments like tool bracket and chuck, cutting tool, work and so on. These machine body and facilities can feature the machining space to various extents.¹

In this context, it is worth suggesting that nearly all the books so far publicised are far from fruition to respond such requirements of wider scope. Reportedly, we have discussed the machining technology so far with narrower scope by only eying the machining method and its mechanism. In addition, it has been, as reported elsewhere, believed that machining technology is very experienced-based engineering problems, although having been endeavoured to sublimate the experience-based know-how into theoretical-based knowledge. Such a belief is, in part, correct, but not correct in certain extent. In retrospect, a trial to interpret material processing from theoretical point of view is, for example, credited to Thomas of Technical College Worcester in (1972) as already introduced.

Conceptually, we can interpret the machining space as to be a cross point of the production and utilisation technologies of the machine tool. From another viewpoint, we can envisage both the material and information flows in the machining space as shown in Fig. 2.1.

From Fig. 2.1, we can obtain duly necessary information according to the machining requirement. It is thus very convenient to discuss, with wider scope, the leading issues in the machining technology by placing the stress on the machining

¹The description, discussion and concerns in this Chapter will be done, provided that the machine tool available for corresponding machining has acceptable functionality and performance specifications. The basic knowledge about the structural design principle of the machine tool will be stated quickly in Appendix B. Such the design principles are mandatory even for the machine tool user.

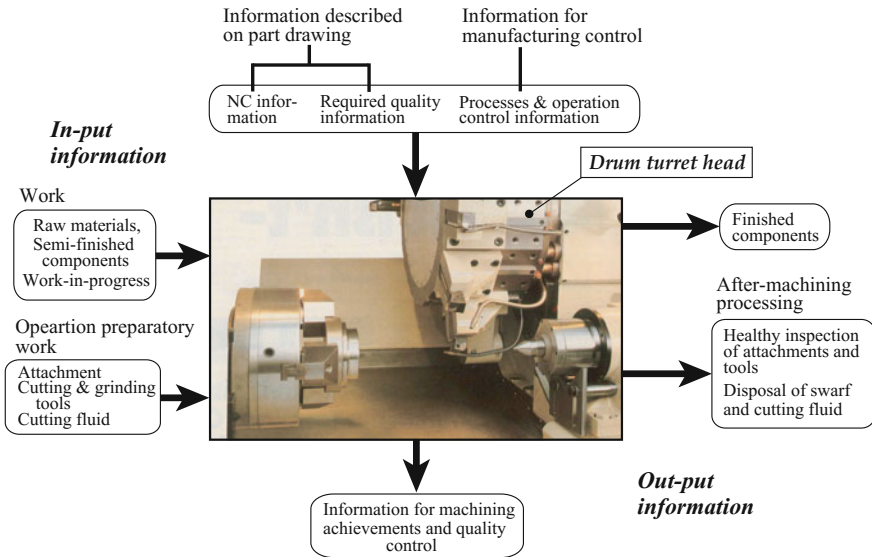


Fig. 2.1 Material and information flows in machining space

space. Of special note, flexible manufacturing means simultaneous management for both the material and information flows within due time, i.e., no redundancy in time and space domain, in the machining space (Weck 1974).

2.1 Facing Problems in Choosing Guide for Preferable Machining Method

Obviously, the choosing guide for the recommendable machining method is one of the leading engineering problems related to the machining space, and for such a purpose we can propose an idea as shown in Fig. 2.2. As can be readily seen from Fig. 2.2, it is possible to enumerate the potential processing, constraint conditions and evaluation indices; however, a choosing guide for practical use is far from completion. One of the hindrances is the amazing advance of the metalworking technology, which may often replace or force to improve the machining technology so far used as exemplified by the friction-welded crankshaft (see Fig. 1.3e).

To simplify and clarify our discussion, thus, we focus now our objective on a choosing flow and diagramme applicable to machining in practice. In this context, we must first suggest the involving problems within Fig. 2.2 as follows.

- (1) No evaluation functions are established as yet.
- (2) Leading constraints are in reciprocal relation to one another, and as a result, we cannot determine the optimum constraint condition, but may use the preferable

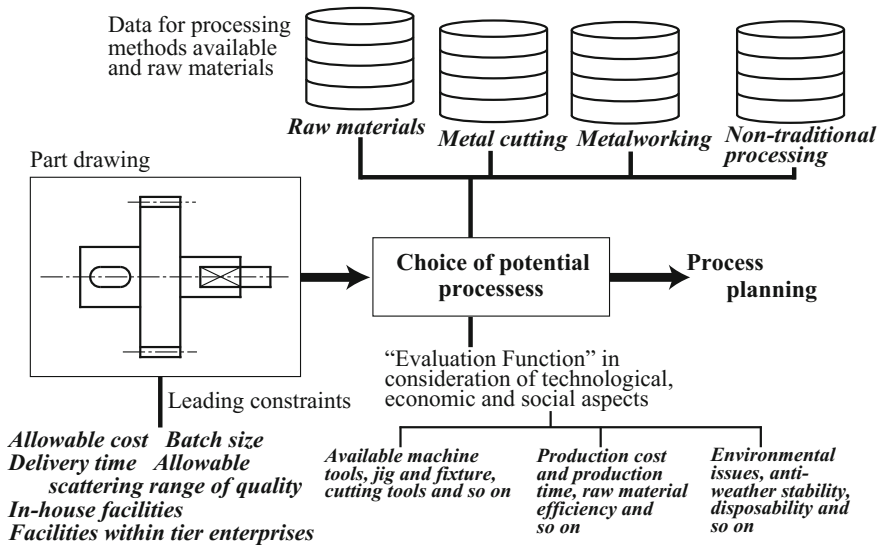


Fig. 2.2 Searching concept of rational processing method

constraint only, resulting in a handful of constraint conditions possible in certain cases.

- (3) Reportedly, there are the three leading attributes in the design of machine tools, i.e., better machining accuracy, higher rotational and travelling speed and heavy-duty cutting capability. These three attributes are also in reciprocal relation, and thus each machine tool can be characterised by its own design features. In consideration of primary compatibility of machine tool available with the machining requirement, we must determine the machining method.
- (4) With the advance of the technologies related to the machine tool, attachment and tool, the machining method available changes to various and large extents as exemplified by the advent of the machining function-integrated kind, e.g., “*Mill-turn*”. In certain cases, the machining method changes drastically by the improvement of the work material itself.

Of these, the novel contrivance for the machine tool affects the choosing guide for the preferable machining method to large extent. For example, Fig. 2.3 shows the interesting gear cutting methods being prevailed, i.e., *gear skiving* and “*Scudding*”, where the scudding is a variant of gear skiving. The gear skiving was already contrived in the 1980s, but has not been positively used so far (Spur and Stöferle 1980). In the 2000s, the gear skiving has been re-considered its effectiveness, e.g., high productivity by cutting the gear blank with high hardness and availability for cutting the stepped gear like gear shaping (Schmidt and Bechle 2003).

More specifically, the gear skiving is a synergy of hobbing and gear shaping, and characterised by the tooth profile-generating movement as follows.

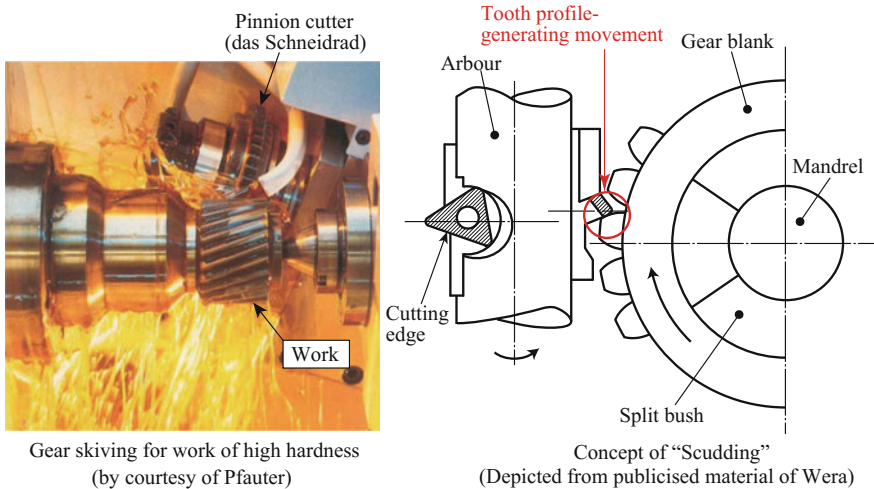


Fig. 2.3 New proposal and resurrected method in gear cutting

- (1) The rotating axis of pinion cutter engages with certain angle to the rotating axis of the gear blank.
- (2) Maintaining such the engagement of the axes, the pinion cutter removes unnecessary allowance along the rotational axis of the gear blank.

Importantly, the gear skiving can be recently carried out by the machining centre (MC), and thus may accelerate the development of the gear production centre.

In addition to the technological aspect, a root cause of difficulties lies in the saving of the machining cost, i.e., economisation, provided that we can guarantee the finished quality of the component as indicated as well as maintaining the delivery time. Importantly, the machining cost depends upon especially the machining pattern, e.g., either batch or large volume and a less variation productions.

Following such conceptual discussion mentioned above, we must then detail the choosing instruction for the preferable machining method from the viewpoint of factory floor. In fact, we must consider the following factors and their complicated combination while machining the component within the in-house and also at subsidiary.

- (1) Machining facilities, their capabilities and healthy conditions, and also expectable machining cost.
- (2) Available cutting and grinding tools, jig and fixture, and so on.
- (3) Machining accuracy and surface quality to be finished, necessity of heat treatment, properties of work material and so on.
- (4) Batch size, allowable delivery time and cost.
- (5) Skill qualification of operator and requirements for extremely special machining.

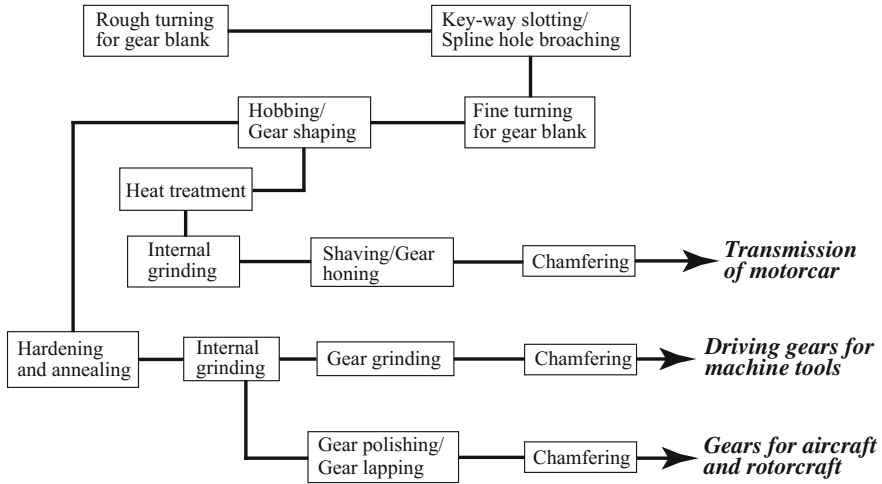


Fig. 2.4 Various machining procedures of spur gear depending upon product kind

Now let us show the two examples, which cause the difficulties in choosing the preferable machining method.

Machining Procedures in Spur Gear

Figure 2.4 illustrates the various machining procedures of the spur gear, which depend upon the product kind. Up to gear cutting, there are no differences; however, after then the gear can be finished by various methods depending upon the product kind. Of course, this is because of fulfilling the function and performance required by each product.

Importantly, the gear for the transmission of motorcar is being finished by gear grinding to reduce the frictional energy loss at the tooth profile (refer to Fig. 1.3f).

Surface Roughness and Machining Method

Figure 2.5 shows a sample work to learn the sensory flair for the quality of the finished work. The surface roughness is, as widely known, one of the indices to evaluate the work quality, and there are various choices in machining methods even when the surface roughness required is the same.

In short, more versatile in the machining requirements, the more difficult is the determination of the utmost preferable machining method.

Against to this context, it is expectable to establish a choosing guide for the suitable machining method by applying the design methodologies in the machine tool structure, i.e., concept of “*Flow of Force (der Kraft Fluß)*” and description of form-generating movement (functional description). In many respects, the *flow of force* is very effective to represent the machining space, i.e., linkage among structural configuration entities, by the direct graph as will be discussed later. Conceptually, we may clarify the correlation between the machining method and the machine tool by such a directed graph.

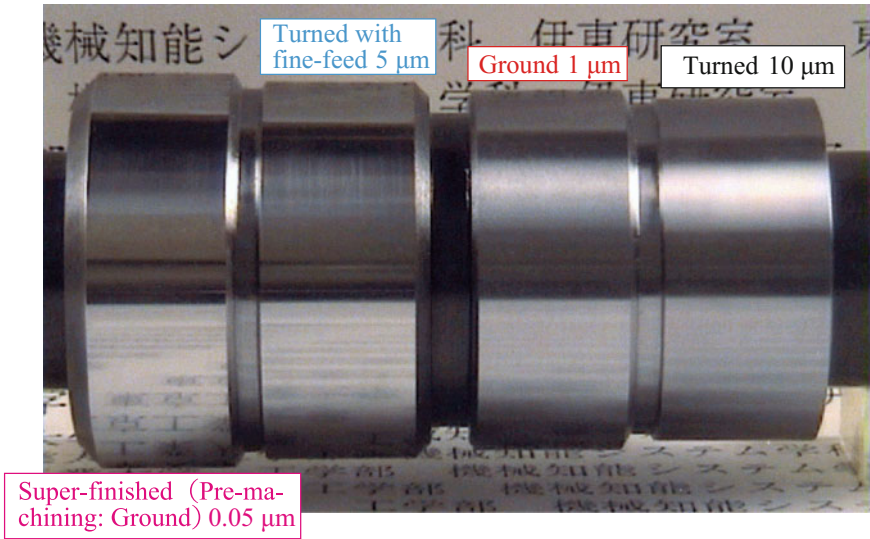


Fig. 2.5 Relationships between surface roughness and machining method

In the following, we will thus discuss the concept of *flow of force*, description of form-generating movement and its application to the choice for suitable machining method, and also the representation of linkage in machining space.

2.2 *Flow of Force* and Description of Form-Generating Movement

It is believed that the concept of *flow of force* was German-originated supporting tool (design methodology) for the structural design of machine tools. In short, the *flow of force* can visualise all the structural body components within a machine tool as a whole, which are being burdened the cutting force, and in the case of large-sized machine tool, its weight.

As can be readily seen from Fig. 2.6, the cutting force acts first on the main spindle in the headstock and barrel of tailstock through the work, and also on the turret head through the cutting tool. These structural body components are mounted on others, e.g., cross slide, bed and base. For the ease of understanding, we display such 3-dimensional loading states by the arrowed line as shown in Fig. 2.6, and thus call it the *flow of force*.

The concept of *flow of force* is very simple, but very effective in conducting the design methodology for the structural design, because the *flow of force* can be converted into the directed graph in the mathematics, where we can represent the

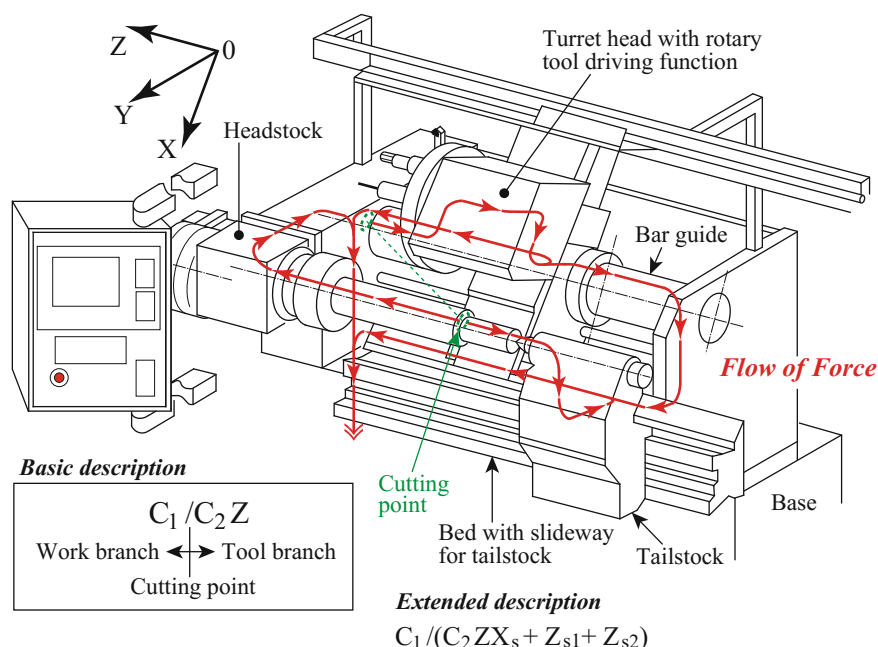


Fig. 2.6 “Flow of Force” in and “Functional Description” of CNC lathe (Modified RNC Series of Monforts-brand in 1990s)

structural body component and flow of force by the “Vertex” and “Directed Edge”, respectively (Ito 2008).

In the design methodology for the machine tool structure, another issue is the description of the form-generating movement, i.e., functional description. More specifically, we can represent all the rotational and liner movements in a machine tool as a whole by using the co-ordinate system, preferably that in accordance with NC axes, as shown also in Fig. 2.6. We can thus describe form-generating movements possible by the combination of several axes. Reportedly, we have already established the functional description without ambiguity, and importantly, the *flow of force* can facilitate it implicitly by giving absolute order of the alphabetical letter in the description.

As will be clear from the above, we can apply the concept of *flow of force* and functional description with narrower scope to the machining space. Conceptually, it is possible to delineate the linkage of structural configuration entities by using the *flow of force* as shown in Fig. 2.7a, b. Importantly, the machining method being carried out in the machining space can be represented by using a variant of functional description. In addition, we may thus discuss the machining technology in detail from the viewpoint of machine-attachment-tool-work system.

Of special interest, the *flow of force diagramme* is very convenient to grasp at glance the mutual relationship between the production (design and manufacture)

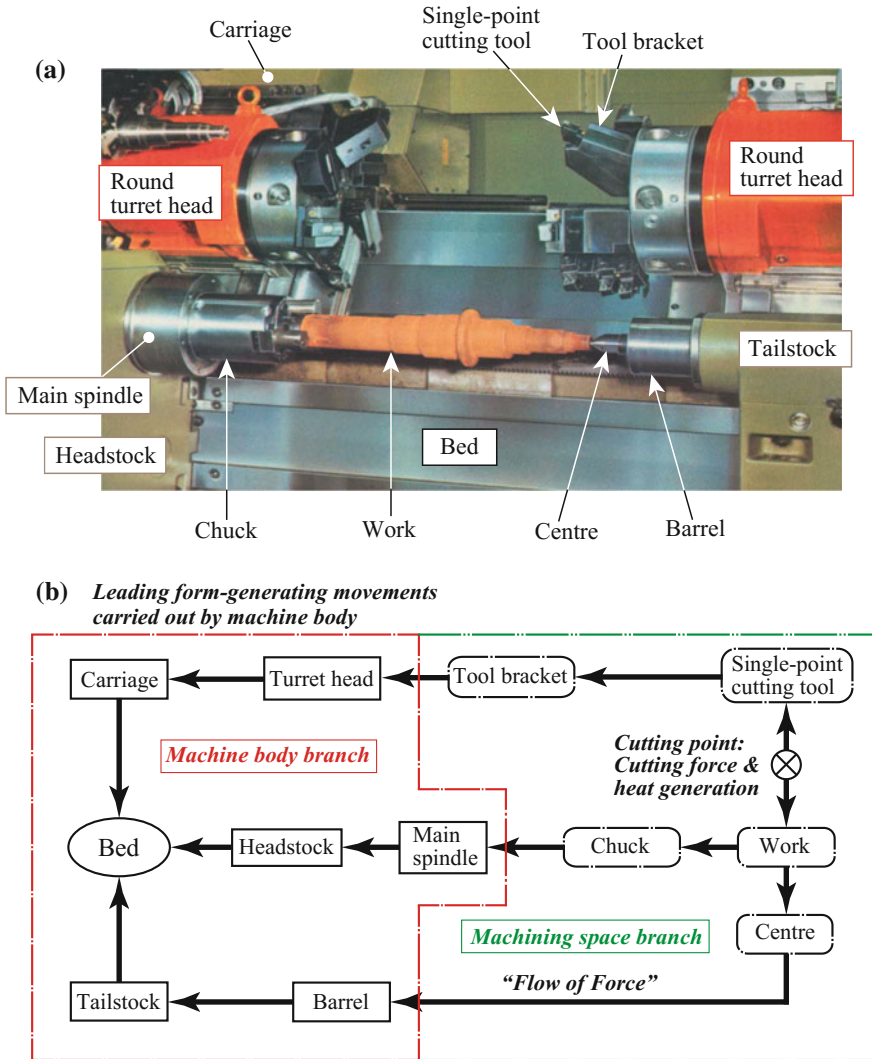


Fig. 2.7 Machining space in NC lathe and its “Flow of Force” diagramme: **a** Typical machining space—NC lathe of twin-turret type (Heyligenstädt-brand 1979). **b** “Flow of Force” diagramme

and utilisation technologies in the machine tool. As already shown in Fig. 2.7b, the branches for the machine body and machining space correspond closely to the production and utilisation technologies, respectively. In general, the machine tool manufacturer pays the special attention to the machine body branch, whereas the machine tool user eyes only the machining space branch; however, it is recommended to understand the total view of the *flow of force diagramme* with the

preferable balance between the machine body and machining space branches with the advance of both the machine tool and its application technologies.

Importantly, similar stories are available for the “Linkage Diagramme” (refer to Fig. 2.24), and also for the illustration to represent the stiffness definition (refer to Fig. B.3). In the former case, the machining method (left-hand side) and the machine kind (right-hand side) belong to the machining space and machine body branches, respectively. In the latter case, we can obviously display the differing design principle of the machine tool from that of other industrial machines.

2.2.1 *Functional Description of a Machine Tool as a Whole*

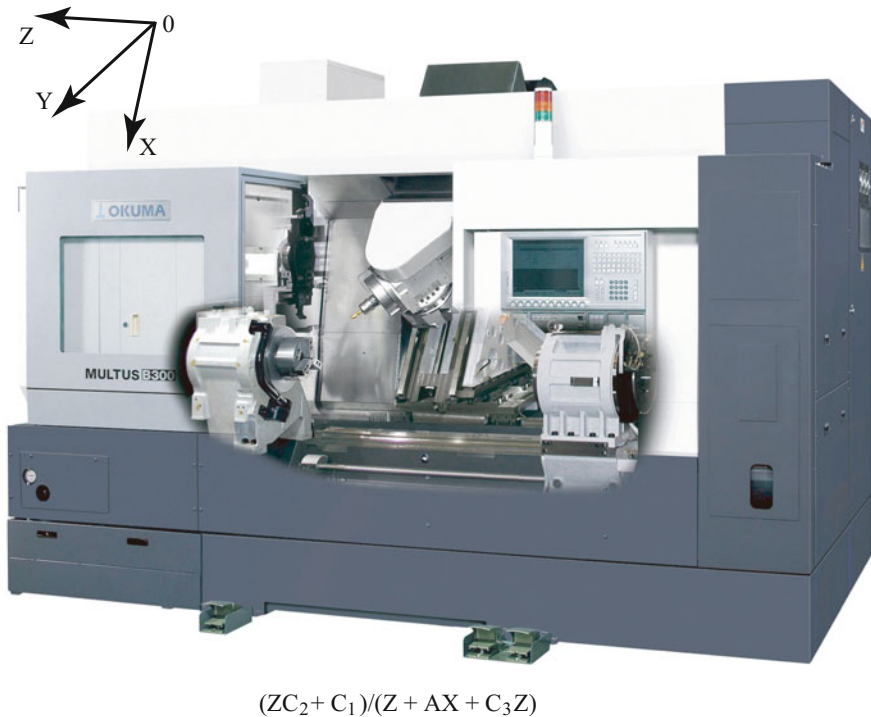
In the functional description, we must first classify the rotational and linear movements into three kinds, i.e., principal, auxiliary and supplementary (supporting) movements. Of these, the supplementary movement is for setting the depth of cut, indexing of turret head, clamping motion of barrel and so on.

Importantly, we can shape, in principle, the component by the principal and auxiliary rotational and travelling movements, and in general, the former and the latter are carried out by the structural body components allocated around the machining space, and also the attachment and tool, respectively.

In the functional description proposed herein, thus, we use the following description rules (refer to Fig. 2.6).

- (1) Indicating the cutting point by the symbol “/”(slash), and then the movements of work and tool are placed at the “left-hand” and “right-hand” branches, respectively.
- (2) Starting from the cutting point, the alphabetical letter is placed in the closer order to the cutting point, in other words, placement of alphabetical letters along with the *flow of Force*.
- (3) When having primary movement designated by the same alphabetical letter more than plural, we use the numerical subscript for the differentiation, and also the symbol “+”, if it belongs the same branch.
- (4) In cases of auxiliary and supplementary movements, we use the subscripts “a” and “s”, and also apply the same rule as per the item (1).
- (5) When the structural body component can move simultaneously more than two axes, the corresponding alphabetical letters are marked by the symbol “^” (hat).
- (6) If necessary, we can place the secondary co-ordinate (U, V, W), which is especially required of describing the machining method-integrated kind.

In the extended functional description in Fig. 2.6, the supplementary movement is given; however, in general, we use the basic functional description, which consists of primary and auxiliary form-generating movements. Figure 2.8 shows a functional description for “*Mill-Turn*”, which is the upmost advanced type within



$$(ZC_2 + C_1)/(Z + AX + C_3Z)$$

Fig. 2.8 A representative “Mill-Turn”—Type MULTUS B 300 (by courtesy of Okuma 2004)

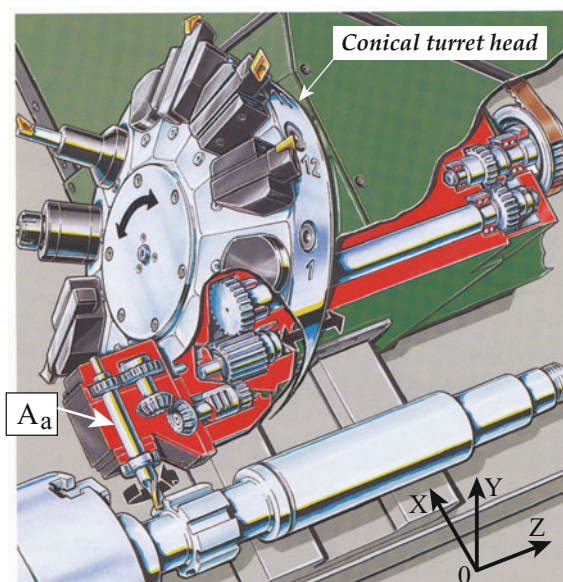
the machining function-integrated kind at present. This kind is extremely characterised by the built-in tool driving mechanism in the tilting head. In the conventional form-generation, the primary movement can be facilitated by the configuration and allocation of the main spindle. Against to this context, the tilting head can facilitate various machining methods and often the auxiliary movement is converted to primary one as can be seen from the functional description shown also in Fig. 2.8.

Of note, we can use the numerical controlled (NC) turning machine like the turning centre (TC) or *Mill-Turn* by attaching the rotating tool spindle to the turret head, and in such a case, the rotating tool plays the role of the auxiliary form-generating movement as shown in Fig. 2.9.

2.2.2 *Form-Generating Movement in Machining Function-Integrated Kind*

In the modern machine shop, the conventional TC and MC are doubtlessly major machining facilities, and thus we often forget that TC and MC belong to the

Fig. 2.9 An auxiliary form-generating movement—rotary tool spindle unit mounted on turret head in CNC lathe (Type TNA, Traub-brand 1993)



Auxiliary movement: A_a

machining function-integrated kind (see Fig. 7.1).² In fact, on the strength of beneficial features of TC and MC, the machining function-integrated kind has been deployed across the whole kinds of the machine tool. For example, Fig. 2.10 shows the vertical turning machine with milling function, where turning and milling are primary and secondary functions, respectively, as can be also assumed from the machine specifications. In short, milling can be carried out by the built-in spindle, which is placed within the ram, and the milling cutter is accommodated within the automatic tool changer (ATC) together with the single-point cutting tool for turning as shown in left top of Fig. 2.10.

In contrast, *Mill-turn* can carry out various machining methods without any discrimination in form-generating movement (refer to Fig. 2.8).

Having in mind that there are a considerable number of variants in the machining function-integrated kind, in general, the primary form-generating movement is, in principle, to be in reality with a handful of configurations in the main spindle and concerns as follows.

²The idea of the machining function-integrated kind is not new, but old. In the 1960s, Ramo merchandised the engine lathe, which is capable of broaching in addition to the ordinary machining function as the lathe. As compared with this lathe, TC and MC are the very advanced type and characterised by the automatic tool and tool cassette changer. Although staying a trial stage, in the Big National Project of Japanese Government called *Flexible Manufacturing Complex Provided with Laser*, we already produced a processing function-integrated kind.

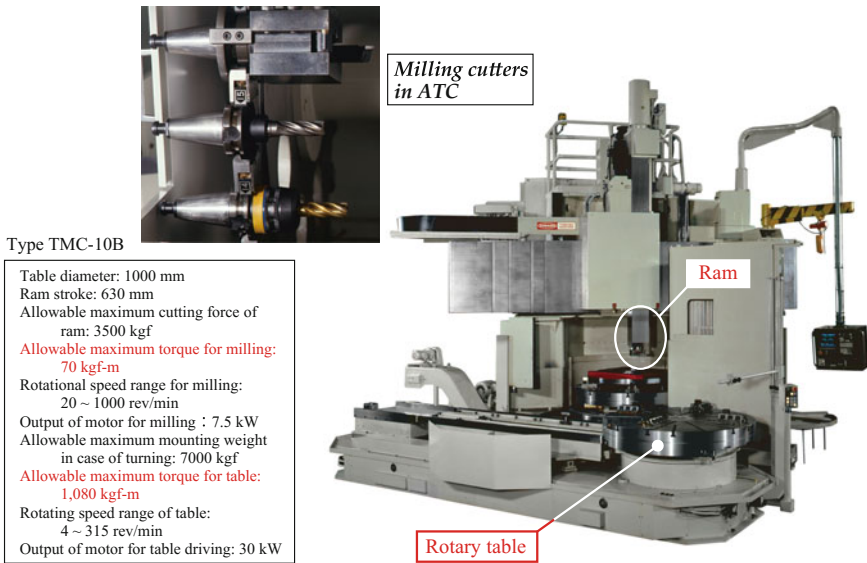


Fig. 2.10 Integration of milling function to vertical TC (Type TMC, around 2005, by courtesy of Toshiba Machine Mfg.)

- (1) Twin-spindle, e.g., vertical and horizontal allocation (refer to Fig. 1.11).
- (2) Main spindle with multiple-layered type, and in certain cases with eccentric type.

Figures 2.11 and 2.12 show two typical configurations of the main spindle. One is for twin-spindle type with travelling function, and the other is for two-layered spindle with also travelling function. For references, Fig. 2.12 shows furthermore the appearance of NC horizontal boring and milling machine with three-layered spindle in its right top. Obviously, the form-generating movement is reinforced much more than that in two-layered spindle, although NC commands become complex.

Intuitively, we can see the capability of carrying out various machining methods from the functional descriptions. With the growing importance of the quinaxial-controlled MC, furthermore, both the tilting spindle head and trunnion table can facilitate the primary form-generating movement as already exemplified in Fig. 2.8.

Paraphrasing, the structural body component allocated around the machining space is closely related to the primary form-generating movement, and a facing issue is to reinforce the versatility in the machining method by adequately incorporating the auxiliary form-generating movement. One of the remedies to such a requirement is to employ a variant of the modular designs, i.e., “*concept of Platform*” (Ito 2015).

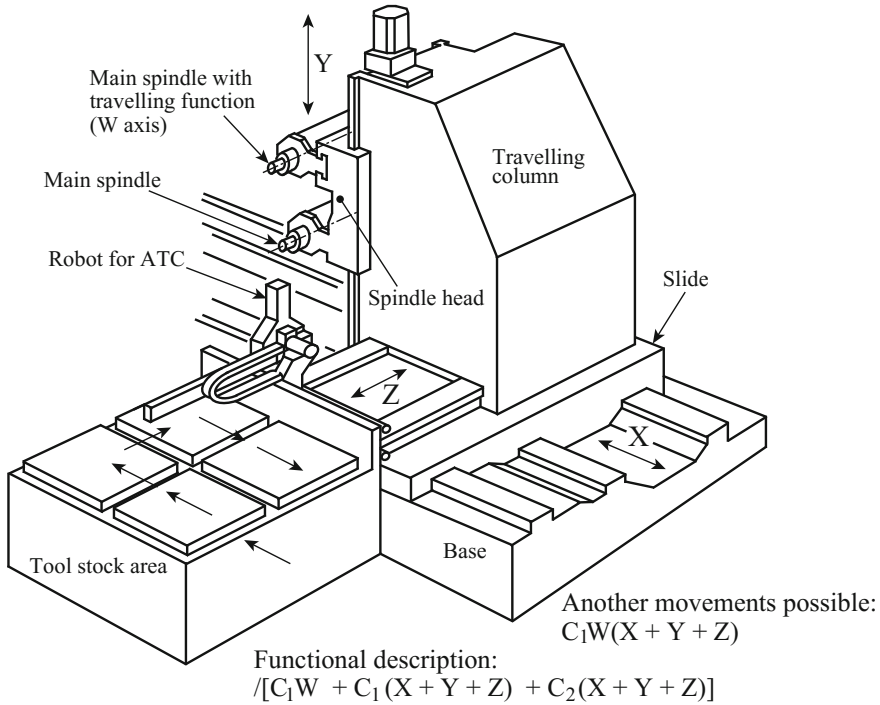


Fig. 2.11 Spar milling machine of twin-spindle type—a variant of AUTOMAX I, MPM-brand, middle of 1980s

In the *concept of platform*, a group of the structural body components allocated far from the machining space is integrated into one large-sized module, and we call it *platform*. Apart from the necessity of pains-taking work in the structural design, we can expect considerable advantages in both the production and the utilisation of the machining function-integrated kind by employing the *platform* as will be discussed in Chap. 7. Supposedly, the user can obtain the lucrative benefit without any awareness by installing, for example, *Mill-Turn*, which is designed on the basis of *platform concept*. Although there is not a relevant symptom at present, a *user-oriented platform design* should be developed hereafter on the strength of vigorous contrivances in the attachment and tooling.

In fact, we may expect more marked economisation by establishing the *user-oriented platform* than ever before, where the auxiliary form-generating movement is to be in reality by the attachment and tool. It is furthermore better to use the cutting function-integrated tool, e.g., formed tool and gang tool. Accidentally, the tooling layout in TC becomes recently more sophisticated, and thus we may elevate the synergy effect of the *user-oriented platform* by combining it with the advanced tooling layout as shown some examples in the following.

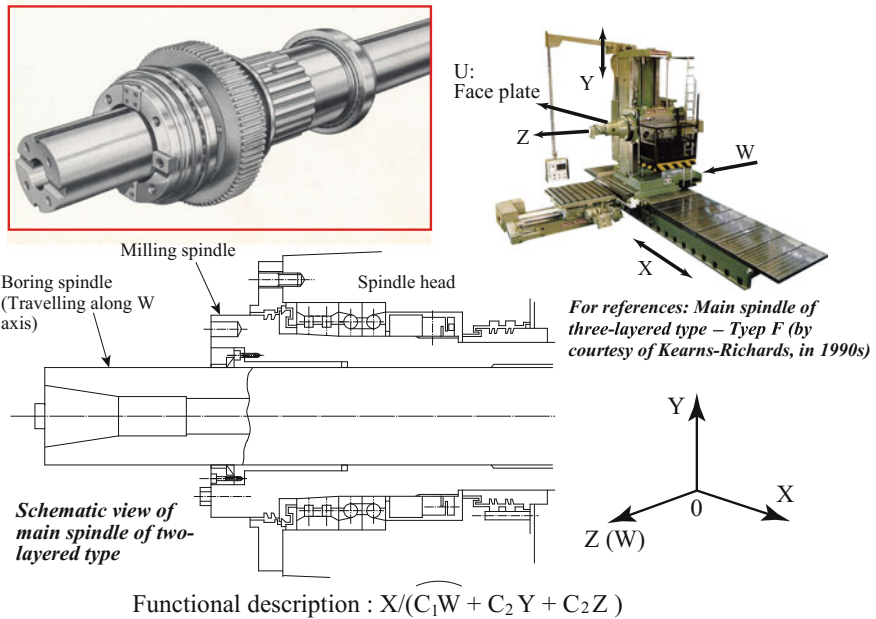


Fig. 2.12 Main spindle of two-layered type in horizontal boring and milling machine

Figure 2.13 shows a machining space in the computerised numerical controlled (CNC) automatic of twin-spindle type of Traub-brand (Type TNL). As can be readily seen, metal sawing is applicable as one of machining methods. In fact, this CNC automatic has several special cutting functions, e.g., gear cutting and gun drilling as like as TC. Reportedly, it is now common senses that MC can facilitate grinding, ultrasonic machining and laser processing as shown in Fig. 2.14, where the mould for the denture (artificial tooth) is being ground by the high-speed quinaxial-controlled MC. In addition, Fig. 2.15 shows the machining scenery in the five-face processing machine, and as can be seen, the machine can generate various work configurations by changing the attachment mounted on the main spindle, i.e., snout and angle head. Of note, MC of gantry type is the successor of the five-face processing machine.

In the integration of the grinding function to MC, there are two facing issues at the spindle-end and front main bearing: one is to maintain the oil and water tights, and the other is to clean the tapered hole by the air cleaning system. It is however said on the basis of our long-standing experience that such an air cleaning system cannot eliminate the debris of worn abrasive grain and micro-particle removed from the work while grinding. Supposedly, MC with grinding function shown already in Fig. 2.14 is well equipped something necessary, although it is not publicised, because of company's confidentiality.

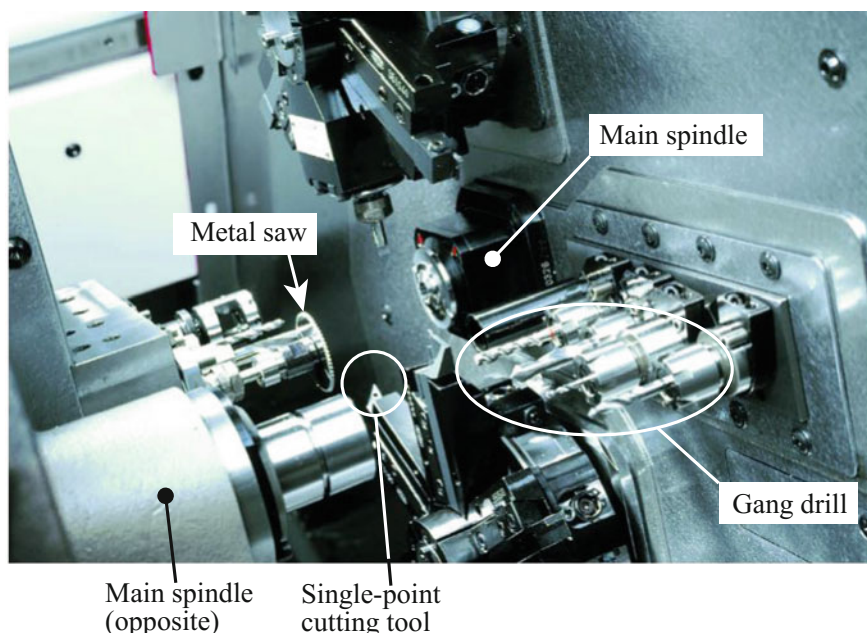


Fig. 2.13 Much more integration of machining methods (by courtesy of Traub 2009)

Another idea is thus to provide the grinding centre (GC) with cutting function, and probably we will be able to solve the problems mentioned above. Figure 2.16 shows a GC, where the internal grinding spindle is for both grinding and milling after stiffening its rigidity and increasing the allowable torque at the lower rotational speed. It sounds very easy to mill the work by GC; however, we will face another new problems as follows.

- (1) GC has two spindles, i.e. grinding and work spindles, and thus GC is, in principle, capable of conducting various form-generating movements as compared with MC. In contrast, there are considerable difficulties in determination of the design specifications, e.g., rotational speed range and allowable maximum spindle torque, which are derived from the essential difference between cutting and grinding as exemplified the three components in the machining force.
- (2) It is desirable to provide GC with hard-turning function, e.g., that for hardened bearing steel (100Cr6, hardness around 62 HRC) by the Poly-crystal Cubic Boron Nitride (PcBN) with TiC coating.³

³Based on the on-the-spot investigation by Ito at Technical University of Aachen (TH Aachen) in 1997. On that occasion, cutting speed, feed rate and depth of cut are 150 m/min, 0.06 mm/rev and 0.1 mm, respectively.



Fig. 2.14 Grinding carried out by high-speed quinaxial-controlled MC—type RXP 500 (by courtesy of Röders 2013)

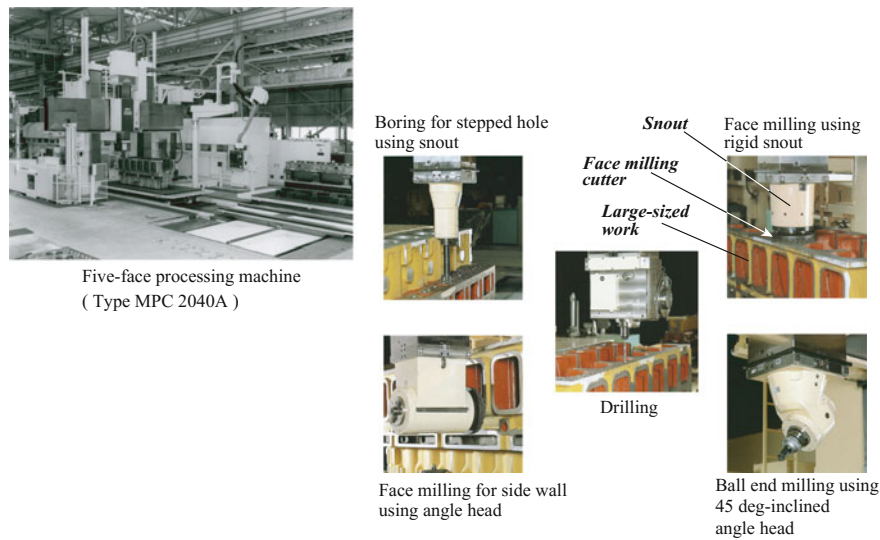


Fig. 2.15 Various machining methods capable of carrying out by five-face processing machine—for box-like work (by courtesy of Toshiba Machine Mfg., late 1990s)

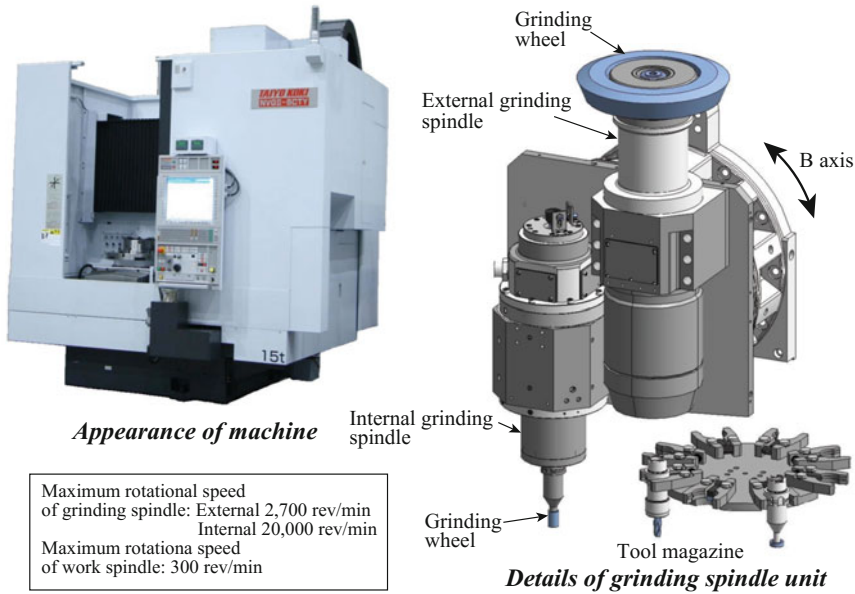


Fig. 2.16 GC with milling function (Type NVG II-5CTY, by courtesy of Taiyo Koki 2013)

As will be clear from the above, it is recommended that we should reinforce the auxiliary form-generating movement by the cutting and grinding tools in the *user-oriented platform*, and accidentally, we can purchase, without any difficulties, such tools, e.g., gang tool, combination tool and special boring tool for stepped holes from the market across the whole world. In the following, thus, some quick notes will be given.

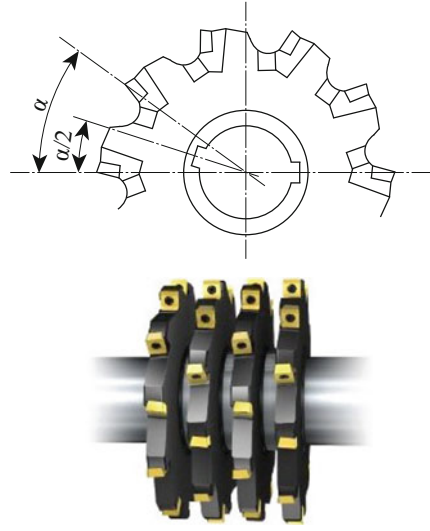
- (1) The multiple-spindle head shown in Fig. 2.17 is for MC and “Transfer Centre” and suitable for gang drilling and boring. In addition, gang milling can be regarded as a variant of formed milling cutter, and as well known, consists of a group of single milling cutters of various configurations so as to economise the tool cost than that for formed milling cutter. In retrospect, these have been in practice since 1960s.

In the case of gang cutter shown in Fig. 2.17, furthermore, we can see an interesting contrivance, i.e., staggered pattern mounting on the arbour, to suppress the chatter vibration. More specifically, the milling cutter has two keyways, one of which is placed with a half of tooth pitch in shifting from the other.

- (2) Trister Engineering has merchandised a combination tool, i.e., “Drill Reamer” as shown in Fig. 2.18. As literally shown, this tool is for drilling and reaming of Al-alloy and of custom-made. In addition, we can purchase another combination tool, e.g., drill and boring bar with chamfering at the entrance of hole and counter-boring. In this context, an interesting contrivance is shown together in

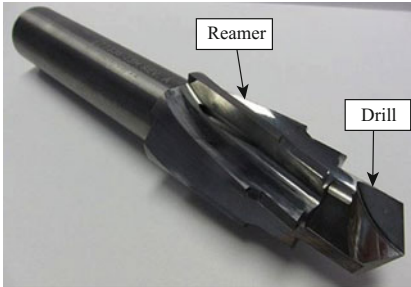


Multiple-spindle head for drilling and boring
(by courtesy of SU-matic, 2015)

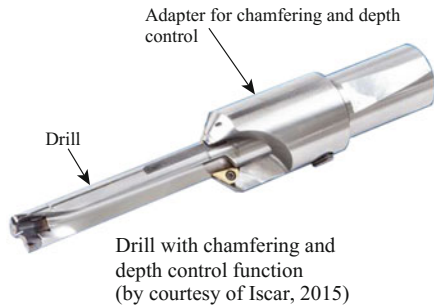


Gang milling in staggered pattern
mounting (by courtesy of Sandvik, 2015)

Fig. 2.17 Gang drilling, boring and milling



Drill reamer (by Tri Star Engineering, 2015)



Drill with chamfering and
depth control function
(by courtesy of Iscar, 2015)

Fig. 2.18 Examples of combination tool

Fig. 2.18, where the drill and adapter with depth control and chamfering function are assembled. Reportedly, in the Al-alloy die casting for the transmission and cylinder block of the motorcar, we have often the hole with unacceptable taper, bending, undersized diameter, and even the deviation of the hole position. Tanoi Co. has thus been on the market a tap called “Multi-Tap” since 2005, in which the end milling function is integrated at the front and side of the tap to provide a remedy for finishing such holes.



Typical boring bar for stepped hole (by Mapal, 2015)



Drill for deep-hole (by Kennametal, 2015)



Other tooling systems by Mapal (2015)

Fig. 2.19 Tools for deep hole and stepped hole

- (3) Kennametal has proposed a special deep hole drilling system as shown in Fig. 2.19, which can be characterised by the pilot drill placed at the centre of the drill. The tool is of insert type, available for the work made of steel, stainless steel, cast iron or non-ferrous metal, and capable of drilling up to 10 times of drill diameter. Of special interest, Mapal supplies the special boring tool for machining the motorcar component made of Al-alloy such as cylinder head, cylinder block, transmission box and so on as shown also in Fig. 2.19. In this case, we can see also the improvement in machining accuracy by providing the pad as compared with that in the past. In addition, it is worth suggesting that the drill and boring tool for stepped hole are now very popular in the cutting tool sphere.

As a matter of course, we must pay special attention to the usability of these gang and combination tools especially from the viewpoint of the machining volume. Equally, we must be aware of the amazing advance in tool technology, and often some novel contrivances render the design technology for machining system and process planning so far generalised useless.

As will be clear from the above, we can expect the potentiality of the *user-oriented platform* available for the machining function-integrated kind in not distant future, and on that occasion, there may be three choosing ways for the machine tool to carry out the machining requirements.

- (1) Placing stress on primary form-generating function
- (2) Placing stress on auxiliary form-generating function
- (3) Synergy of primary and auxiliary form-generating functions.

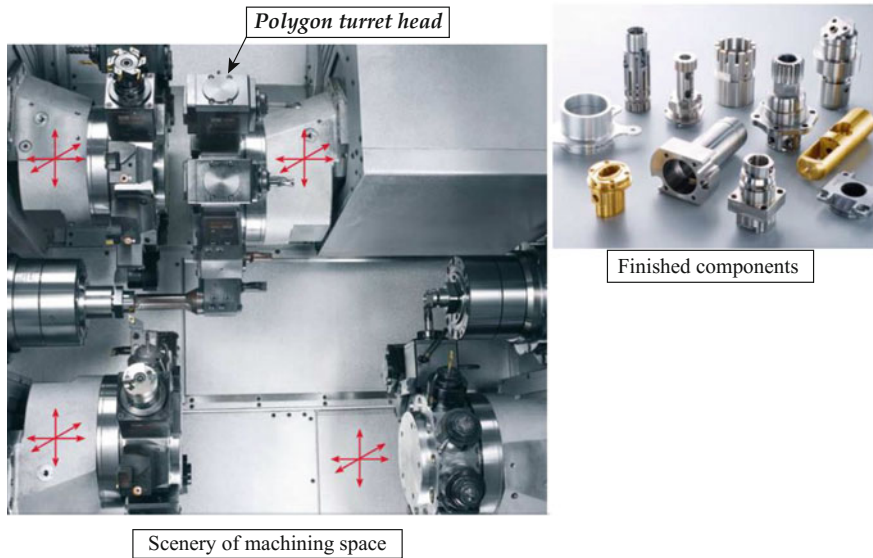


Fig. 2.20 Machining space of Mill-Turn consisting of three same turret heads (Type TNX65/42, by courtesy of Traub 2009)

Within the choice of machine tool context, furthermore, we must pay special attention to the economic problem. For example, Fig. 2.20 reproduces the layout of the turret head in the machining space of “*Mill-Turn*”, i.e., allocation of the same three turret heads with built-in-rotary tool function. It is worth suggesting that Traub, one of the leading German machine tool manufacturers, asserts the large economic benefits by responding much more requirements of the user, although not facilitating the costly tilting head. In this context, we must recall the necessity of establishing an economic evaluation for the modular design. From the past, we have endeavoured it; however, up to now, there are no reliable and quantitative evaluation methods as yet, although Kersten et al. (2009) reported a trial.

2.3 Trial to Establish Choosing Guide for Kind of Machine Tool and Machining Method

As already shown in Fig. 2.2, the facing problem may be called the “*Choice Problem of Rational Processing Methods*” and is closely concerned with process planning. It is however regrettable that there are no effective and convenient guidelines widely acceptable for such a choice as yet. This can be attributed to the difficulty in decision-making in full consideration of the technological, economic

and social prerequisites related to each machining requirement. In addition, we have a myriad of machining methods possible, once the part drawing is released.

In contrast, there are growing demands and importance for such a choice methodology or technology in accordance with the enhancement of the component quality with keen price. In fact, a root cause of difficulties lies in the determination of *one-to-one relationship* between the part drawing and process plan. More specifically, we must convert the geometrical information on the part drawing into the machining-related information, i.e., information conversion into differing properties. For example the *cylindrical profile (geometrical information)* is to be in reality by various *turn tops (machining information)* as already suggested in Figs. 1.6 and 1.7.

As will be clear from such difficulties in information conversion, we cannot guarantee the one-to-one relation, and thus the process design engineer determines, in general, process planning on the basis of her or his long-standing experiences and also with the trial-and-error method. As can be easily imagined, there have been no generalised and objectified guidelines for choosing the utmost suitable machining method when a part drawing is given.

In process planning, this is thus called “*One-to-one Paring Problem*” between the part drawing and machining methods available, and to give a clue for solving such a crucial problem, a trial will be discussed in the following.

In short, an idea is to use the machining symbol, which is, in general, enacted by the National Standards, e.g., JIS B0122 (Symbols of Metal Working Processes), and by which the process plan can be described. It is furthermore convenient that the machining symbol can be converted into the combination of several alphabetical letters in the order of the predetermined rule, i.e., machining function description, as similar as the functional description of the machine tool.

Admitting that we have still some uncertainties in the conversion, it is possible to estimate some pairs among the kinds of the machine tool and machining methods, by which the finished component can be produced correctly according to the part drawing.

Figure 2.21 shows a challenging trial to correlate the kind of the machine tool and the work to be machined. In the top middle and bottom of Fig. 2.21, the sample work and its process plan are shown, and furthermore, the machining symbols described in the process plan can be converted into the machining function description as shown in the top right of Fig. 2.21. In short, the movement of “ $C/(X + Z) +/C_a(X + Z)$ ” is necessary to finish the sample work, whereas TC can move “ $C/(X + Z) +/(A_a + C_a)(X + Z)$ ” as can be estimated from the top left of Fig. 2.21. As compared the machining function description with the functional description of TC, we can judge that TC is capable of machining the sample work.

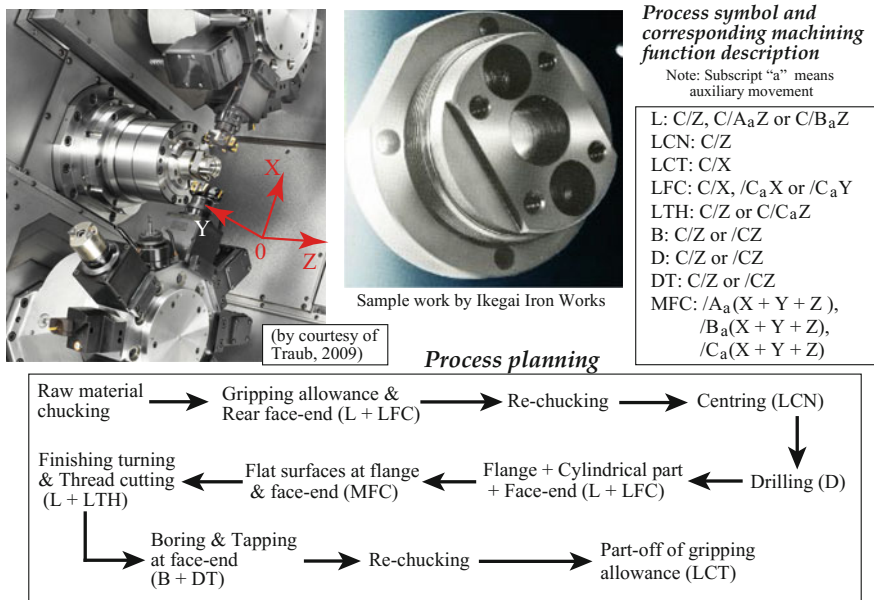


Fig. 2.21 Sample work with its process planning and conversion of “Process Symbol” into “Machining Method Description”

2.4 Linkage Diagramme of Structural Configuration Entities

As can be readily seen, the *flow of force* and functional description can be considered the powerful tools in the choice of the suitable pair of the machining method and machine kind, and also in the improvement for the machining technology hereafter. It is however suggested that the *flow of force* does not contain satisfactory information for evaluating the synergy effect of an innovative contrivance on the machining technology, which is obtainable by integrating the functionality and performance of the structural configuration entities and concern.

For example, Fig. 2.22 shows first rear face parting-off, and Fig. 2.23 shows furthermore complex turning, i.e., integration of reverse-feed turn top, grooving and parting-off. In fact, such the turning methods were impossible in the past, and we needed re-chucking of the work. In contrast, a combination of TC of twin-spindle type and the novel cutting tool can facilitate these turning methods without re-chucking the work at present. It emphasises that TC of twin-spindle changes the machining scenery by its hand-off function to large and various contexts.

It is thus necessary to detail the “Vertex” in the *flow of force* by giving the properties, i.e., identities of corresponding entity. Of special interest, we can thus propose a concept shown in Fig. 2.24, which is called “Linkage Diagramme for

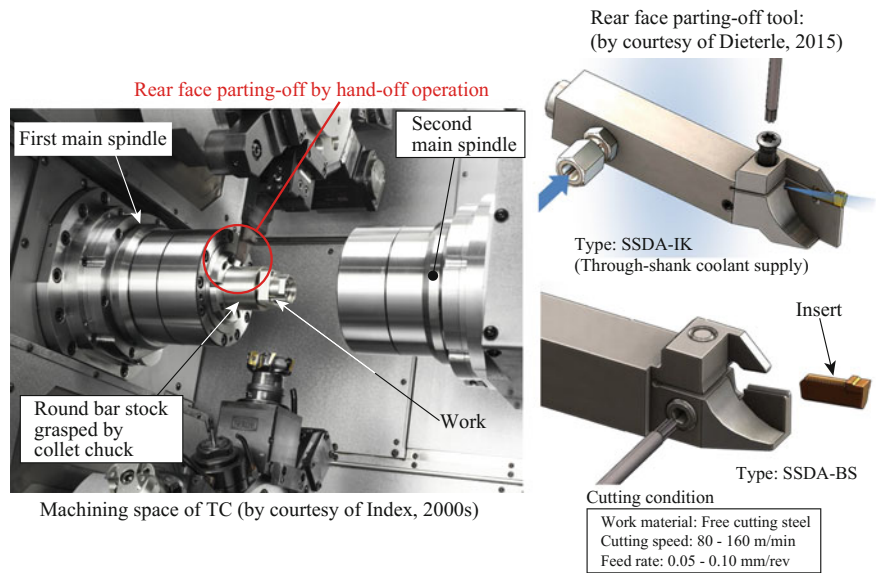


Fig. 2.22 Innovative turning by combination of twin-spindle and new cutting tool—rear face parting-off

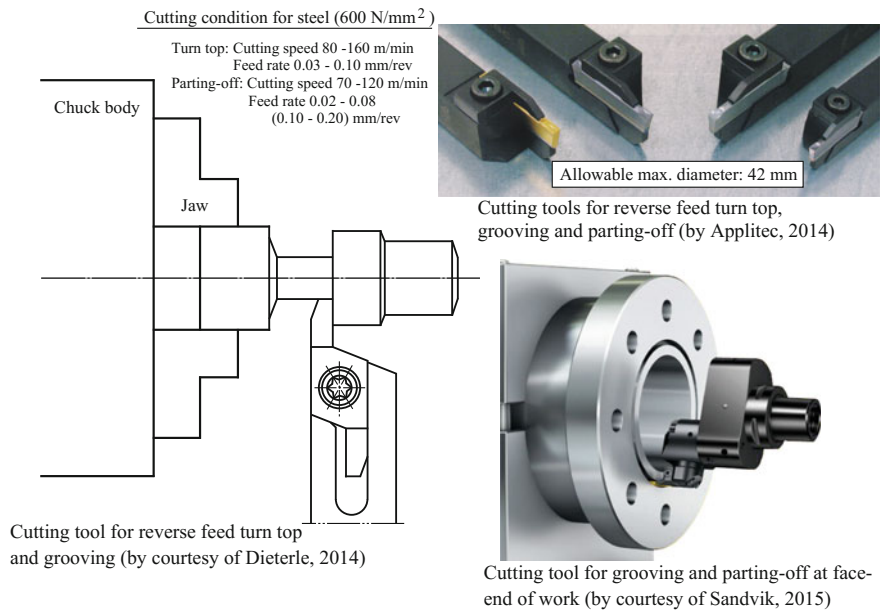


Fig. 2.23 New horizon in process planning by innovative cutting tools

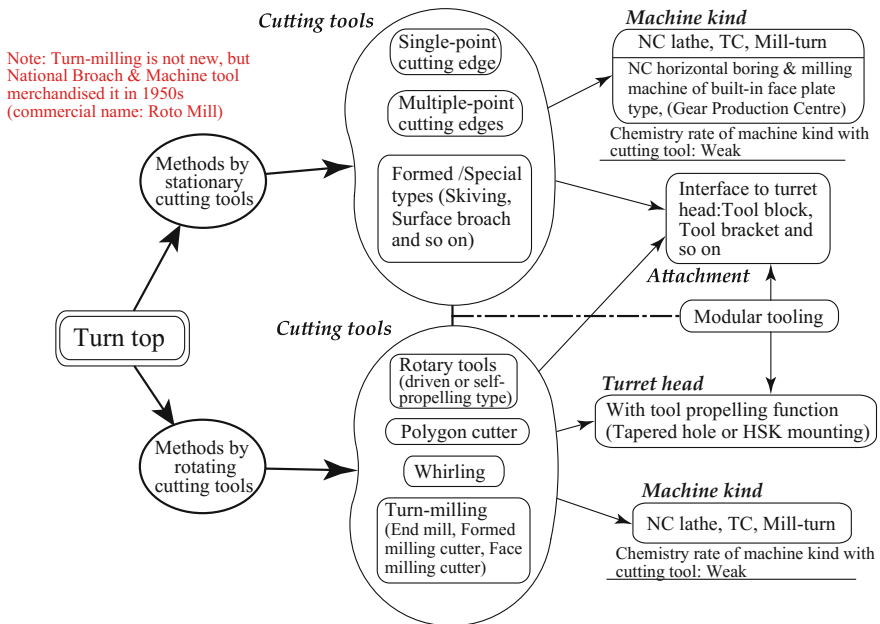


Fig. 2.24 Linkage diagramme ranging from machining method to structural configuration entities—turn top

Structural Configuration Entities and Concerns”. In the case of Fig. 2.24, we can grasp at glance the preferable linkage ranging from the machining method, through the cutting tools, to the structural configuration entities. Finally, we can choose a suitable combination among the related entities, i.e., not optimum, but preferable machining scenery. At present, there is something to be seen for such a concept; however, in addition to turn top, Figs. 2.25 and 2.26 show such linkage diagrammes for drilling and grinding. In Fig. 2.25, the automatic back spotfacer of Hahn and Kolb-brand is for spotfacing, counterboring, deburring and chamfering.

Importantly, we can see the apparent difference in the linkage diagrammes between the turn top and the cylindrical or surface grinding. In fact, grinding shows the simple diagramme due to the simplicity in grinding tools. More importantly, we can see the chemistry rate between the kind of available machine tools and the machining method from the linkage diagramme. In general, the chemistry rate is not so strong apart from the special machining method like gun (deep hole) drilling as shown in Fig. 2.27.

Of special interest, it appears that such the “Linkage Diagramme” increases its importance duly with the prevalence of the machining function-integrated kind of various types. Apparently, we face much more difficulty in the choice of the suitable combination between the machine method and the machine kind with the

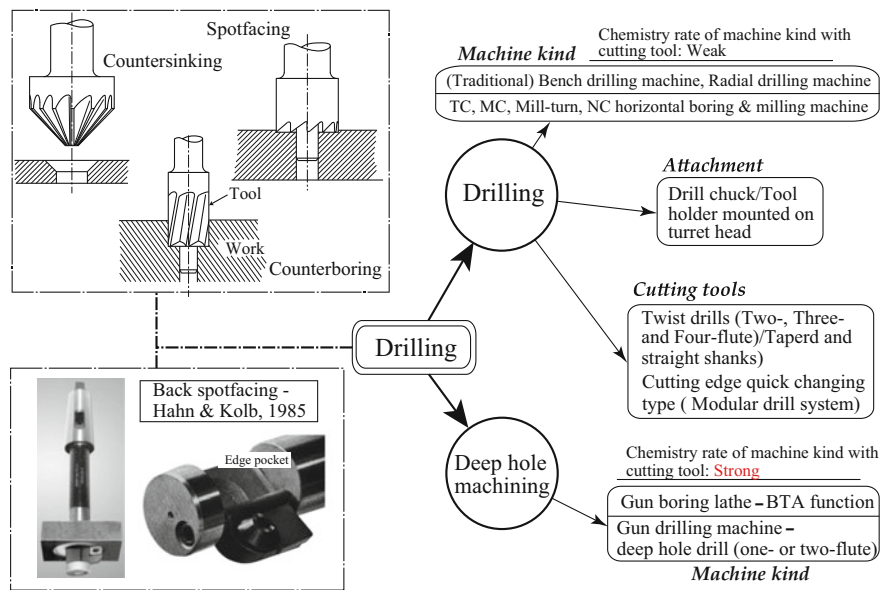


Fig. 2.25 Linkage diagramme ranging from machining method to structural configuration entities—drilling

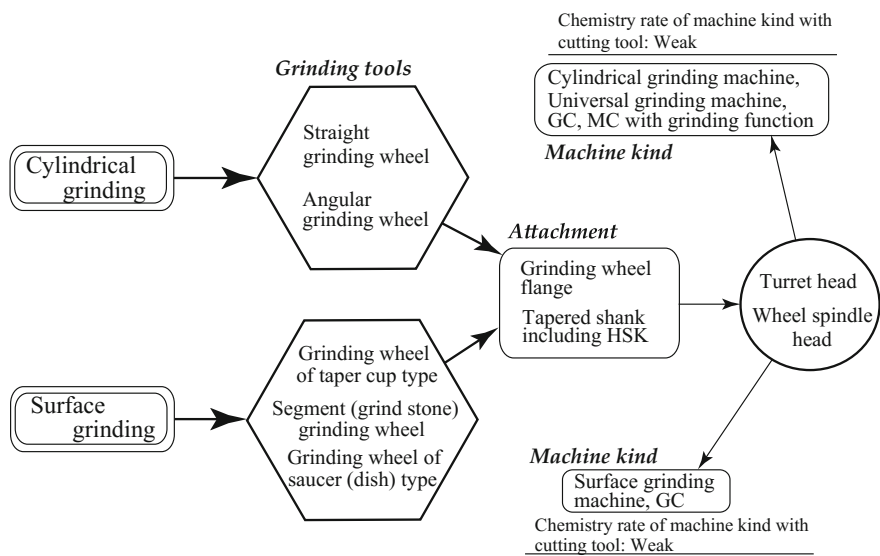


Fig. 2.26 Linkage diagramme ranging from machining method to structural configuration entities—grinding

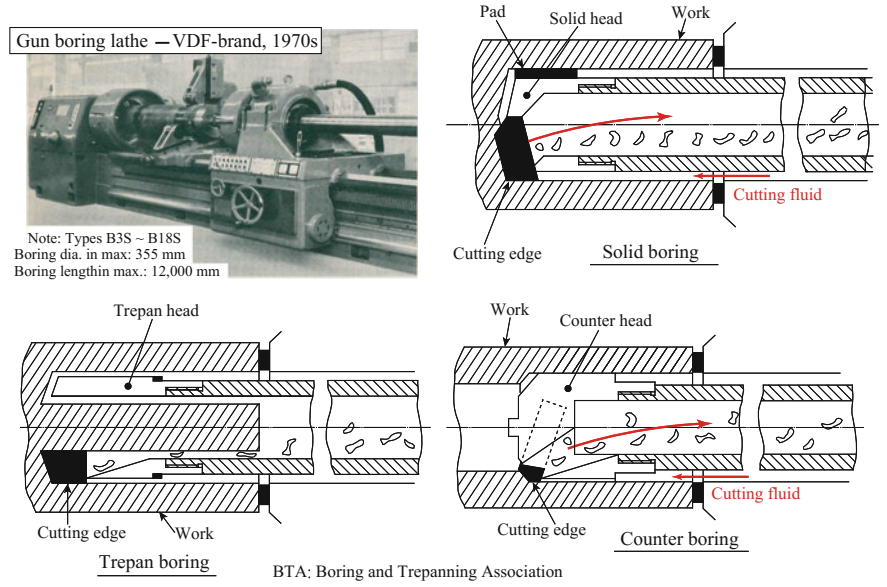


Fig. 2.27 Deep hole drilling and boring of BTA type by gun boring lathe

increase of the machining function-integrated kind, a classification of which is, for further reference, shown in Fig. 2.28. Importantly, we must eye the possible direction in near future of the machining function-integrated kind to the “One-machine Factory” as will be discussed in Chap. 7 (see Fig. 7.13).

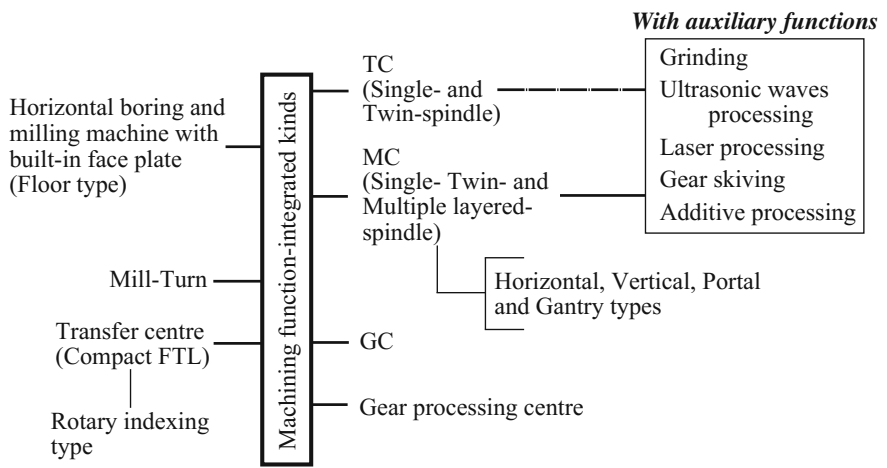


Fig. 2.28 A classification of machining function-integrated kinds in 2010s

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