Applicability of “Platform Concept” to machining function-integrated machine tools
- A new “Raison d’être” for modular design -

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Abstract
The current modular design has been established on the basis of engineering knowledge and concerns for the traditional machine tool, which has the limited machining function. With the growing importance of the machining function-integrated machine tool, we need to establish a new “Raison d’être” of the modular design, and a symptom is the “Platform Concept”. This paper reviews first the present perspective for the “Platform Concept” after quickly noting the modular design at present. The paper conceptualizes then a “Platform-based Unit Construction”, i.e., a variant of the new modular design, discusses its leading applications possible, and suggests a handful of research and engineering development subjects to establish it.

Key words: Modular design, Hierarchical structure, Platform concept, Machining-function integration, Machine tools

1. Introduction
The modular design is one of the leading methodologies and skills for the engineering design in machine tools since 1930s, although changing its term to be compatible with the engineering environments on each occasion. In fact, we used to call it by the term, “Unit Construction” between 1930s and 1950s, “BBS (Building Block System)” between 1950s and late 1960s, and “Modular Design” since 1970s (Ito, 2008a).

On the strength of our long-standing academic researches and engineering experiences, we can establish a rational system for the modular design at present, i.e., “Different Kind-Generating Modular Design of Hierarchical Type”, and benefit considerably from it. Importantly, in accordance with the user’s myriad requirements, the machine tool manufacturer must produce the product with various functionalities, and also performance and dimensional specifications’ by using the modular design. It is however worth suggesting that the modular design at present is on the basis of engineering knowledge and concerns for the traditional machine tool, i.e., those obtained from the machine tool with limited machining function, to a large extent (Ito, 2008b).

With the advent of (multiple) machining function-integrated kinds, e.g., “Mill-Turn”, which is a synergy of TC (Turning Center) and MC (Machining Center), the machining sceneries change considerably beyond our expectation. In fact, we can observe a handful of contrivances and remedies in the machining technology to be compatible with such new sceneries. Of these, an important symptom is the ongoing prevalence of the “Platform Concept” in the modular design. The concept is not new, but already proposed in the early 1990s; however, with the growing importance of the machining function-integrated kinds, the “Platform Concept” is going to play a leading role in the design of their structural configurations. Paraphrasing, we may consider it a new “Raison d’être” for the modular design. Intuitively, the “Platform Concept” is for the machining space-oriented modular design, and thus has certain potentialities to enhance the beneficial aspects of the modular design in new spheres.

This review paper first quickly notes the first-hand view of the modular design at present, and then a
“Platform-based Unit Construction” is conceptualized by investigating some forerunning trials. In addition, the review paper describes the applicability of such the concept to the machining function-integrated kinds, and also to the kinds for remanufacturing and localized globalization era. Importantly, the paper suggests furthermore some core research and engineering developments subjects to establish the “Platform-based Unit Construction”.

2. First-hand view of whole concept for modular design at present

Figure 1 shows a whole concept of the “Different Kind-Generating Modular Design of Hierarchical Type”. This concept has been established on the basis of two outstanding achievements (Brankamp and Herrmann, 1969, Koenigsberger, 1974). Importantly, Ikegai Iron Works initiated a novel application of similar concept beforehand to the production of a group of the large-sized machine tools, e.g., planomiller, vertical turning and boring machine, and bed guideway grinder in 1962. Following it, VEB of Karl-Marx-Stadt in East Germany was also the same concept to be in reality by producing, for example the planomiller, boring machine, and bed guideway grinder in 1976.

As can be readily seen, we can deploy various modular design, depending upon to which layer the basic module belongs, e.g., either unit or unit complex layer, and also to what extent the modular design should be ranged, e.g., either within the same kind or within the same type.

![Fig. 1 A whole concept of modular design - Different-kind generating type with hierarchical structure](image)

In consideration of the technological difficulties, economization, practical applicability and so on, reportedly, the modular design of unit type has been and is being prevailed, and accordingly, such the unit construction can be defined as follows.

“Once a group of basic units can be determined, we can produce a considerable number of variants, which have multifarious functional, performance and dimensional specifications’, by combining these units in accordance with user’s requirements”.

Eventually, we need to have certain design guides to create the variant on the strength of this definition. In this context, Doi of Toyoda Iron Works is credited to the first proposer of “Four Principles for Modular Design” in the 1960s, i.e., Principles of Separation, Unification, Connection and Adaptation (Doi, 1963). Having in mind the importance of the proposal of Doi, Ito modernized and detailed the contents of each principle in his proposal together with discussing the state-of-arts around 2005 (Ito, 2008b).

In short, the “Principles of Connection and Adaptation” have been sublimated to the corresponding engineering spheres, i.e., “Machine Tool Joint Problems” and “Machine Tool Description”, respectively, to some extent. In
contrast, “Principles of Separation and Unification” are not established in the form of some design methodologies and engineering guides as yet. Importantly, at burning issue is to seek a clue for remedies with special respect to “Principle of Unification”. More specifically, the “Principle of Unification” can facilitate to determine and form a group of basic modules, which is an essential prerequisite in conducting the modular design in practice.

In the meanwhile, “Four Principles for Modular Design” can be regarded as the implicit design flow of the modular design, which is even in 2013 at issue. For example, Schuh et al of TH (Technische Hochschule; Technical University) Aachen has investigated such a design flow within a BMBF (German Federal Ministry of Education and Research) Project, and it consists of the following four phases (Schuh, et al., 2013).

1st phase: Identification of attributes, which can clarify the application range of the modular design to differentiate the product from those made by the competitors, and also which give rise to the product simplicity.

2nd phase: Possibility of module standardization and clarification of characteristic features of product to be created.

3rd phase: Creation of much more suitable structural configurations with a less number of modules.

4th phase: Embodiment design for structural configuration together with the formation of organizational structure for management.

Although Schuh et al consider the incorporation of SCM (Supply Chain Management), OEM (Original Equipment Manufacturer) and manufacturing in subsidiaries, in principle, their proposal appears not to be new, but warmed-up as compared with that of Doi.

Of note, FMS (Flexible Manufacturing Systems) of modular type is at present the leading manufacturing facilities in the industrial nation, in which FMC (Flexible Manufacturing Cell) is the basic module, and thus it is called “FMC-integrated FMS”. Reportedly, the FMC itself is also the leading machining facility for SME (Small- and Medium-sized Enterprise). Importantly, the manufacturing facilities in both the large-sized enterprise and SME should have three core functions, i.e., “Flexibility”, “Expandability” and “Redundancy”, and as a matter of course, these functions can be facilitated by the modular design. For further understanding, Fig. 2 shows a system layout of large-sized FMC, and as can be seen, the system has these functions duly. Obviously, in the first stage, FMC No.1 is installed and with the increase of order for machining, FMCs Nos. 2 and 3 will be in turn installed.

![Fig. 2 Large-sized FMC of Cincinnati Milacron-make in the 1990s](image)

### 3. Some practical applications of “Platform Concept”

Admitting that the “Different Kind-Generating Modular Design of Hierarchical Type” has been established to
some extent, we must be aware that the “Platform Concept” becomes to prevail with growing importance of the machining function-integrated kind. In retrospect, Gleason Pfauter Hurth conducted a forerunning application of the platform concept to the production of a series of hobbing machine, gear shaping machine and gear grinding machine in the early 1990s (Metternich and Würsching, 2000). After then, the platform concept was applied to the “Mill-Turn” and MC as shown in Figs. 3 and 4. In the former case, the “Platform” is of monolithic structure by integrating the base, bed, and so on, and some variants can be produced by assembling the headstock, turret head and milling head of tilting spindle type, and if necessary the feed unit, with the platform in accordance with the user’s requirements.

To understand in detail, Fig. 4 shows an application of “Platform Concept” to MC of Grob-make (Dreer, 2008). Importantly, there are three leading variants in accordance with different dimensional specifications, and each leading variant consists of a platform, which is of integration of the base and column and of steel welded structure, spindle head (single- or twin-spindle with two different tapered holes; either HSK-A63 or HSK-A100), and table (single- or twin-type). In addition, the spindle is of modular design, where the speed range is between 6,000 and 18,000 rev/min, and maximum allowable torque is between 34 and 1,270 Nm. The machine is of quinaxial NC control and for 5-face machining, especially aiming at the automobile component machining. More importantly, the machine can be characterized by its form-generating movement, i.e., movement of spindle head being X- and Z-axes, whereas table of bridge type being Y-axis, respectively, where the table travels within the column of two-pillar type.

It is very interesting that Kellenberger has applied the platform concept to the cylindrical grinding machine in 2013 as shown in Fig. 5. As can be readily seen, we can produce both the universal and production types by assembling the grinding wheel headstock, work spindle headstock, tailstock and table with the platform. It is worth suggesting that the grinding machine manufacturer has not employed so far the modular design apart from that of Schaudt in 1965. This is because the grinding machine is for work finishing, and thus there are, in general, no necessities to employ the modular design. In addition, Mitsui Seiki and Wera have recently applied the platform concept to produce the vertical thread grinding machine and gear cutting machine, respectively.

Reportedly, there is another machining function-integrated kind, i.e., “Compact FTL (Flexible Transfer Line)”, which is applicable to the batch-like production in the automobile industry. The compact FTL is one of the variants of FMC-integrated FMS, and as literally shown, of machine-like structural configuration such as a rotary indexing machine. In fact, the compact FTL can be classified into three types, i.e., MC-integrated type, advanced head changer (Commercial name: Transfer Center), and rotary indexing machine. Of these, we can suggest that in MC-integrated type of Icon-make in 2011, the main structural body can be regarded as the platform, and the machining space consists of a group of machining units with quick changing function as shown in Fig. 6. More specifically, the machining space
can allow to place up to 8 three-axis controlled machining units. Thus, the machine appears as to be a “Way Machine”.

From these forerunning trials mentioned above, it may be concluded that the platform concept has been employed extremely aiming at the design rationalization for machining function-integrated kind and also by emphasizing the “Modular Design in Machining Space”. Paraphrasing, we can expect that the machining function-integrated kind may render the modular design useless, because of its much wider flexibility in the machining method than ever before. It is however very interesting that we need the platform concept even in such a kind to meet neatly the user’s requirements. More specifically, the user does not like to purchase the expensive machine with over-specifications, which results in the redundancy in functionality and performance.

4. Concept of “Platform-based Unit Construction” – A new “Raison d’être”

On the basis of the forerunning trials mentioned above, proposed herein is a whole concept of “Platform-based Unit Construction” as shown in Fig. 7, which is especially available for machining function-integrating kinds ranging from TC and MC including that with grinding function, through GC (Grinding Center) and Gear Processing Center, to “Mill-turn”. Importantly, this concept can be characterized by the obvious separation between the platform and a group of structural (body) units for form-generating movement. In fact, the feed unit can facilitate the intermediation between the platform and the structural unit by regulating the number of feed axes as like as the adapter in TL (Transfer Line). In due course, the feed unit might be driven by the double-pinion mechanism to ease the adaptation of the structural unit rather than the ball screw.

As can be readily seen, the “Platform-based Unit Construction” may be regarded as “Different-kind Generating Type of Unit and Unit Complex Layers” in Fig. 1., and in retrospect, such a modular design was once investigated, provided that the structural body components allocated around the machining space can vary, while other components maintain their fixation states (Shinno and Ito, 1987). As a matter of course, the definition of the “Traditional Unit Construction” already stated elsewhere is available for this new unit construction, provided that we allow the settlement of the large-sized module, i.e., “Platform” within the concept. Of special note, an advanced “Platform-based Unit Construction” has already been conceptualized as shown in Fig. 8 (Abele and Wörn, 2004). In their proposal, the module for form-generating function is first defined by the combination of the “Work Fixing Phase” and “Movement Function Phase”, after classifying broadly the work into the rotational and box-like shapes. Then, they consider the “Technology Phase Module” and “Tool Layout Phase Module” as same as those in the
traditional modular design. In short, Abele and Wörn determine first the form-generating movement module and then
detail such a functional module to the corresponding structural modules.

Fig. 7 Concept of “Platform-based Unit Construction” – A group of structural units forming basic machining space

Fig. 8 Reconfigurable phases in machine tool structure and details of each phase (by Abele and Wörn)

Obviously, that of Abele and Wörn is noteworthy in some extent; however, in paving a way to its fruition, a root
cause of difficulties lies in the absolute conversion procedure from the functional module to the structural module, i.e.,
“One-to-one Conversion Problem”. Substantially, one functional module can be converted, at least, a handful of
structural modules as already obviously suggested elsewhere; however, they did not discuss anything for this problem.
Reportedly, we have the same problem in CAPP (Computer Aided Process Planning), where the geometrical
information on the drawing should be converted into the manufacturing-related ones. More specifically, a shaft-like
component depicted in the part drawing is to be in reality by various turning method ranging from the turn-top with
single-point cutting tool, through turning with rotary cutting tool, to turn-milling. Conceptually, the former and latter correspond with the functional and structural attributes, respectively.

Now let us discuss potential variants in the “Mill-Turn”, which are capable of producing on the strength of the “Platform-based Unit Construction” together with suggesting the corresponding research and engineering development subjects necessary to carry out for their establishment.

4.1 Variants for practical use – In case of “Mill-Turn”

There is two-pronged way to discuss the potential variants possible to produce from the concept shown in Fig. 7. One is to discuss the structural configuration obtainable from the combination of the conventional structural units as follows.

1. Type I: Combination of “Principal headstock”, “Milling spindle head” and “Turret head”
2. Type II: Combination of “Principal and Auxiliary headstocks” and “Milling spindle head”
3. Type III: Combination of “Principal and Auxiliary headstocks” and “Turret head with rotating tool axes”

The other is to discuss the variation of the structural unit by facilitating it with various functionalities as follows.

Auxiliary headstock (Second headstock)

The auxiliary headstock may be, in certain cases, converted into the tailstock. It is thus preferable to provide it with mechanized barrel driven by electric, pressurized air or oil hydraulic power in addition to the traveling function of the headstock itself. This function may assist the long shaft machining with better accuracy.

Milling spindle head

The milling spindle head at present remains that of universal head in MC, and thus it is preferable to enhance its functionality by enabling the small-sized turret and cassette for work holding to be mounted. In this context, we may recall the special work fixture shown in Fig. 9, and also recommend certain technology transfers from the traditional TL of rotary indexing type, i.e., hanging square turret for work holding as shown in Fig. 10. In addition, we must eye to the attachment manufacturer, e.g., Rückle Group, who provides us with the milling head of quick changing type, e.g., 2-axis simultaneous control milling head of tilting type. Obviously, such milling heads can be mounted to MC and ram
of 5-face processing machine.

Turret head

The turret head can be classified into “Polygon”, “Drum”, “Disk” and “Conical” types. Of these, the polygon type has been prevailed in the “Mill-Turn”; however, it is recommendable to investigate the further advantageous features when employing other types. For example, the conical type can be characterized by its special functionality, by which the rotating cutting tool can direct its axis to either perpendicular or parallel to work axis. In addition, it is worth investigating the effect of the “Twin-turret Head”.

Having in mind that the turret head has certain limitation in the number of the tool seats, furthermore, we must consider the resurrection of tool layout technology of the NC lathe in 1980s, e.g., “Turret Bar with Multiple Turning Head”, which is for drilling, rough turning, facing and chamfering as shown in Fig. 11. Such a turret head-like attachment can benefit to machine the component, which is required of the longitudinal movement with short range by the turret bar, although the tool layout becomes relatively complex. Reportedly, the vertical twin-allocation of the main spindle and turret bar may solve the “Cold turret – Hot spindle Problem”, and thus we may conduct machining with better accuracy.

To this end, it is worth suggesting a percussion effect of the platform-based unit construction on remanufacturing. More specifically, we can produce the “Mill-Turn” with functionality for “Self-innovation in specifications” and with “Asian region-oriented specifications with keen price” by replacing some structural units with “Up-to-date” and “Re-use” ones, respectively. As can be readily seen, we have a considerable number of orders for the retrofitted “Mill-Turn” in Asian region, e.g., Mainland of China and Vietnam, and importantly, the platform-based unit construction is suitable for such purposes. More importantly, such a proposal was already publicized in 1989, i.e., an idea for “Remanufacturing of machine tool” (McMaster, 1989).

4.2 First-hand view for facing research and engineering subjects

We can first suggest that the platform-based unit construction should have the better adaptability with the attachment and tooling of modular type. Although having been no proposals, such a total modular system in the machining space is capable of enriching and enlarging the obtainable benefits. In consideration of such a precondition, we will discuss the leading research and engineering development subjects in the following.

(1) Establishment of configuration generating methodology

Although “Principles of Separation and Unification” become simple, a facing problem is, on the strength of the “Machine Tool Description”, to establish the configuration generating methodology for the variant, which is capable of changing the corresponding unit at user’s factory. In certain cases, the methodology must determine the priority order among design attributes with special respect to the machining method to avoid unnecessary complexity.

(2) Choosing methodology for a preferable structural configuration

In the modular design, a root cause of difficulties lies in the final choice of the preferable configuration from a handful of outputs, although the platform-based unit construction reduces such a burden to some extent.

(3) Preferable structural design for platform

It is vital that the platform is designed and manufactured in consideration of multifarious cutting force vectors (magnitudes and directions of force) and various heat sources and their magnitudes. In principle, we must use positively the “Directional-orientation Effects in Rigidity”, although having considerable difficulty. More specifically, Fig. 12 reproduces the skeleton of an MC of Hermle-make. As can be readily seen, the resultant of cutting force in milling directs to the niche-like recess in the column, and also we may realize the leverage between the force vector and the feed force in the same vertical plane. In addition, the better guiding accuracy of the cross-beam can be facilitated by the three-way linear guide, in which the central way placed very closely to the feed screw regulates the guiding reference.
(4) Availability of simulation technology
Reportedly, the simulated results are often displayed on the product catalog to appeal the high quality of the machine to the user. Without identifying the “Dynamic and Thermal Boundary Conditions”, however, such simulated results are not reliable.

Fig. 12 Characteristic features of structural design in quinaxial-controlled MC (Type B 300, by Courtesy of Hermle)

Fig. 13 An example of function integrated unit in internal grinding machine - Type ICF, Heald-make in 1960s

Fig. 14 “Mill-Turn” with multiple-turret head for economization (by Courtesy of Traub, 2009)
Development of multiple function-integrated unit
To enhance the beneficial aspects of the platform-based unit construction, it is desirable to develop a function-integrated unit. Fig. 13 reproduces a feed unit for the internal grinding machine in the past, and as can be seen, the guideway can be facilitated by the outer surface of the hydraulic cylinder, whereas the piston placed inside of the cylinder provides the feed driving force. Of special interest, the cylinder should be for the reference of the better guiding accuracy, and thus a crucial engineering problem is to suppress the thermal deformation of the cylinder within the allowable magnitude.

For the ease of further understanding, two burning issues in the choosing methodology will be, for example, detailed in the following.

Economic evaluation
The economic evaluation of the modular design has not been investigated yet, although it is vital. Against to the common sense that the Mill-Turn with milling spindle head is superior to other types, Traub asserts the outstanding economization of a Mill-Turn having no milling spindle heads, which can be produced by assembling the platform with the multiple turret heads of the same specifications as shown in Fig. 14. As suggested by this example, we need a rational evaluation method for the economization.

Of note, an idea has been proposed by using the “Costs-by-cause” concept (Kersten et al., 2009). In fact, Kersten et al tried to estimate the direct costs for inventory and quality controls and also indirect costs with special respect to engineering, product variety, delivery time and so on. As can be readily imagined, their idea is far from completion, but very interesting.

Choosing methodology by functional description
At present, there are no reliable and rational methodologies for choosing the preferable configuration from a myriad...
of outputs. An expectable remedy is to use both the functional description for the machine tool (Ito, 2008c) and the process symbol in the process planning. Fig. 15 (a) shows an example of the process planning, and each process symbol can be converted into the necessary form-generating movement, i.e., combination of movement axes. Thus, we can obtain the least combination for movement axes necessary, when giving a group of components to be machined. In fact, in the case of work shown in Fig. 15 (a), we need the form-generating movement, “ C/A1ZX ”. In contrast, if we have now a TC shown also in Fig. 15 (b), its functional description yields to “ (C1Z + C)/(A1ZX + ZX) ”. By comparing these two descriptions, we can conclude that TC shown in Fig. 15 is applicable, because the functional description includes the necessary form-generating movement.

5. Concluding remarks

As will be clear from the above, the “ Platform-based Unit Construction ”, is applicable to the design of machining function-integrated kinds to large and various extents with satisfactory economization, and has higher potentiality to be compatible with the advanced kinds and also with the local region-oriented “ Mill-Turn ” in the year 2010 and beyond.

As exemplified by an Asian region-oriented “ Mill-Turn ”, we must extremely investigate such further possibilities of applying the “ Platform-based Unit Construction ” to those for SME across the whole world. SME cannot afford, in general, to purchase TC and MC with full specifications. SME must however install them with acceptable prices, but not with over-specifications, so as to overcome the fierce competition in the world and domestic markets.

Accidentally, an idea has been already proposed for the modular design, which will be applicable to the machining environments in the localized globalization era (Ito, 2011). In fact, the idea can be, in principle, characterized as follows.

1. “Choice of a Group of Principal Modules”: Primary concerns are “Form-generating Movement” and “Three Leading Principal Design Attributes”, i.e., higher-speed, better-machining accuracy and heavy cutting capability.
2. “Conversion Table” for form-generating functional unit to structural unit: A group of sub-unit complexes should be pre-determined as the principal module. In this case, a crucial problem is to what extent three leading attributes should be integrated.

Of special note, it emphasizes finally that the modular design has explicitly and implicitly considerable repercussions effects on the product design in other industrial spheres. In fact, the automobile industry has belatedly employed the “Platform Concept” as exemplified “Module Carrier” of Matsuda in 2005, and MQB (Modularer Querbaukasten; Modular-like Cross-block” of Volkswagen in the early 2010s. Importantly, we must be aware of the differing benefits obtainable from the modular design, depending upon the product kind. Fig. 16 demonstrates such a differentiation, where the evaluation indices are based on the leading attributes in the use of the modular design. As can be seen, each product uses the modular design by considering satisfactorily its marked features, and intuitively such ex-
experienced knowledge in other industrial product is somewhat useful for the machine tool design.

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