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## **A PROPOSAL OF MODULAR DESIGN FOR LOCALIZED GLOBALIZATION ERA**

In localized globalization era, it appears that the modular design enables something new to be played, and thus at burning issue is the reconsideration of to what extent the modular design is applicable. To delve into a desirable modular design in not distant future, this paper describes first the present perspective including some facing problems and milestones in the developing history of the modular design. Then, the paper shows some applications of the modular design to other industrial spheres, ranging from automobile, through food processing plant, to submarine. On the strength of such awareness and also in consideration of characteristic features of the manufacturing environment in future, proposed is a new concept for modular design, in which primary concerns are two leading attributes, i.e., functionality-related, and also culture- and mindset-related attributes. These two should be duly converted into the quantified design specifications, and we must conduct the “ One-to-One “ conversion from functionality to structural configuration, and also conversion from the uncertain attribute to the quantified factor. Of note, the forerunning research is reviewed.

### **1. INTRODUCTION**

The modular design has been very popular in the structural design of the machine tool since 1930s as exemplified by a report of Koenigsberger in 1974 [1]. In due course, the modular design has been developed and deployed to various extents to respond properly to machining requirements of users so far. As a result, it appears that the modular design is in mature nowadays in machine tool sphere, and we can furthermore see its multifarious applications to other industrial products.

With the advent of the manufacturing environment for localized globalization, the modular design may play some new roles at a new theater, where a new determinant is uncertain design attributes such as culture-and mindset-related ones. More specifically, at burning issue is the applicability of to what extent the modular design, and also the necessity is to unveil what variant in modular design is desirable. In short, we must establish an innovative modular design, by which the products salable across the whole world and also to the local area are to be reality. In the latter case, an original product should be modified in part its functional, performance and dimensional specifications in accordance with the technological, economic and social environment of each local region. In addition,

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the uncertain attributes should be converted into the quantified ones.

At present, we have no proposals and concepts for such a modular design mentioned above; however, aiming at the establishment it, we must first conduct obviously various challenging research activities. Thus, especially for the sake of thought-provoking of young engineers, this paper describes the outline of the modular design at present, and on the basis of such knowledge, delves into the attractive research subjects within the innovative modular design for the manufacturing environment in future 1).

## 2. MODULAR DESIGN IN GENERAL

### 2.1. DEFINITION AND DEVELOPING HISTORY OF MODULAR DESIGN

As widely known, the modular design can be roughly defined as follows.

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

In retrospect, the modular design was first proposed in the machine tool industry in the 1930s, and then advanced leap-frog-like in the 1950s, 1960s and late 1990s. With its Footnote 1: For the detail of the modular design, refer to the book entitled “Modular Design for Machine Tools “ ( Y. ITO, McGraw-Hill, 2008 ).

Amazing advance, some noteworthy concepts and innovative ideas have been made together with changing the term as will be stated in the following. Obviously, such a situation induces certain confusion in not only the term, but also the understanding of the due technology, although the essential feature of the modular design has not been changed. In due course, the modular design has become ramification resulting in the successful establishment of various variants.

#### (1) Modular design from 1930s to 1950s

With respect to the term, we used to call “Unit Construction “. The unit construction was applied to the milling machine and planomiller, and as literally shown, the basic module is that of “Unit “, e.g., headstock, base, and column.

#### (2) Modular design between 1950s and 1960s

We used to call “BBS (Building Block System) “. In this developing stage, the utmost application was, as widely known, TL (Transfer Line) for automobile industry, where the “Station “ was the basic module, consists of the units, such as spindle head, column and base, and can be regarded as an unit complex at present. On the strength of the success story in TL, BBS was applied to the structural design of the conventional machine tool once again. Importantly, TL has been installed some industrial sectors even now as exemplified by that of Vogtland-make, one of sister companies of Hüller Hille.

#### (3) From 1960s to today, the term of “Modular Design “ has become widely acceptable, and the proposal of this term is credited to Koenigsberger in early the 1970s. More specifically, he designed the milling machine by using the unit construction at

Wanderer in the 1930s, and since then conducted the research into the modular design at UMIST (University of Manchester Institute of Science and Technology). On the basis of his long-standing experiences, he proposed the change of the term, from BBS to the modular design.

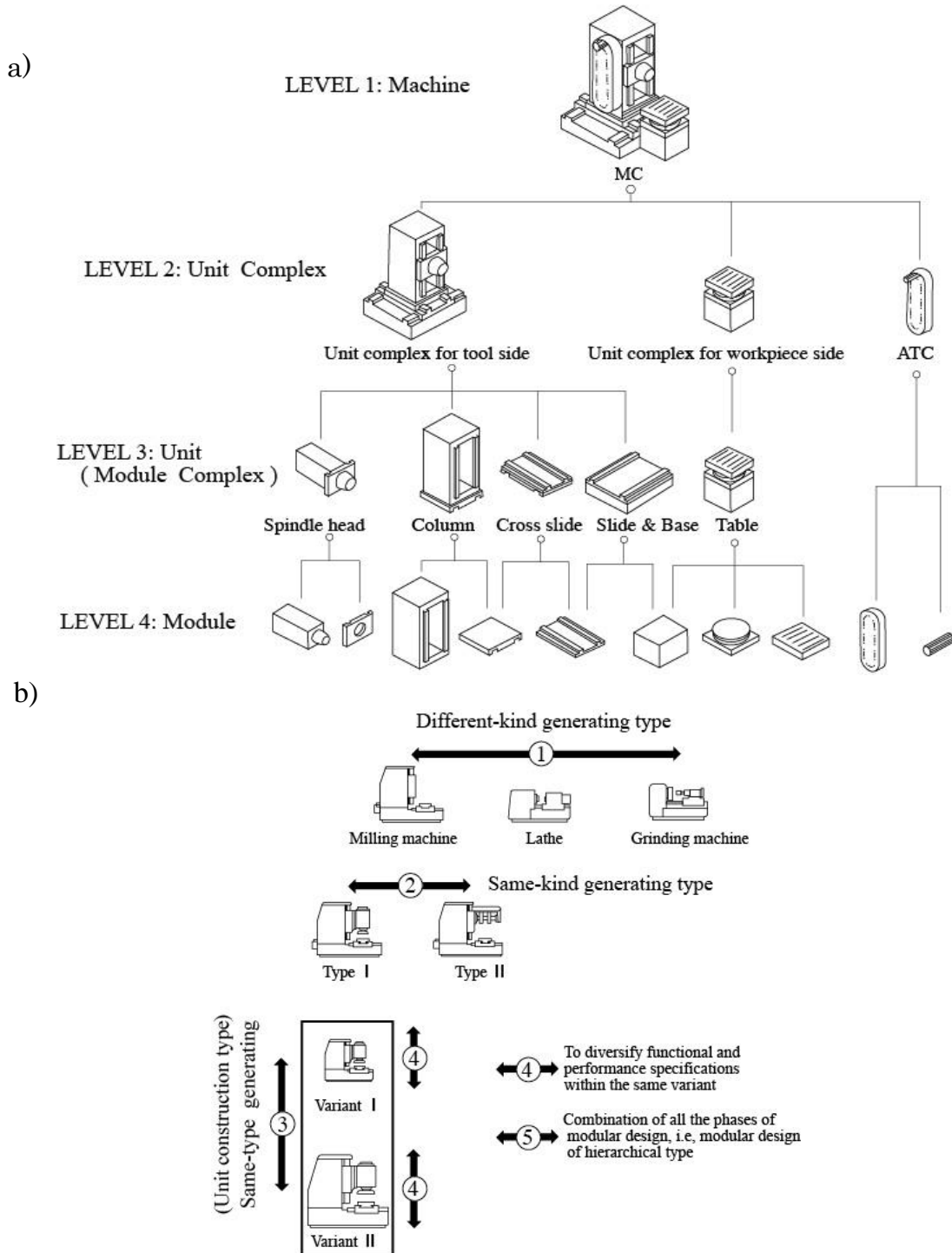


Fig. 1. A whole concept of modular design  
 a). Hierarchical structure in product – in case of MC b). Proposal of Brankamp and Herrmann

As will be clear from those mentioned above, we have had the confusion in terms to some extent, and often we observe the wrong term, such as a “ Reconfigurable Manufacturing Systems “. In fact, this term is not definitely based on the essential features of the modular design. More specifically, the reconfigurable system is that of “ Hierarchical Modular Design System for Different Kinds “ as will be obviously stated later.

While carrying out the leap-frog-like development, we achieved three noteworthy proposals, i.e., (1) “Métier Definition“ of modular design available across the whole industrial products by Brankamp and Herrmann in 1969 [2], (2) concept for “Different-kind. Generating Modular Design “ by Koenigsberger in 1974 [1], although a forerunning practical application was already carried out by Ikegai Iron Works for the large-sized machine tool in the beginning of the 1960s, and (3) modular design considering “ Hierarchical Feature in Product “ by H S Lee in 1986 [3].

On the strength of these achievements and basis of other contrivances and evidences, at present, we can summarize an overall view of the modular design in machine tools as the combination of those shown in Figs. 1 (a) and (b). More specifically, the modular design at present is applicable across the whole kinds of machine tools in full consideration of hierarchical features within a product kind 2). Importantly, we can conceptualize it as the “ Hierarchical Modular Design System for Different Kinds “.

As can be literally shown, this modular concept can facilitate the wider applicability by properly determining a group of basic modules. In fact, a variant of the modular design can be settled depending upon the application area and also from which layer the basic module is chosen. In addition, the concept shown in Fig. 1 has been furthermore deployed to the production system, and thus is applicable to those ranging from the system, through machine tool itself, to cutting tool, jig and fixture.

## 2.2. APPLICATION TO OTHER INDUSTRIAL PRODUCTS

For the sake of ease of understanding, Figs. 2 and 3 show the modular designs in TC (Turning Center) of Traub-make around 2005, and large-sized FMC (Flexible Manufacturing Cell) of Cincinnati Milacron-make for JIT (Just-in-Time) production in the 1990s. It appears that these modular designs are similar to those merchandized in the 1960s and 1970s, although there is a different phase between the traditional and NC machine tools. In fact, that of Traub is basically of “ Unit Construction “ in the past. In the case of FMC, primary concerns have so far been the five system functions to consist of the cell, i.e., machining, transportation, storage, surveillance and maintenance and cell controller, for each of which a group of modules should be pre-determined. As can be readily seen, thus, large-sized FMC shown in Fig. 3 has the following characteristic features.

The basic module is an FMC consisting of the horizontal MC (Machining Center) and  
Footnote 2: In general, the product shows such a hierarchical feature as “ Product – Unit complex – Unit – Functional complex – Part “.  
APC (Automatic Pallet Changer) “, and is duly capable of running with the stand-alone operation mode.

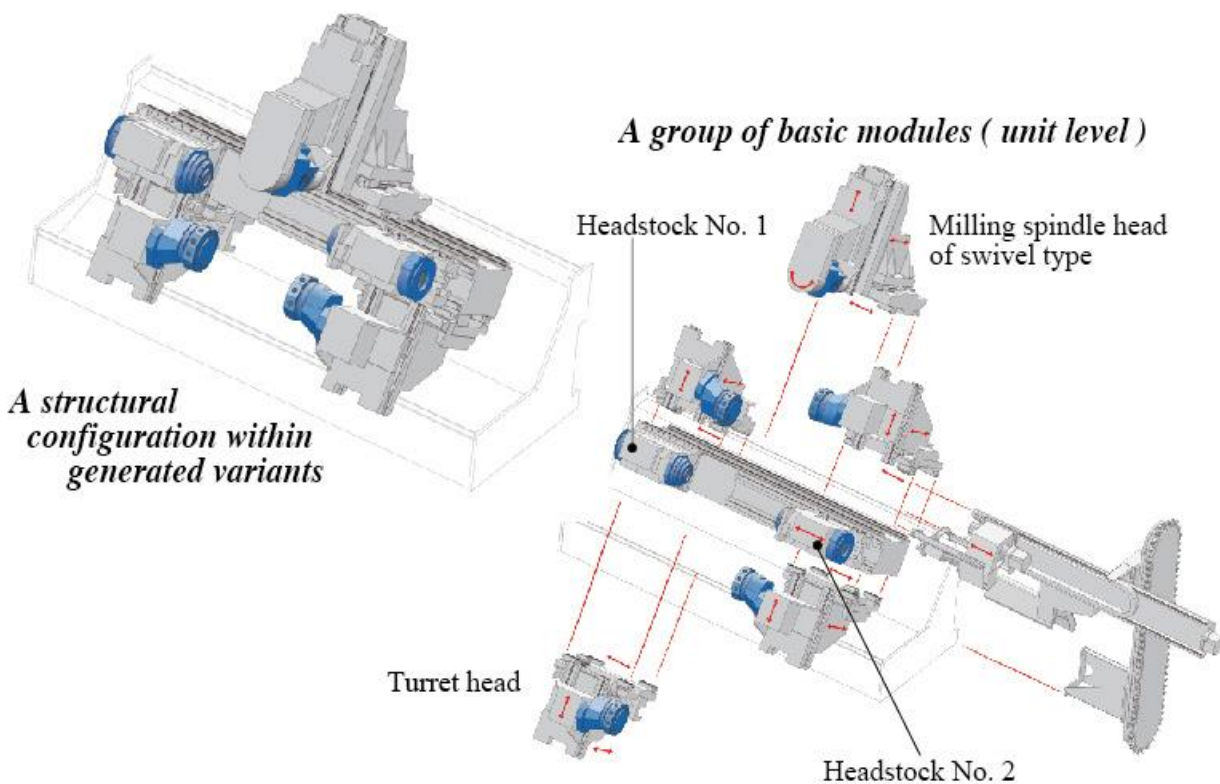


Fig. 2. Modular design in TC ( by courtesy of Traub )

The large-sized FMC can be formed by integrating the required number of such FMCs together with integrating other modules for transportation and storage.

The modules for machining, transportation and storage are of “ Standardized Off-the-Shelf “ type.

Reportedly, people in other industrial sector eyed already the amazing economization effect and technological benefits of the modular design when applying it to TL for automobile industry in the 1960s. In fact, Brankamp and Herrmann stated the modular design for the transportation equipment and construction machine; however, we must wait up to the year 2000 and beyond to observe the vigorous application of the modular design to other industrial products.

Figure 4 reproduces a mind map for demonstrating the characteristic features of modular design in each industrial product. In other words, the modular design should be used in full consideration of its advantageous aspects, which depend upon the product kind and differ from one another. From Fig. 4, we can observe some interesting trends as follows. Notwithstanding the product kinds, the modular design benefits the “ Rationalization of Production Processes “ and “ Ease of Repair “.

There are, for example, considerable differences in expectable factors between the machine tool and the automobile. This may be caused by the technological qualification of user: the former and the latter are for the professional and non-professional people, respectively. Although not showing in Fig. 4, we can enumerate another application cases as follows.

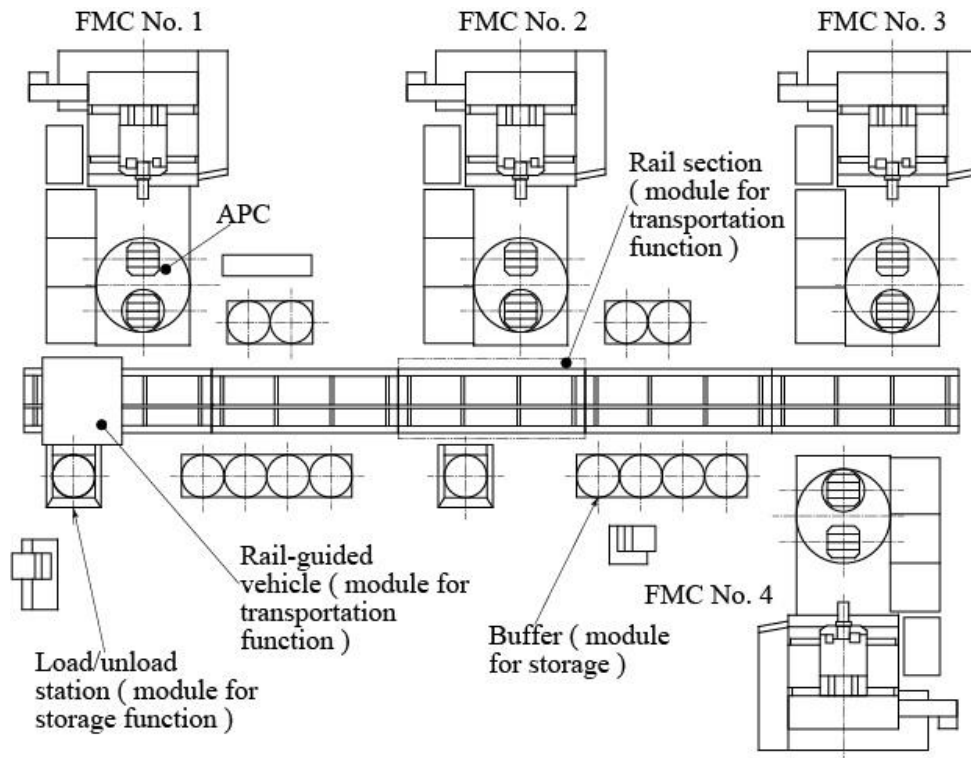


Fig. 3. Large-sized FMC of Cincinnati Milacron-make in 1990s

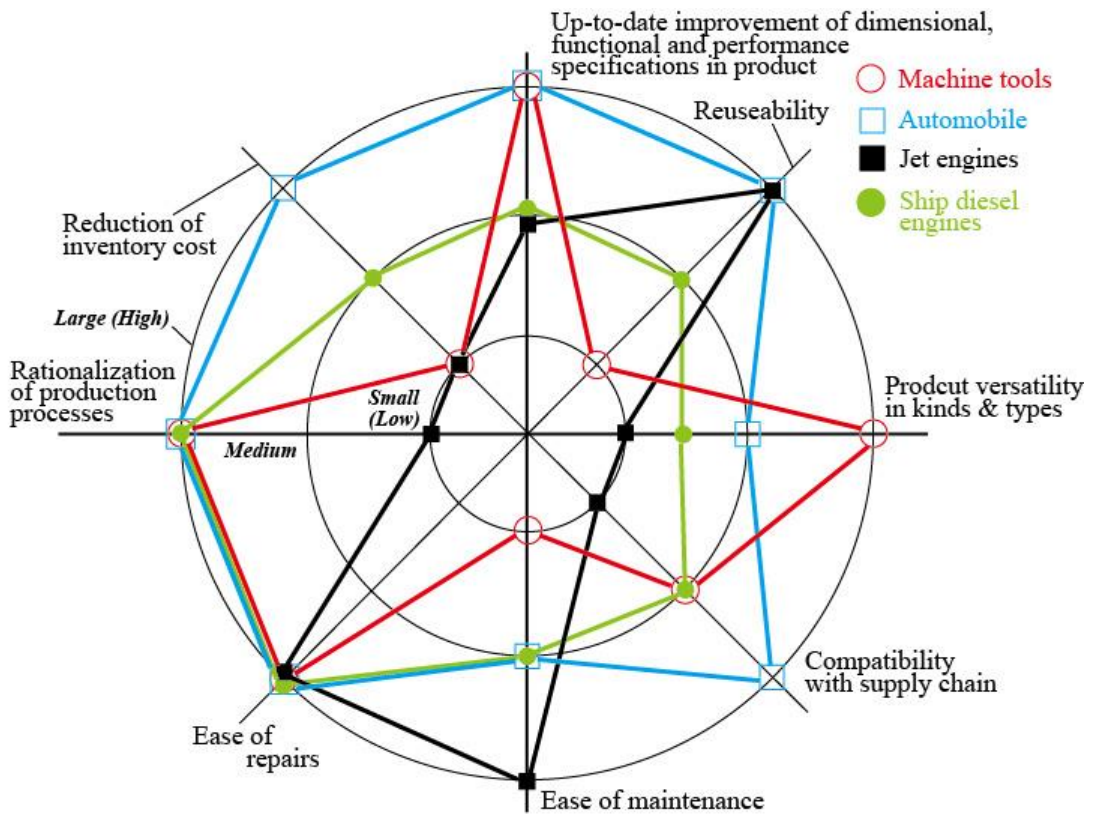


Fig. 4. Different advantages of modular design depending upon product kinds

Van by Volvo in late the 1980s. In this case, FTL (Flexible Transfer Line) for producing the van is of modular concept.

Rollingstock by Siemens in the 2000, which aims at the realization of light-weight and integration of production processes resulting in the reduction of manufacturing time.

Food factory by AMTRI (Advanced Manufacturing Technology Research Institute) in UK [4].

Nuclear attack submarine by Devonshire Dock in 2009 [5], and also the nuclear super-aircraft carrier by Northrop Grumman Newport News in the 1950s. Importantly, the modular design in the aircraft carrier is called “ Superlifts Concept “.

### 3. FOUR PRINCIPLES OF MODULAR DESIGN AND REMAINING PROBLEMS

From the past, present and in very near future perspectives of the modular design, it appear that the modular design is in mature, and that we can use it without any problems. This interpretation is from an aspect correct, but from the other aspect wrong, and for further discussion, it is very convenient to recall the “ Four Principles in Modular Design “. Doi of Toyoda Iron Works proposed the “ Four Principles “, i.e., (1) Principle of Separation, (2) Principle of Unification, (3) Principle of Connection and (4) Principle of Adaptation, in the modular design in 1963, when he conducted the design of TL for Toyota Motorcar [6]. Even up to the year 2000, his proposal is worth praising to a larger extent, because similar proposals are also publicized even in the 2000s.

Of these principles, the corresponding methodology and technology have been established to some extent in the cases of the “ Principle of Connection “ and “ Principle of Adaptation “. In short, the former and latter are those related to the “ Machine Tool Joint Problem “ and “ Machine Tool Description “, respectively. In contrast, we have not theoretical tools when applying the “ Principle of Separation “ and “ Principle of Unification “ to the practice, but we conduct such activities on the basis of our long-standing experiences.

In accordance with the “ Principle of Separation “, a product should be disintegrated into a group of modules with certain dimensional, performance and functional specifications “. In this work, we must take into account user’s requirements, individual difference, penchant and so on to larger and various extents. After having the huge number of modules, we must determine a group of basic modules in full consideration of the product range capable of generating, i.e., a group of variants. This is “ Principle of Unification “, and we must be aware of to what extent variants to be generated. In many respects, the variants should be salable much more and have higher marketability across the whole world. Importantly, the more versatile of pre-determined modules, the more variants are producible. As a result, easier fulfillment of user’s requirements becomes reality; however, the much more number of the pre-determined modules results in the more increase of stock and through-put costs. In addition, we must pay the special attention to the over- and redundant specifications when integrating the modules.

Apparently, it is very difficult to carry out the desirable design, and in principle the

primary concern is the “ Preferable Design “ in generating the variant. More specifically, a group of modules should be determined with preferable leverage among multifarious technological, economic and social attributes, although an attribute conflicts often others. Of these, a new comer in the social attribute is the costumer’s penchant, and it results in the attractive industrial design for enclosure to enhance the marketability. As will be clear from the above, at burning issue in the modular design currently employed is the establishment of a methodology for the “ Principles of Separation and Unification “ like the “ Machine Tool Description “ for the “ Principle of Adaptation “.

Intuitively, the “ Platform Concept “, i.e., large-sized modular concept, may be one of the remedies to establish a due methodology. Fig. 5 reproduces the “ Platform Concept “ proposed by Metternich and Würsching in 2000 [7], and from it we may consider that the issue mentioned above could be solved to some extent. Supposedly, they proposed the “ Platform Concept “ on the basis of the product lineup at Gleason Pfauter Hurth in early the 1990s. More specifically, a group of the large-sized modules can facilitate the production of hobbing machine, gear shaping machine and gear grinding machine. In this context, Matsuda publicized the employment of the modular design for passenger car, and also belatedly proposed the “ Platform Concept “ in 2005. As shown in this example, we must be aware of the importance of collecting the useful information from other industrial sectors. To this end, it is emphasized that the modular design at present is not in mature in certain aspects, and that we can find ramified research subjects to establish the “ Four Principles “ as the design guides. More importantly, the academic research into the modular design follows the practical applications.

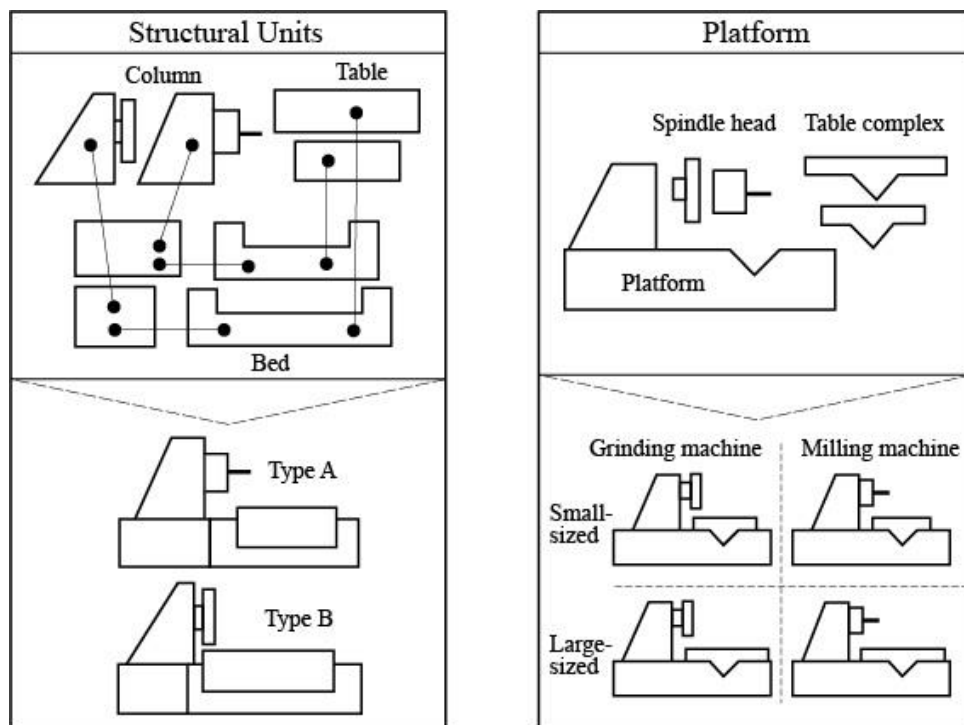


Fig. 5. Concept of “ Platform “ by Metternich and Würsching ( by courtesy of Carl Hanser )



#### 4. MODULAR DESIGN COMPATIBLE WITH LOCALIZED GLOBALIZATION ERA

In the localized globalization era, the basic necessity is to create the product, which is, as already mentioned, salable across the whole world, and also to the local area by modifying in part the design specifications. In due course, such modifications should be neatly responded to the requirement of users in each local region. As can be readily seen, one of the potential solutions for such requirements is to employ a new modular design; however, we cannot find any proposals and thus a concept proposed by author will be discussed in the following.

Within this context, we must first clarify and identify the leading characteristic attributes for the modular design in future, and in due course, can suggest the representative two as follows.

**Functionality-related attributes.** A new modular design must enlarge and enrich its availability so as to respond to the local requirement to a larger extent from various aspects. This can be realized by positively incorporating the functionality-related attributes. In contrast, in the modular design at present, the emphasis is, with narrower scope, placed on the attributes in closer relation to the structural configuration, performance and dimensional specifications. This is because we have much more difficulties in the disintegration of a product and determination of a group of modules by including the functional module.

**Culture and mindset-related attributes.** On the strength of the achievements in the manufacturing culture, a root cause of difficulties lies in how to satisfy the compatibility with local environments when designing the region-oriented machine tool as exemplified by that of Höft and Ito [8]. Reportedly, we must deal with the voltage difference of supply power, qualification level of operator, penchant of operator, and so on in each local region, even when designing the shipping-destination-oriented machine tool, i.e., predecessor of region-oriented one. Importantly, the region-related attributes, e.g., skill qualification and penchant of the operator, have uncertainty and are far from quantitative.

#### 5. MODULAR DESIGN EMPHASIZING FUNCTIONALITY

As can be readily seen, the modular design can facilitate much more flexibility with adding the functional module to the generation of structural configurations possible, whereas we necessitate dealing with much more tedious procedures. Substantially, the modular design with the functional module has two major obstacles as follows, which cause considerable difficulties to become it in practical use.

In general, we can conduct the product design by in-putting the functional attribute and converting it to the structural attributes, i.e., design specifications, and thus the functional attribute is superior to the structural one as can be understand from the manufacturing morphology. More importantly, the property of the functional attribute differs definitely and absolutely from that of structural attribute. There is no “ One-to-one “ relation when converting the functional attribute to the structural one. In fact, we can have a considerable number of the structural configurations with respect to one function.

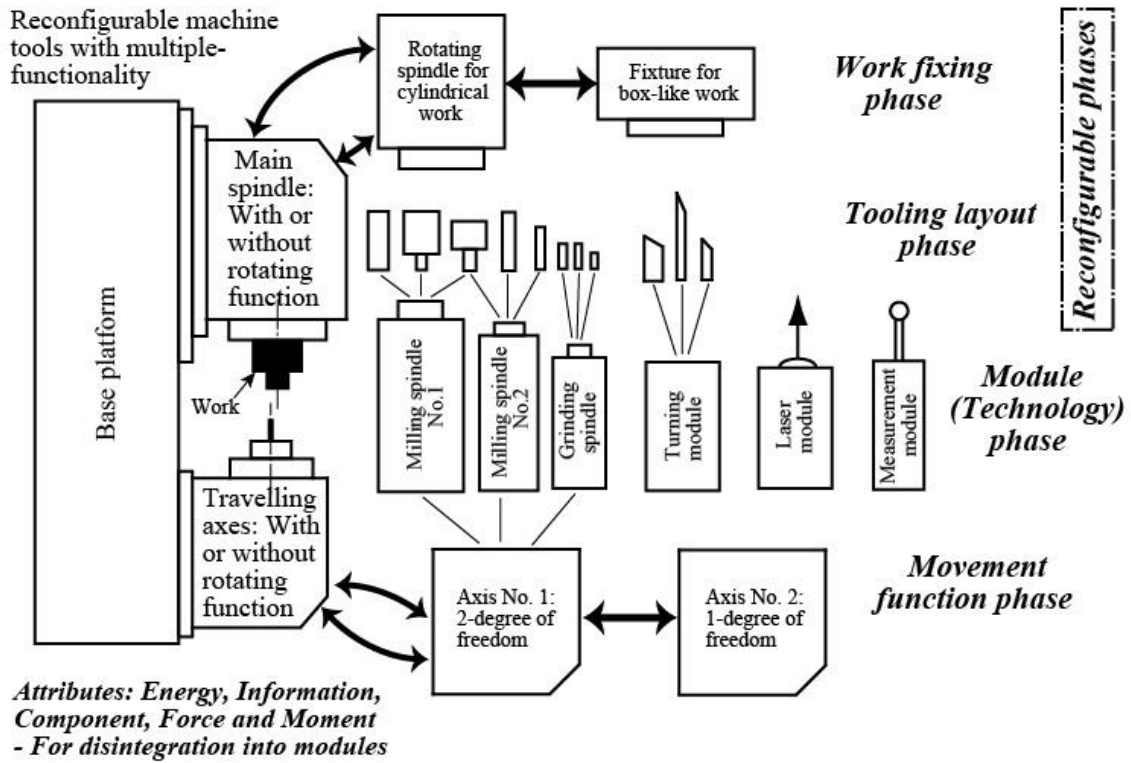


Fig. 6. Reconfigurable phases in machine tool structure and details of each phase ( by Abele and Wörn )

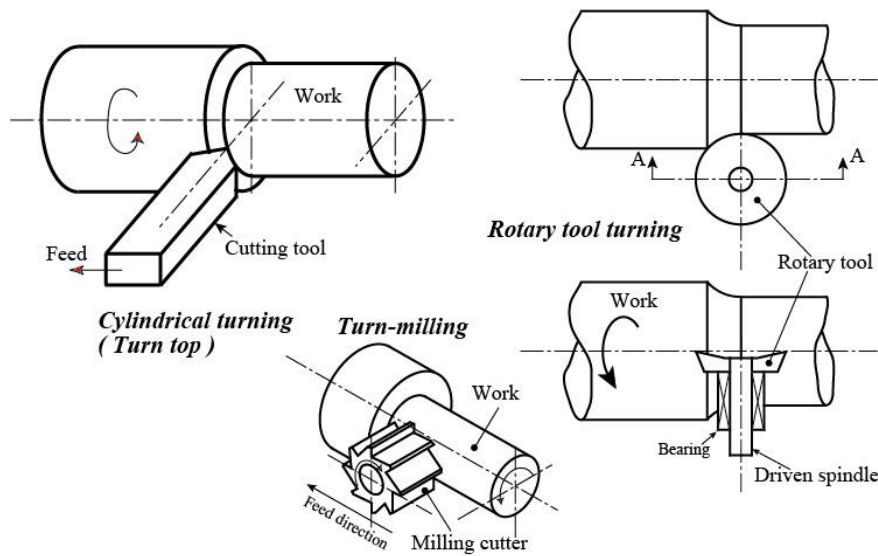


Fig. 7. No obvious “ One-to-one “ relation between geometrical and machining-related information

Typically, Abele and Wörn conceptualized such a modular design as shown in Fig. 6 [9]. In their proposal, the module for form-generating function is first defined by the combination of the “ Work Mounting 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. In addition, it is very interesting that they also employ the idea of “ Platform “.

Obviously, that of Abele and Wörn is worth appraising; however, it is far from fruition. At least, they must challenge to solve the “ One-to-one Problem “ mentioned above. For further convenience, Fig. 7 shows a similar problem in CAPP (Computer Aided Process Planning), where the geometrical information on the drawing should be converted into the manufacturing-related ones. Conceptually, the former and latter correspond with the functional and structural attributes, respectively. Fig. 7 demonstrates three representative machining methods to produce the cylindrical part.

### 5.1. MODULAR DESIGN WITH CULTURE- AND MINDSET-RELATED ATTRIBUTES

Although placing the emphasis on culture- and mindset-related attributes, we must consider simultaneously the leading principal design attributes in the machine tool, i.e., those for higher-speed, better- machining accuracy and heavy cutting capability. As a result, a concept can be proposed as shown in Figs. 8 (a) and (b), in which we furthermore take into account the knowledge obtained from some new proposals to improve the modular design at present.

In the ascending procedures of the proposed concept, the “ Choice of a Group of Principal Modules “ should be carried out. Importantly, primary concerns are “ Form-generating Movement “ and “ Three Leading Principal Design Attributes “, and using the 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 scrutiny of to what extent three leading attributes should be integrated “. Following it, the determinant is the number of NC control axes, and the applicability of the modular design may be regulated whether the number of NC axes is more than 3 or within 3. Typically, the former and latter are for globalization and localization, respectively. More specifically, the sub-unit complex can be formed from both the sub-units, which belong to the work and tool branches. For example, we can produce a sub-unit, which consists of “ Main spindle “, “ Transmission “ and “ Servomotor “. This sub-unit may extend to various variants by functioning the main spindle and servomotor as quick-changing entities, and by fixing the transmission. Obviously, the transmission could become redundant in certain cases.

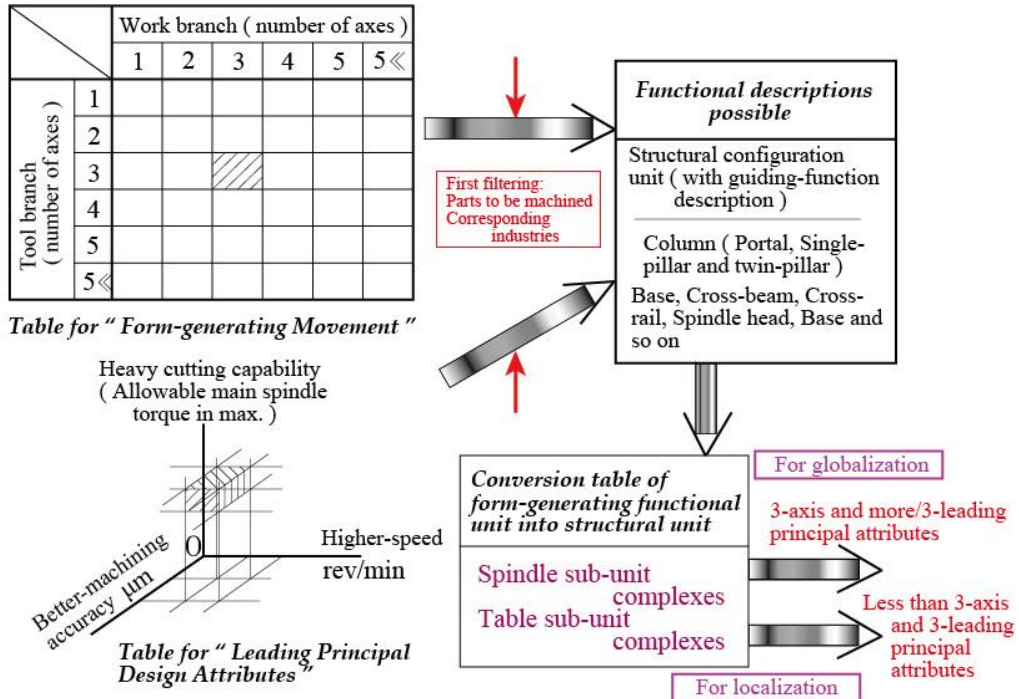
In the descending procedures after bifurcating, we need to filter unnecessary sub-unit complexes depending upon either globalization or localization, so that finally a group of “ Main Spindle-Table Unit Complexes “ can be determined.

Admitting that the concept shown in Fig. 8 has certain realities, as can be readily seen, there are a handful of research subjects as follows.

Together with establishing the conversion method between the functionality and structural configuration, another necessity is to investigate the quantification method of the culture- and mindset-related attribute with considerable uncertainties. Fig. 9 shows such

qualitative conversion processes in the case of shotgun, and Höft once tried to establish such a methodology as reproduced in Fig. 10. The uncertain attribute can be converted stepwise into the quantified one using QFD (Quality Function Deployment) of hierarchical type and radar chart [10].

a)



b)

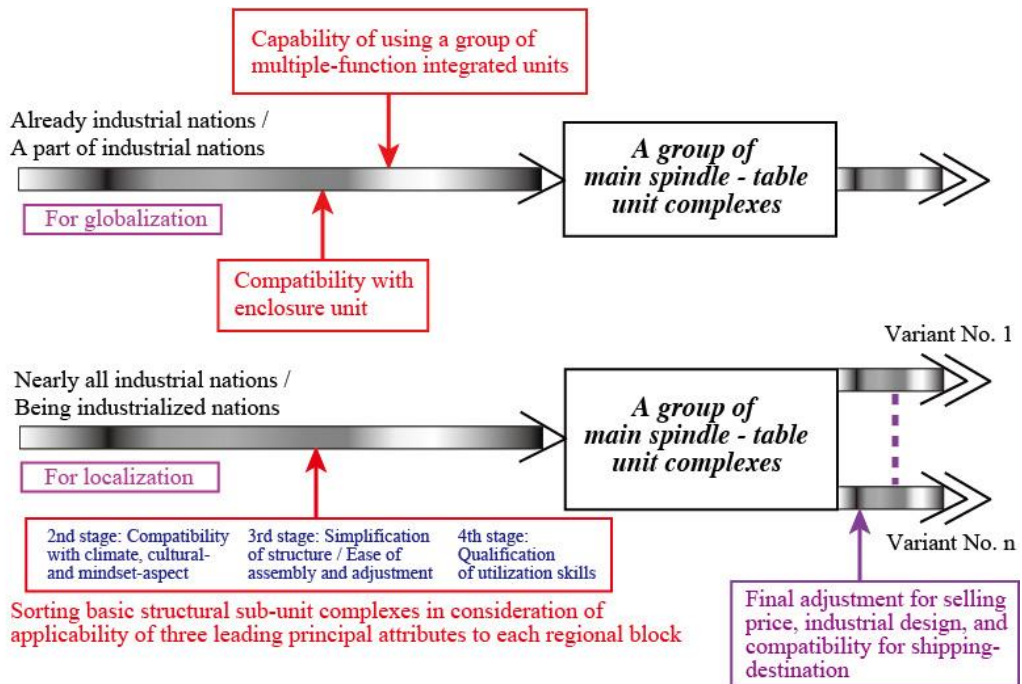


Fig. 8. Modular design facilitating products applicable to environments in localized globalization (a) Choice of sub-unit complex (b) Determination of a group of basic unit complexes

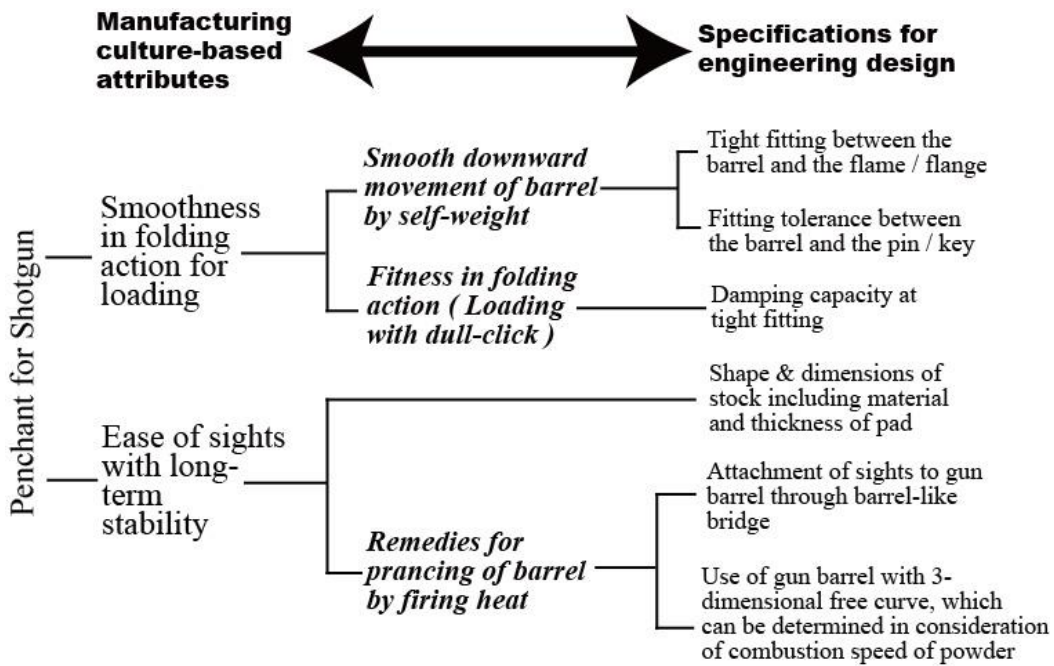


Fig. 9. Tree structure representing conversion processes of manufacturing culture-related attributes to engineering specifications

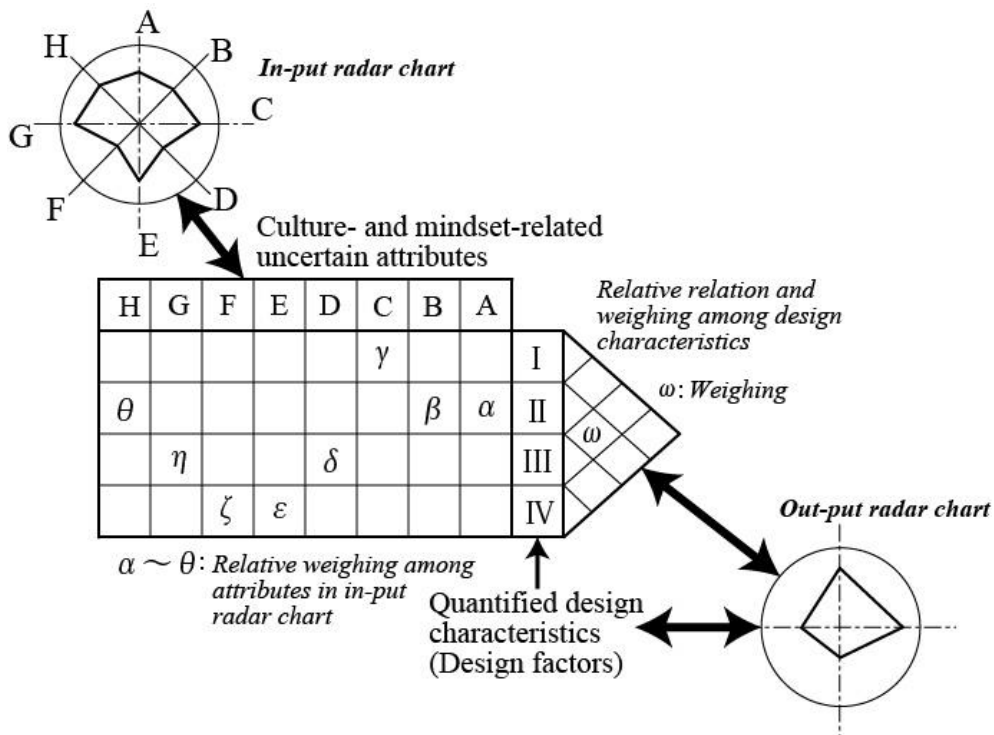


Fig. 10. Quantification of uncertain attributes by using radar chart and QFD of hierarchical type

In the globalization-oriented type, how to deal with the modules for enclosure together with maintaining the marked feature in its industrial design facet.

In the globalization-oriented type, the contrivance of multiple-function integrated unit such a shown in Fig. 11, where the outer face of the cylinder for hydraulic feed driving can facilitate the bar guide.

In the localization, what are suitable filtering factors and to what extent the local environment should be considered. In the localization, the contrivance of economized unit with simplified specifications and higher compatibility with regional requirements. For example, a comparative research into the applicability of either ball screw or double-pinion driving.

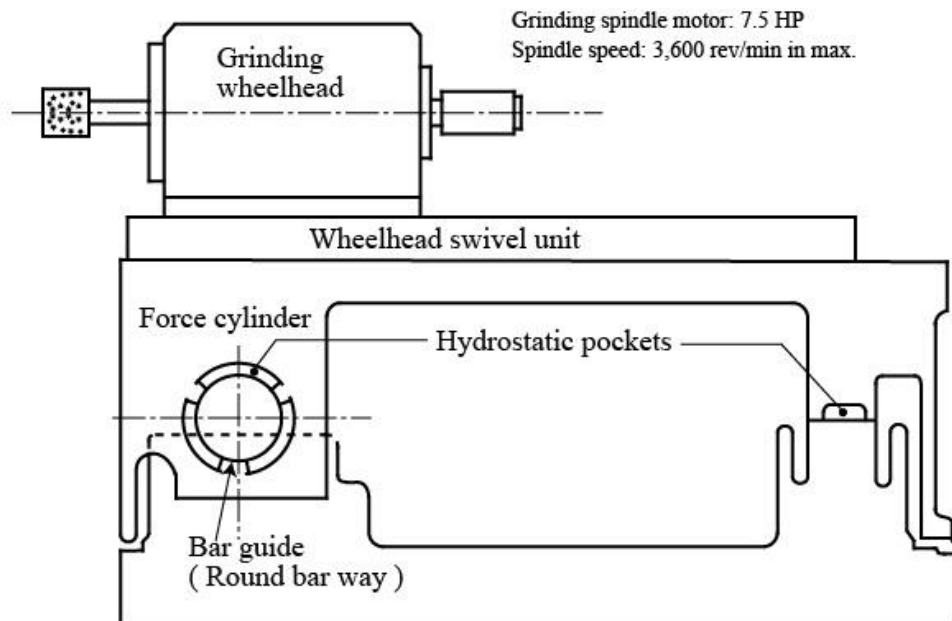


Fig. 11. Integration of bar guide with feed cylinder for cross-slide traveling in internal grinding machine – Type ICF of Heald-make in 1960s

## 6. CONCLUDING REMARKS

We must eye the new horizons of the modular design with the advent of unexperienced manufacturing environment, and to establish an innovative and effective modular design compatible with such new horizons, we must also conduct the research into core technologies. Summarizing, some leading research subjects are as follows. Establishment of the design methodologies for the “ Principles of Separation and Unification “.

Rational conversion measures between the functionality and structural configuration. Quantification of the uncertain attribute and its sublimation as engineering design specifications.

Incorporation of to what extent social environment-related attributes in an advanced modular design available for localized globalization era.

Further development of multiple-function integrated modules for the globalization and economized module for the localization.

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