The Modular Design in Consideration of Influence of Noise

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Abstract

The paper describes the modularization technology based on DSM (Design Structure Matrix). DSM usually represents the interrelationship between product components. In this paper, DSM which represents relationship product components and noise is proposed as noise DSM. The noise DSM is merged with relation DSM to construct integration DSM. A product can be modularized according to the integration DSM to minimize the influence of noise and assembling. In order to verify the effectiveness of the proposed method, it was applied to modularization of a lathe model.

Keywords: modular design, modularization, DSM

1 Introduction

With the hard product competition on a global scale, various manufacturers are advancing rapidly globalization of manufacturing sites. In the globalization of manufacturing sites, regardless of the production base, the Japan quality must be ensured. However, because large-scale and complex relationship between product components with improvement of the product performance and diversification of function is accelerating, it is difficult to guarantee a certain quality in the world.

Therefore, design and manufacturing technology that can maintain the same high quality who is where can make the product and that takes into account the complexity of the product between product components is required. As a design method of one to realize it, modular design of the product can be considered.

The modular design is investigated because it is to be effective to solve the problem of various manufacturers. For example, Miwa et al have developed a modular design including the uncertainty between the components and using the product worth flow analysis to visualize the flow of worth handled between the components and interrelationships engineering basis [1]. Tsumaya *et al.* is intended to build a modular design method using qualitative information found in the concept phase [2]. Ogawa et al have proposed a modular design method to simultaneously evaluate the functional and environmental information by combining the features of the module of an environmental information and function information of the product [3]. In addition, Inoue et al have proposed a method to guide the module structure that is consistent also geometrically based on the information asked of products and life-cycle scenario and satisfy various requirements across the entire product life cycle [4].

In the modular design of the product, it is important to configure the module without the mutual relationship. That is, when the relationship between modules making up the product is one-way, development management and design changes of the product is facilitated. In particular, modularization of the products complex and large scale is leading and important. Further, in order to influence the product functions transmitted between the components, disturbance (noise) applied to the product is also a factor to be considered in modularization. However, it is not seen Studies on modular design considering the influence of the noise.

Therefore, in this study, we propose the modular design method using DSM (Design Structure Matrix) in consideration of the noise in addition to the interaction between the components. In addition, we apply the proposed method to the modularization of the lathe model and confirm its usefulness.

2 Modular design method with DSM

2.1 DSM

This study proposes a modular design method based on DSM (Design Structure Matrix). DSM is a method to express the complexity of the system of qualifying product as a matrix by reducing the dependency between the components.

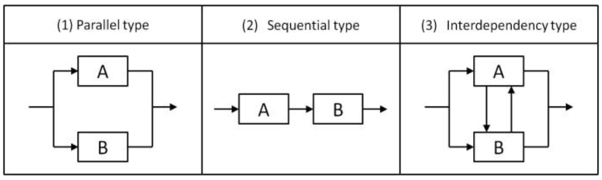


Fig. 1 Diagraph example of inter-element dependencies

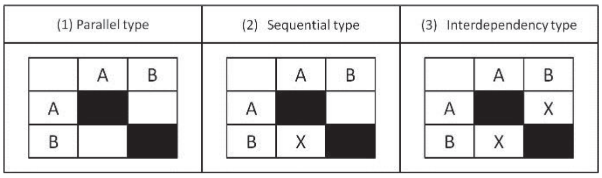
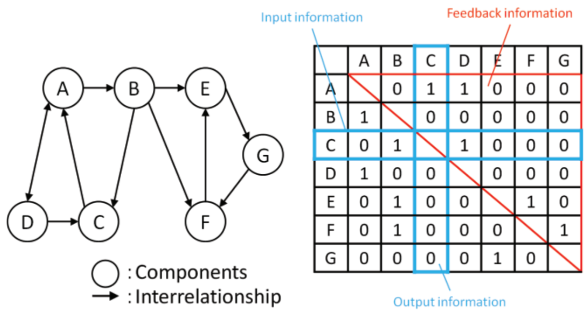


Fig. 2 DSM example of inter-element dependencise



(a) Diagraph (b) DSM

Fig. 3 DSM example

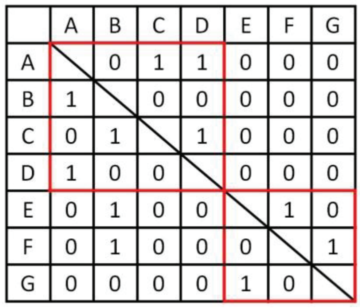


Fig. 4 Modularization example

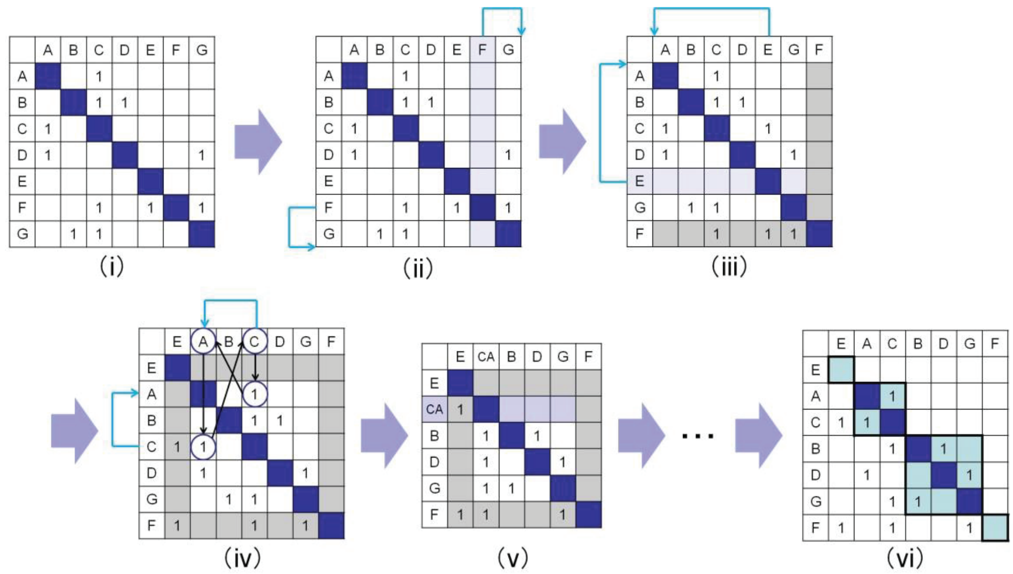


Fig. 5 Partitioning Algorithm

Relationships between components can be indicated by a diagraph. The relationships between components are divided into three main types as shown in **Fig. 1**.

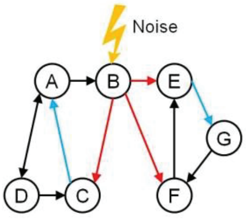
Parallel type, **Fig. 1(1)**, is a pattern that component A and component B has no dependencies. Namely, when designing of component A, no information is required from component B, and also when designing of component B, no information is required from component A. Therefore, in the parallel type, it is shown that it is possible to design independently each other component A and component B.

Sequential type, **Fig. 1(2)**, is a pattern that component A affects component B, but component B does not affects component A. That is, when designing of component B, input from component A is required. So it is necessary to design the component A is completed in advance.

Interdependency type, **Fig. 1(3)**, is a pattern that component A and B is mutually influence each other. That is, this pattern requires input from component A to design component B, and also requires input from component B to design component A. So, result of designing component B affects the design of component A. In this case, the loop of information between components occurs and design changes of each component create a chain of influence. Therefore, if there is no such to limit to some extent, there is a risk that the design is not complete and continues forever.

Figure 2 expresses these three dependencies pattern between components in DSM. DSM represents the components which make up the system in row and column. The components are arranged in the same order in both row and column of DSM. When read in the column direction, it is understood that the component is whether the effect to any component. Further, when read in the row direction, it is understood that the component is affected by which components. In **Fig. 2**, the presence or absence of the influence between components is represented by 1 filled with [5].

Figure 3 shows example of diagraph and DSM when the number of components is high. If it is possible as shown **Fig. 3(a)** to show the interrelationships of the components A ~ G as a diagraph, DSM is **Fig. 3(b)**. Sequence of row and column elements of the DSM are arranged in the order of implementation of the design of the components. Even if the number of components is large, **Fig. 2** as well, the influences between components is understood by reading DSM in the column direction and the row direction. By reading in the column direction, output information, i.e., whether the element affects which elements can be seen. By reading in the row direction, input information, i.e., whether the element is affected by which elements can be seen. In addition, the area of the top right of the diagonal matrix



(a) Diagraph

	A	B	C	D	E	F	G
A		0	0.2	0	0	0	0
B	0		0	0	0	0	0
C	0	0.3		0	0	0	0
D	0	0	0		0	0	0
E	0	0.8	0	0		0	0
F	0	0.2	0	0	0		0
G	0	0	0	0	0.5	0	

(b) Noise DSM

Fig. 6 Noise DSM example

(red triangular part in **Fig. 3(b)**) shows a feedback relationship. If feedback information is present between the components, it causes rework when performing product design.

For example, looking at the DSM of **Fig. 3(b)**, it is understood that design result of component C and D is required to carry out the design of component A. However, design result of component C and D is not clear in the design stage of component A, so component A is designed assuming the design result. Then, the design proceeds to C and D, the design result of the two components are obtained, so necessary to perform the design review of component A which was designed assuming the design result come out. At this time, if the design result obtained and assumed were very different, design change of component A and rework may occur. In addition, if design change of component A is made by rework, the design change extends to component B based on the design result of component A, influence of rework will continue to propagate.

In this way, it is undesirable that the design in which the relationship between the components is abundantly present in the area at the top of the diagonal of the DSM, namely in which many feedback relationship exists. Therefore, the modular design performs design with less rework as much as possible by replacement of components and putting together each component with a feedback relationship in a module. In DSM example of **Fig. 3(b)**, the modular design is performed as shown in **Fig. 4**. Then, when components A ~ G are separated to one module and another, components A ~ D and components E ~ G, though feedback relationship exists within the module, the design in which the feedback relationship between modules does not exist is possible.

2.2 Partitioning Algorithm [6]

In modular design based on DSM, replacement of components is performed by Partitioning algorithm Eppiger et al propose. The procedure is described with reference to DSM in **Fig. 5(i)**. For the sake of simplicity, don't put a number on the part there is no relationship between the components.

First, read in the column direction the DSM, components that any relationship is also not filled, that is, components that have no input information (component F in **Fig. 5(ii)**) is moved to the most back the DSM, and don't consider these components future (**Fig. 5(iii)**). Similarly, read in the row direction DSM, components that any relationship is not filled, that is, components that have no output information

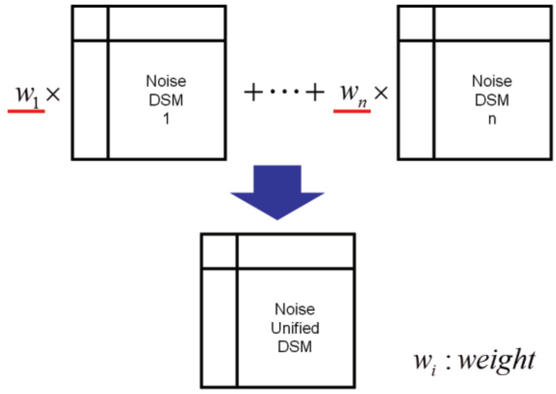


Fig. 7 Construct of Noise Unified DSM

(component E in **Fig. 5(iii)**) is moved to the most front the DSM, and don't consider these components future (**Fig. 5(iv)**).

When there is no component without input information and output information, components in the loop relationship (component A, C in **Fig. 5(iv)**) is summarized in one (**Fig. 5(v)**).

Then, repeat the search for components without input information and output information and the combination of the components in the loop relationship again, and end processing when there is no loop relationship or loop relationship becomes minimum.

Figure 5(vi) is the result of applying the algorithm Partitioning algorithm to **Fig. 5(i)**. Thus, swapping the components can achieve modular design as to minimize a feedback relationship.

2.3 Overview of the proposed method

First, as has been proposed, we define DSM from interaction between the components of the products and systems of interest (later refer to this DSM as Relation DSM). Relation DSM in this study represents only the contact situation between the components for the sake of simplicity. In this study, we propose Noise DSM in consideration of the noise applied to the product and define Integrated DSM in combination relation and noise using Relation DSM and Noise DSM and perform modular design based on Integrated DSM. Thus, modularization can be realized less susceptible to noise and without correlation.

2.4 Construction method of Integrated DSM

When the noise applied to the components of the system and the product acts, the degree of influence of the noise applied to the other components through the component applied the noise is represented by DSM, as Noise DSM.

For example, as **Fig. 6 (a)**, consider a system consisting of components A ~ G. At this time, assume that the noise is applied to the component B. The influence of the noise affects the other components through component B. So, the influence and the relationship between components are represented by the Noise DSM. The Noise DSM is shown in **Fig. 6 (b)**. In the construction of Noise DSM, elements with influence of the noise directly have a value 1 and elements affected by the noise indirectly have a value less 1

Tabel 1 Relation DSM

		1	2	3	4	5	6	7	8	9	10	11	12
		Tool	Tool rest	Cross	Saddle	Motor(Saddle)	Ball screw	Motor(Ball screw)	Bed	Tailstock	Main spindle	Spindle guide	Motor(Mail spindle)
1	Tool		1	0	0	0	0	0	0	0	0	0	0
2	Tool rest	0		1	0	0	0	0	0	0	0	0	0
3	Cross	0	0		1	1	0	0	0	0	0	0	0
4	Saddle	0	0	1		1	1	0	1	0	0	0	0
5	Motor(Saddle)	0	0	1	1		0	0	0	0	0	0	0
6	Ball screw	0	0	0	0	0		1	1	0	0	0	0
7	Motor(Ball screw)	0	0	0	0	0	1		1	0	0	0	0
8	Bed	0	0	0	0	0	0	0		0	0	0	0
9	Tailstock	0	0	0	0	0	0	0	1		0	0	0
10	Main spindle	0	0	0	0	0	0	0	0	0		1	1
11	Spindle guide	0	0	0	0	0	0	0	0	0	1		1
12	Motor(Mail spindle)	0	0	0	0	0	0	0	0	0	1	1	

Tabel 2 The result of modularization by Relation DSM

			8	9	6	7	10	11	12	3	4	5	2	1
			8	9	6	6	10	10	10	3	3	3	2	1
			Bed	Tailstock	Ball screw	Motor(Ball screw)	Main spindle	Spindle guide	Motor(Main spindle)	Cross	Saddle	Motor(Saddle)	Tool rest	Tool
8	8	Bed		0	0	0	0	0	0	0	0	0	0	0
9	9	Tailstock	1		0	0	0	0	0	0	0	0	0	0
6	6	Ball screw	1	0		1	0	0	0	0	0	0	0	0
7	6	Motor(Ball screw)	1	0	1		0	0	0	0	0	0	0	0
10	10	Main spindle	0	0	0	0		1	1	0	0	0	0	0
11	10	Spindle guide	0	0	0	0	1		1	0	0	0	0	0
12	10	Motor(Main spindle)	0	0	0	0	1	1		0	0	0	0	0
3	3	Cross	0	0	0	0	0	0	0		1	1	0	0
4	3	Saddle	1	0	1	0	0	0	0	1		1	0	0
5	3	Motor(Saddle)	0	0	0	0	0	0	0	1	1		0	0
2	2	Tool rest	0	0	0	0	0	0	0	1	0	0		0
1	1	Tool	0	0	0	0	0	0	0	0	0	0	1	

(a) Noise DSM : saddle motor heat

		1	2	3	4	5	6	7	8	9	10	11	12
		Tool	Tool rest	Cross	Saddle	Motor(Saddle)	Ball screw	Motor(Ball screw)	Bed	Tailstock	Main spindle	Spindle guide	Motor(Mail spindle)
1	Tool		0	0	0	0	0	0	0	0	0	0	0
2	Tool rest	0		0.2	0	0	0	0	0	0	0	0	0
3	Cross	0	0		0.3	0.6	0	0	0	0	0	0	0
4	Saddle	0	0	0.3		0.5	0	0	0	0	0	0	0
5	Motor(Saddle)	0	0	0.4	0.3		0	0	0	0	0	0	0
6	Ball screw	0	0	0	0	0		0	0	0	0	0	0
7	Motor(Ball screw)	0	0	0	0	0	0		0	0	0	0	0
8	Bed	0	0	0	0	0	0	0		0	0	0	0
9	Tailstock	0	0	0	0	0	0	0	0		0	0	0
10	Main spindle	0	0	0	0	0	0	0	0	0		0	0
11	Spindle guide	0	0	0	0	0	0	0	0	0	0		0
12	Motor(Mail spindle)	0	0	0	0	0	0	0	0	0	0	0	

(b) Noise DSM : ball screw motor heat

		1	2	3	4	5	6	7	8	9	10	11	12
		Tool	Tool rest	Cross	Saddle	Motor(Saddle)	Ball screw	Motor(Ball screw)	Bed	Tailstock	Main spindle	Spindle guide	Motor(Mail spindle)
1	Tool		0	0	0	0	0	0	0	0	0	0	0
2	Tool rest	0		0	0	0	0	0	0	0	0	0	0
3	Cross	0	0		0	0	0	0	0	0	0	0	0
4	Saddle	0	0	0		0	0.1	0	0	0	0	0	0
5	Motor(Saddle)	0	0	0	0		0	0	0	0	0	0	0
6	Ball screw	0	0	0	0	0		0.8	0	0	0	0	0
7	Motor(Ball screw)	0	0	0	0	0	0.5		0	0	0	0	0
8	Bed	0	0	0	0	0	0	0.4		0	0	0	0
9	Tailstock	0	0	0	0	0	0	0	0		0	0	0
10	Main spindle	0	0	0	0	0	0	0	0	0		0	0
11	Spindle guide	0	0	0	0	0	0	0	0	0	0		0
12	Motor(Mail spindle)	0	0	0	0	0	0	0	0	0	0	0	

(c) Noise DSM : spindle motor heat

		1	2	3	4	5	6	7	8	9	10	11	12
		Tool	Tool rest	Cross	Saddle	Motor(Saddle)	Ball screw	Motor(Ball screw)	Bed	Tailstock	Main spindle	Spindle guide	Motor(Mail spindle)
1	Tool		0	0	0	0	0	0	0	0	0	0	0
2	Tool rest	0		0	0	0	0	0	0	0	0	0	0
3	Cross	0	0		0	0	0	0	0	0	0	0	0
4	Saddle	0	0	0		0	0	0	0	0	0	0	0
5	Motor(Saddle)	0	0	0	0		0	0	0	0	0	0	0
6	Ball screw	0	0	0	0	0		0	0	0	0	0	0
7	Motor(Ball screw)	0	0	0	0	0	0		0	0	0	0	0
8	Bed	0	0	0	0	0	0	0		0	0	0.2	0.4
9	Tailstock	0	0	0	0	0	0	0	0		0	0	0
10	Main spindle	0	0	0	0	0	0	0	0	0		0.3	0.4
11	Spindle guide	0	0	0	0	0	0	0	0	0	0.3		0.3
12	Motor(Mail spindle)	0	0	0	0	0	0	0	0	0	0.1	0.1	

(d) Noise DSM : cutting resistance

		1	2	3	4	5	6	7	8	9	10	11	12
		Tool	Tool rest	Cross	Saddle	Motor(Saddle)	Ball screw	Motor(Ball screw)	Bed	Tailstock	Main spindle	Spindle guide	Motor(Mail spindle)
1	Tool		0	0	0	0	0	0	0	0	0	0	0
2	Tool rest	0.2		0	0	0	0	0	0	0	0	0	0
3	Cross	0	0		0	0	0	0	0	0	0	0	0
4	Saddle	0	0	0		0	0	0	0	0	0	0	0
5	Motor(Saddle)	0	0	0	0		0	0	0	0	0	0	0
6	Ball screw	0	0	0	0	0		0	0	0	0	0	0
7	Motor(Ball screw)	0	0	0	0	0	0		0	0	0	0	0
8	Bed	0	0	0	0	0	0	0		0	0	0	0
9	Tailstock	0	0	0	0	0	0	0	0		0	0	0
10	Main spindle	0	0	0	0	0	0	0	0	0		0	0
11	Spindle guide	0	0	0	0	0	0	0	0	0	0		0
12	Motor(Mail spindle)	0	0	0	0	0	0	0	0	0	0	0	

Fig. 8 Each Noise DSM

Tabel 3 Each weight of noises

Noise	The position error of the tool tip	Weight
Fever of motor (Main spindle)	20µm	1
Fever of motor (Saddle)	10µm	0.5
Fever of motor (Ball screw)	10µm	0.5
Cutting resistance	10µm	0.5

Tabel 4 Integrated DSM

		1 Tool	2 Tool rest	3 Cross	4 Saddle	5 Motor(Saddle)	6 Ball screw	7 Motor(Ball screw)	8 Bed	9 Tailstock	10 Main spindle	11 Spindle guide	12 Motor(Mail spindle)
1	Tool		0.50	0	0	0	0	0	0	0	0	0	0
2	Tool rest	0.19		0.63	0	0	0	0	0	0	0	0	0
3	Cross	0	0		0.69	0.88	0	0	0	0	0	0	0
4	Saddle	0	0	0.69		0.81	0.56	0	0.50	0	0	0	0
5	Motor(Saddle)	0	0	0.75	0.69		0	0	0	0	0	0	0
6	Ball screw	0	0	0	0	0		1	0.50	0	0	0	0
7	Motor(Ball screw)	0	0	0	0	0	0.81		0.50	0	0	0	0
8	Bed	0	0	0	0	0	0	0.25		0	0	0.25	0.50
9	Tailstock	0	0	0	0	0	0	0	0.50		0	0	0
10	Main spindle	0	0	0	0	0	0	0	0	0		0.88	1
11	Spindle guide	0	0	0	0	0	0	0	0	0	0.88		0.88
12	Motor(Mail spindle)	0	0	0	0	0	0	0	0	0	0.63	0.63	

according to the degree of influence. For example, assuming that the noise heat generated from the component 1, if the heat is transmitted to another component 100%, it sets the value of 1, and if the heat is transmitted to another component with attenuating, it sets the value of less than 1. Further, in the case of multiple noises, construct Noise DSM corresponding to noises, respectively. In rough design stage, the degree of influence of noise of each element is determined based on experience of the designer, but, in the detailed design phase, it may be strictly determined by the results of engineering analysis.

When many Noise DSMs are constructed, set a common evaluation function on each noise, and calculates a weight factor taking into account the degree of influence to the evaluation function. Multiply each Noise DSM and weights obtained together, and sum, so Noise Unified DSM is created (**Fig. 7**). Adds Noise Unified DSM obtained and Relation DSM, followed by normalization, define DSM finally obtained as Integrated DSM. Apply Partitioning algorithm to Integrated DSM, to create a component module.

3 Application

3.1 Lathe model

In this study, the modular design based on Noise DSM

Tabel 5 The result of modularization in consideration of noise

			8 / 8 Bed	9 / 9 Tailstock	6 / 6 Ball screw	7 / 6 Motor(Ball screw)	10 / 10 Main spindle	11 / 10 Spindle guide	12 / 10 Motor(Main spindle)	3 / 3 Cross	4 / 3 Saddle	5 / 3 Motor(Saddle)	2 / 2 Tool rest	1 / 1 Tool
8	8	Bed		0	0	0	0	0	0	0	0	0	0	0
9	9	Tailstock	0.50		0	0	0	0	0	0	0	0	0	0
6	6	Ball screw	0.50	0		1	0	0	0	0	0	0	0	0
7	6	Motor(Ball screw)	0.50	0	0.81		0	0	0	0	0	0	0	0
10	10	Main spindle	0	0	0	0		0.88	1	0	0	0	0	0
11	10	Spindle guide	0	0	0	0	0.88		0.88	0	0	0	0	0
12	10	Motor(Main spindle)	0	0	0	0	0.63	0.63		0	0	0	0	0
3	3	Cross	0	0	0	0	0	0	0		0.69	0.88	0	0
4	3	Saddle	0.50	0	0.56	0	0	0	0	0.69		0.81	0	0
5	3	Motor(Saddle)	0	0	0	0	0	0	0	0.75	0.69		0	0
2	2	Tool rest	0	0	0	0	0	0	0	0.63	0	0		0
1	1	Tool	0	0	0	0	0	0	0	0	0	0	0.50	

to propose is applied to the lathe model. Components of the lathe model, tool, tool rest, cross, saddle, motor (attached to saddle), ball screw, motor (attached to ball screw), bed, tailstock, main spindle, spindle guide, motor (attached to main spindle).

3.2 The modular design based on relation DSM

First, modularization of components of the lathe model is performed based on relation DSM. Relation DSM is constructed based on the interrelationship between each component of the lathe model. **Table. 1** shows the relation DSM. Partitioning Algorithm is applied to Table. 1 and modularization is performed. **Table. 2** shows the result of modularization.

3.3 The modular design based on Noise DSM

Then, modularization of components of the lathe model is performed based on Noise DSM. Components are the same as those mentioned in the 3.2. Noises are defined as the fever of three motors (attached saddle, ball screw and main spindle) and cutting resistance. In consideration of the influence of the noise, Noise DSMs for each noise are created. Here, assume a rough design stage, values are set appropriately based on the temperature of fever. **Fig. 8** shows each Noise DSM created.

The weight for each Noise DSM is determined. Here, evaluation function is the position error of the tool tip, the weight is calculated from the degree of influence that each noise gives to the position error of the tool tip. **Table 3** shows each weight of noises. Multiply these weights and each Noise DSM and sum these, obtain Noise unified DSM. By adding the Noise Unified DSM and Relation DSM (**Table 1**) and normalizing, obtain Integrated DSM as **Table 4**. **Table 5** shows the results of modularization to apply Partitioning Algorithm to Integrated DSM (**Table 4**).

The result of modularization by Relation DSM and the results of modularization by Integrated DSM (Proposed method) is the same. So, lathe model targeted has been found that it is difficult under the influence of the disturbance.

4 Conclusion

In this study, we proposed construction method of DSM in consideration of the influence of Noise and modular design in consideration of the influence of Noise. We apply the propose method to Lathe model and perform modularization of Lathe model.

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