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Study on Clarification of the Core Technology in a Monozukuri Company

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***Abstract*—**It is important to clarify the company's core technology in product development process to strengthen their power in providing technology that meets the customer requirement. QFD method is adopted to clarify the core technology through identifying the high element technologies that are related to the voice of customer, and offer the most delightful features for customer. AHP is used to determine the importance of evaluating factors. A case study was conducted by using this approach in Japan's Monozukuri Company (so called manufacturing company) to clarify their core technology based on customer requirements.

***Keywords*—**QFD, product development process, core technology, AHP.

I. Introduction

THE product life cycle for various manufacturing sectors in Japan is shown in Fig. 1. It presents that the product life cycle has been shortened in recent years, from the data survey of the Japanese Ministry of Economy, Trade and Industry [1]. For manufacturing companies, short product life cycle stresses the importance to understand what their core technologies are, and how to utilize their core technologies in manufacturing within their limited resources.

The definition of core technology is the technology that satisfying the conditions; accumulates in the company and can be expanded in the future, become the source of company's added value; and differentiated or hardly to imitate by another company [2]. The other definition stated that core technology is the technology that become a source of competitiveness [3], and the technology that is used as a source of company's strategy to enhance their competitiveness [4]. In this study, core technology is defined as the technology which plays a central role to achieve the function that make customers delighted with in-house development products.

It is essential for manufacturing companies to understand their core technologies first and efficiently utilize the limited resources in their product development process. Otherwise, they will not be aware of their "power" and lose track of strategic direction on their product development process. Furthermore, by objectively acknowledging and assessing their core technology, the manufacturer can cultivate their future technology that facilitates innovation and generates new customer value.

We applied our study in a manufacturing company in Japan to clarify their core technology. The company initially was founded in 1991 as a general trading company dealing with semiconductor manufacturing equipment. It aims to become a sustainably growing company. Therefore, carrying out its many changes, this company has been evolved into a manufacturer that currently develops and makes devices such as semiconductor manufacturing equipment, processing machines and inkjet equipment etc. Starting as a trading company that did not possess technology, it had collaborated with several companies and universities to develop equipment, and gradually has cumulated and acquired its own technology.

First problem found from opportunity loss cost in the company on their product development process. The difference between planning and actual of (e.g. delivery time) has generated the opportunity loss cost. Fig. 2 is an example of the opportunity loss cost for a product with planned man-hour had being 1,970 hours whereas the actual total being 3,195 hours (± 62% excessed).

Incorrect estimation of man-hour required in the product development and production that is strongly associated with the company's incorrect assessment of their core technology. It is critical for the company to clarify the core technology to achieve fast product innovation. Clarification of the core technology is the first step. The study on how to clarify a company's core technology was introduced in previous study [2]. However, there is no specific steps and detailed process which is easy to implement. Our research will offer an applicable process as a guide for manufacturing company to clarify their core technology.

II. The Relationship between QFD and This Research

Fig. 3 shows the procedure in clarifying the core technology. There is a similarity between our core technology clarification steps and Quality Function Deployment (QFD) method. QFD is a method for defining the customer needs or requirements and translating them technically into specific plans to produce products that appropriate with those requirements [5]-[9]. QFD is a powerful tool and has been proven to be very effective in translating customer's voice [10].

In QFD, based on customer requirements, company must decide the technology requirement to achieve customer satisfaction. In the other words, QFD is "How" to fulfill "What". In our study, QFD method is modified to clarify company's core technology by converting the customer requirements to clarify the related high element technologies.

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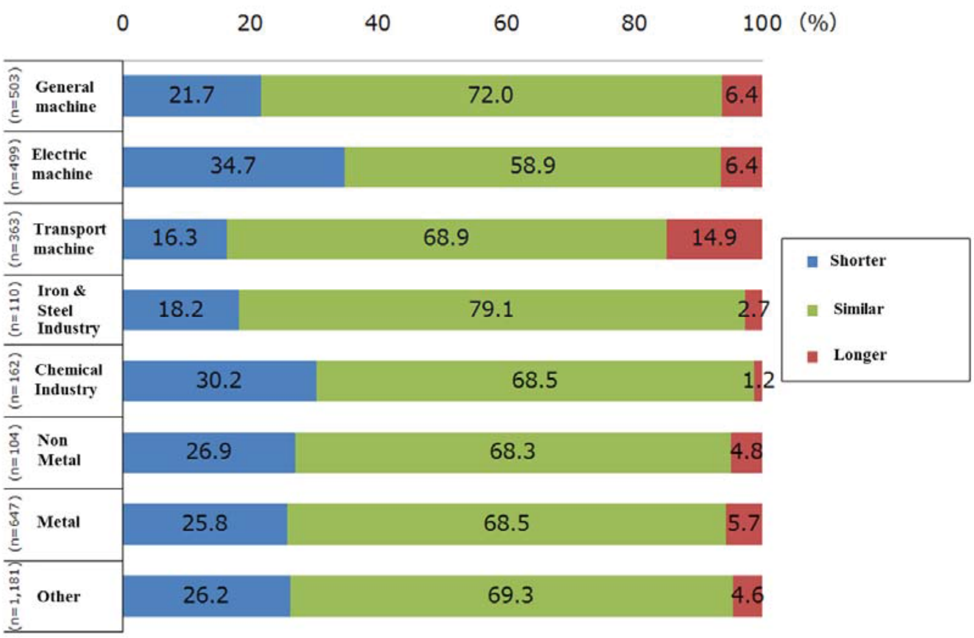

Fig. 1 Product life cycle in 2005 vs. 2010 in Japan [4]

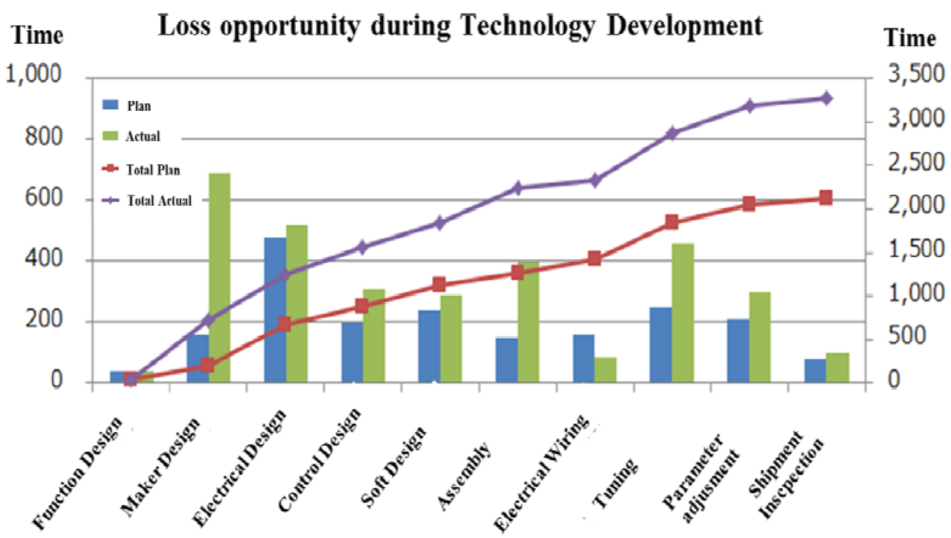

Fig. 2 Example of opportunity loss in equipment development

III. Detailed Steps for Clarifying Core Technology

Research flow to evaluate the company's core technology is shown in Fig. 4.

Step 1. Product selection: The products are selected from the in-house developed products that contribute substantial sales to the company.

Step 2. Defining customer requirements: This step is to define the customer requirements of the selected product through the stated product specifications.

Step 3. Extraction of quality requirement item.

The extraction of quality requirement item is conducted by translating the customer requirements based on the product specifications to the relevant quality characteristic item. Then, the quality requirement items are subsequently categorized in groups. The translating and grouping process must be centered on why those specification items are requested by customers, rather than just re-expressing the specifications as it is. An example of quality requirement item hierarchy of each device this step is shown in Table I.

Step 4. Evaluation of the acquired quality requirements

The evaluators that conduct a survey are among the staff whose holds information about the customers. To avoid the opinion of other staff's will influence the answer, the survey will be held on an individual basis. In our example, the number of staff interviewed is as follows:

- Mask-less exposure apparatus: 5 of 10 people

- Bench-top NC micro-processing machine: 5 of 5 people
- On-demand ink jet device: 6 of 6 people

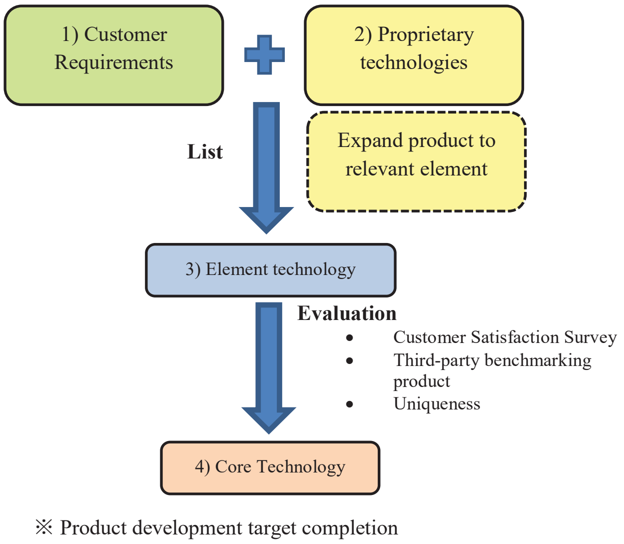

Fig. 3 Steps adopted from QFD for clarifying core technology

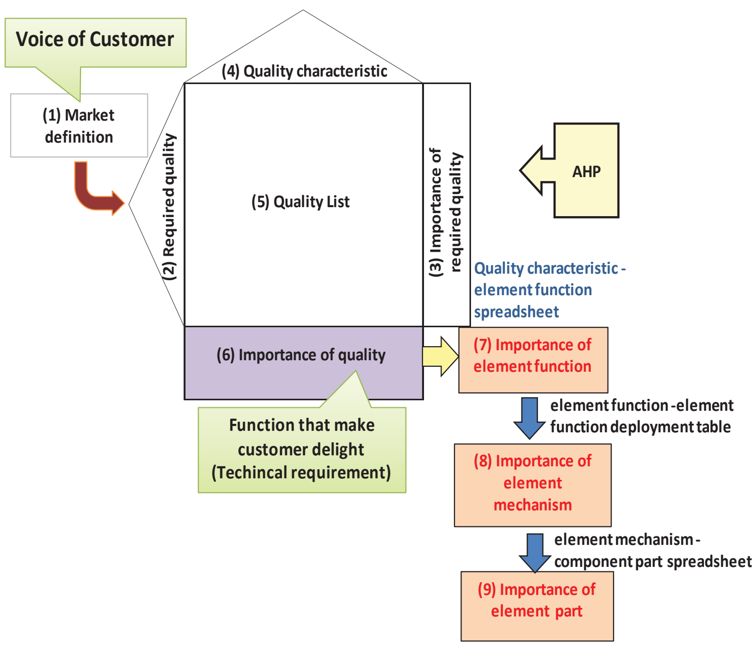

Fig. 4 Evaluation flow of core technology research

TABLE I
HIERARCHY BY ITEM NUMBER OF THE REQUIRED QUALITY ITEM OF EACH DEVICE

Apparatus	*1st order*	*2nd order*	*3rd order*
Mask-less exposure apparatus	8 unit	17 unit	38 unit
Bench-top NC micro-processing machine	5 unit	16 unit	—
On-demand ink jet device	7 unit	18 unit	—

Step 5. Calculation of the importance degree of quality requirement items.

The integration of QFD-AHP proved a reliable approach to probe the customers' needs during the product development process [10], [11]. The collected questionnaire results in step 4 are evaluated for each item related to the primary, secondary and tertiary for each quality requirement. Afterwards, the average of the evaluation results is taken to calculate the importance degree of the quality requirement items.

Then, the overall evaluation score of quality requirement items is obtained by multiplying the importance evaluated in each item with the associated entries. Fig. 5 shows the quality requirement evaluation result for the mask-less exposure device.

Step 6. Extraction of quality characteristics item

The quality requirement items are converted to measurable terms that are called as quality characteristics items. Quality characteristics items are subsequently grouped according to their closeness in meaning. Fig. 6 shows the quality characteristics items for mark-less exposure device.

Step 7. Creating the quality table with the importance degree of the quality characteristics items.

This step is to create the quality table that is a two-dimensional table between the quality requirement and quality characteristics items with the importance degree of the quality characteristics items. The weight ◎ ○ △ is the degree of measurability of the quality characteristics for each requirement quality item. In this research, we set ◎=4, ○=2, △=1. The evaluators shall be a project leader who has product knowledge. The interview was also conducted on an individual basis. Fig. 7 shows the quality table for a mask-less exposure device. Furthermore, the top three importance degrees of the quality characteristics importance for each device are shown in Fig. 8. Those results have revealed the "functions" that customers are most pleased with. The next steps are to convert those functions to elemental functions, elemental mechanisms and elemental parts, and then clarify the technologies that are relevant to achieve the functions that make customers delighted.

Step 8. Conversion to the elemental function importance

Based on the device operation process of each product, the elemental functions of each product will be extracted. Those will be then categorized. Subsequently, a two-dimensional table (quality-element function development table) such as Fig. 9 was created with the quality characteristics item and the grouped element function item, and the importance of the elemental function is calculated by weighting.

Step 9. Conversion to the elemental mechanism importance

The elements are extracted by the mechanisms associated with the elemental function items (Fig. 10)

1st order		2nd order						3rd order					
Quality requirement Item	AHP	Quality requirement Item	Number of Item (Numerator)	Minimum number of item (Denominator)	AHP	Importance: Before adjusment	Importance: After adjusment	Quality requirement Item	Number of Item (Numerator)	Minimum number of item (Denominator)	AHP	Importance: Before adjusment	Importance: After adjusment
Short production time	0.05	Able to exposed in short time	2		0.24	0.011	0.011	Able to test some condition of exposure in a short time	2		0.66	0.007	0.007
								The exposure condition is able to putted out in a short time			0.34	0.004	0.004
		Ready to manufactured			0.76	0.036	0.036	Try out ideas that came up immediately	2		0.83	0.030	0.030
								Waiting time until the device ready to use is short			0.17	0.006	0.006
Can be exposed a micro pattern	0.11	Able to create a small device	2		0.24	0.027	0.027	Able to expose micro straight line	2		0.62	0.017	0.017
								Able to expose a smooth curve			0.38	0.011	0.011
		Able to exposed for any pattern shape			0.76	0.086	0.086	Able to expose the vertical and horizontal lines at the same time	2		0.44	0.038	0.038
								Able to expose many patterns in one work			0.56	0.048	0.048
Quality of exposure range over the entire surface is constant	0.28	smooth joints between the swaths	2		0.41	0.116	0.116	Joint portions between swaths is not separate	2		0.77	0.089	0.089
								Joint location between swaths is not collapse			0.23	0.026	0.026
		Able to exposed in wide range with high			0.59	0.164	0.164	extensively to exposure and also the exposure size is constant	2		0.60	0.098	0.098
								extensively to exposure and also the exposure shape is constant			0.40	0.066	0.066
Can operated by any one	0.06	The quality is same with different operator	3		0.64	0.036	0.054	Work automatically	3		0.19	0.007	0.015
								It is easy work equipment			0.08	0.003	0.006
								Exposure result is stable			0.74	0.027	0.060
		Work construction is easy			0.11	0.006	0.009	Able to draw a separated good unit	2		0.71	0.004	0.006
								Can be used familiar file format			0.29	0.002	0.003
		Able to process Image in any state		2	0.25	0.014	0.021	Image processing can be located at any angle	3		0.29	0.004	0.009
								Image processing is able in any mark shape alignment		2	0.20	0.003	0.006
								Image processing is able to change the tint of work surface			0.51	0.007	0.016

Fig. 5 Quality requirements evaluation result for a mask-less exposure device

1st order	2nd order
Optical system performance	Exposure resolution
	Data resolution
	Light source output
Stage Performance	Stage positioning accuracy
	Stage positioning time
	Stage constant velocity accuracy
	Stage resolution
	Response speed
	Exposure in focus follow up range
	speed
	Stage stroke
	Exposure rate
Image Processing Accuracy	Image recognition rate
	Auto focus accuracy
Exposure Uniformity	Illuminance unevennes
	Light source aberration
	Stage constant velocity accuracy
Exposure Result	Minimum line width
	Swath junction accuracy
Body appearance	Size
	Shape
	Mass

Fig. 6 Quality characteristics item; (An example of Maskless exposure device)

Request Quality Item 1st order	2nd order	3st order	Quality characteristics importance	Optical system performance: Exposure resolution	Optical system performance: Data resolution	Optical system performance: Light source output	Stage performance: Stage positioning accuracy	Stage performance: Stage positioning time	Stage performance: Stage constant velocity accuracy	Stage performance: Stage resolution	Stage performance: Response speed	Stage performance: Exposure in focus follow-up range	Stage performance: Exposure in focus follow-up speed	Stage performance: Stage stroke	Stage performance: Exposure rate
Short production time	Able to exposed in short time	Able to test some condition of exposure in a short time	0.007					◎					○		◎
		The exposure condition is able to putted out in a short time	0.004					◎					○		◎
	Ready to manufactured	Try out ideas that came up immediately	0.030		○										
		Waiting time until the device ready to use is short	0.006					◎					◎		◎
Can be exposed a micro pattern	Able to create a small device	Able to expose micro straight line	0.017	◎	◎		◎		○	◎		○	○		
		Able to expose a smooth curve	0.011	◎	◎		◎		○	◎		○	○		
	Able to exposed for any pattern shape	Able to expose the vertical and horizontal lines at the same time	0.038	◎	◎		◎		○	◎		○	○		
		Able to expose many patterns in one work	0.048	◎	◎		○		○	○					
Quality of exposure range over the entire surface is constant	smooth joints between the swaths	Joint portions between swaths is not separate	0.089				◎			◎					
		Joint location between swaths is not collapse	0.026				◎			◎					
	Able to exposed in wide range with high accuracy	extensively to exposure and also the exposure size is constant	0.098	○	○		◎		◎	○		○			
		extensively to exposure and also the exposure shape is constant	0.066	○	○		◎		◎	○		○			
Can operated by any one	The quality is same with different operator	Work automatically	0.015												
	Work construction is easy	It is easy work equipment	0.006											◎	
Compact device	The device size is small	Able to unify the standard size of all equipment in factory	0.015												
		Can be used in narrow work place	0.066												
	Easy to relocated	This is a light weight device	0.018												
		This is a easy-handling equipment	0.011												
			Component parts importance	1.38	1.31	0.25	2.79	0.07	1.51	2.34	0.36	1.46	0.35	0.25	0.07
			Relative component parts importance	6.85	6.48	1.22	13.9	0.34	7.47	11.6	1.77	7.25	1.74	1.24	0.34

Fig. 7 Quality table with quality characteristic importance of the Mask-less exposure apparatus

Step 10. Calculation of the elemental parts importance

Based on the component diagram of each product, the element part items are extracted. Subsequently, a two-dimensional table (elemental mechanism - elemental part development table) is created with the elemental mechanism item and the extracted elemental part items. Weighting is performed to calculate the importance of the elemental part.

Fig. 11 shows the deployment table of elemental mechanism – elemental part for a mask-less exposure apparatus. Through the aforementioned procedures, elemental functions, elemental mechanisms and elemental parts with high relevance to the "functions" most pleasing to customers are clarified.

Step 11. Summary of core technology

Fig. 12 shows the summary of the core technology evaluation on PMT Co. Ltd. applied from this study's framework.

By analyzing the relationships within the product development process, we can identify the core technology that plays a central role in achieving the functions that customers are most pleased with.

Device	Rank	Quality characteristics item: 1 order	Quality characteristics item: 2 order	Importance
Maskless Exposure device	1	Expose	Adjust the synchronization of DMD and stage	9.84
	2	Expose	Track the exposure focus position	7.19
	3	Expose	Move the stage	6.34
Tabletop NC Fine processing machine	1	Process	Adjust the synchronization of the spindle and the stage	16.42
	2	To measure the height of the work	To measure the height of the work	14.52
	3	Do the Training	home position return	9.31
On-demand Ink-jet Device	1	Apply	Adjust the synchronization of the head and the stage	16.22
	2	Alignment is performed	get the alignment coordinate	10.43
	3	Apply	Ejecting the ink	10.11

Fig. 8 Quality characteristics importance of each device (top three)

apparatus	Ranking	Quality characteristics item: 1 order	Quality characteristics item: 2 order	importance
Maskless Exposure device	1	Stage performance	Stage positioning accuracy	13.85
	2	Stage performance	Stage resolution	11.63
	3	Stage performance	Stage constant velocity accuracy	7.47
Tabletop NC Fine processing machine	1	Stage performance	Stage positioning accuracy	16.63
	2	Stage performance	Stage resolution	14.26
	3	Spindle performance	Control resolution	14.23
On-demand Ink-jet Device	1	Stage performance	Stage positioning accuracy	12.95
	2	Stage performance	Stage constant velocity accuracy	12.01
	3	Head performance	Negative pressure	11.39

Fig. 9 Element function importance of each device (top three)

■ **Mask-less exposure apparatus**

1st order
Data conversion mechanism
Data generation mechanism
The observation light irradiation mechanism
Observation light amount adjustment mechanism
Exposure light irradiation mechanism
Exposure light quantity adjustment mechanism
Exposure light-blocking mechanism
Image display mechanism
Illumination uniformity correction mechanism
Work surface observation mechanism
Laser mark detection mechanism
Work shape detection mechanism
An alignment mark detection mechanism
Stage horizontal movement mechanism
Stage vertical movement mechanism
Stage rotating mechanism
Stage follow-up mechanism
Stage speed adjustment mechanism
Exposure irradiation stage synchronization control mechanism
Work fixing mechanism

■ **Bench-top NC micro-processing machine**

1st order
Spindle rotation mechanism
Spindle rotation amount adjusting mechanism
Spindle vertical movement mechanism
Stage horizontal movement mechanism
Stage speed adjustment mechanism
Spindle stage synchronization control mechanism
Work fixing mechanism
Processing data editing mechanism

■ **On-demand ink jet device**

1st order
Ink ejection mechanism
Ink discharge amount adjustment mechanism
Head vertical movement mechanism
Head horizontal movement mechanism
Stage horizontal movement mechanism
Stage rotational movement mechanism
Suction table mechanism
Head-stage synchronization control mechanism
Droplet observation unit
Trestle
Application data editing mechanism

Fig. 10 Element mechanism item of each device

	Element mechanism importance	LED: For observation	LED: For exposure	Objective lens	Imaging lens	Reflecting mirror	DMD	Camera for: Precision camera	Camera for: Wide-area camera	shutter	ND filter	The control board	X, Y-axis: Z-axis incremental encoder	Cross roller guid	Ultrasonic motor (USM)	Ultrasonic motor driver	Drive plate (ceramic)	Piezo (Y-axis only)	X-axis base	X-axis table	Y-axis base	Y-axis table
Data conversion mechanism	1.29																					
Data generation mechanism	1.63											○										
The observation light irradiation mechanism	0.91	◎		△	△	○	○	○	○			△										
Observation light amount adjustment mechanis	0.87											○										
Exposure light irradiation mechanism	6.45		◎	◎	◎	○	○	△	△			◎										
Exposure light amount adjustment mechanism	4.43		○									○										
Exposure light-blocking mechanism	0.34									◎	◎	△										
Light reduction projection mechanism	8.33	△		◎	◎	△	△															
Image display mechanism	3.28						◎					◎										
Illumination uniformity correction mechanism	2.08		◎	◎	◎	○	△					○										
Work surface observation mechanism	0.05	○		△	△	△	△		◎			△	○									
Laser mark detection mechanism	0.36						△		◎			△										
Work shape detection mechanism	0.36								◎													
Alignment mark detection mechanism	0.36							◎														
Stage horizontal movement mechanism	13.73											◎	◎	○	◎	◎	△	◎	◎	◎	◎	◎
Stage vertical movement mechanism	15.57											◎										
Stage rotating mechanism	4.08											◎										
Stage compliance mechanism	3.67											◎	○	△	○	○	△	△				
Stage speed adjustment mechanism	13.41												○	△	○	○	△	△				
Exposure irradiation stage synchronization cont	17.75											◎	○	△	○	○	△	△				
Work fixing mechanism	1.07																					
Component parts importance		12.1	43	68.4	68.4	27.3	38.7	9.7	11.3	1.4	1.4	278	124.7	62.3	124.6	124.6	48.6	89.8	54.9	54.9	54.9	54.9
Relative component parts importance		0.4	1.6	2.5	2.5	1.0	1.4	0.4	0.4	0	0	10.1	10.1	2.3	4.5	4.5	1.8	3.3	2.0	2.0	2.0	2.0

Fig. 11 Elemental mechanism – Elemental part deployment table of mask-less exposure apparatus (part)

	Mask-less exposure apparatus	NC processing machine	On-demand ink jet device
Quality characteristics	Stage positioning accuracy	Stage positioning accuracy	Stage positioning accuracy
Elemental function	Optical system - stage synchronization	Spindle - stage synchronization	Inkjet head - stage synchronization
Elemental mechanism	Stage synchronization control mechanism	Spindle - stage synchronization control mechanism	Inkjet head - stage synchronization control mechanism
Elemental part	Optical system control board	NC control board	Controller

Fig. 12 Evaluation results on PMT Co., Ltd.

IV. Conclusions

In our research's study case, core technology is evaluated by using the QFD method on products such as mask-less exposure apparatus, tabletop compact NC micro-processing machine, and on-demand inkjet device. Through the application on the company as the research object, we found that the most delighting function for customers in all products of this company is "high accuracy in stage positioning". Therefore, the company's core technology is stage synchronizations control mechanism. They will benefit from designing the combination of the mechanism in accordance with the high accuracy.

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