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Proposals for Research and Development on Monodzukuri (Manufacturing) Measurement Supporting the Competitiveness of Japanese Manufacturing Industries

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1 Introduction

Japan's manufacturing industries are the driving force supporting the economic growth of the nation. Japan has succeeded in producing products of the highest quality and reliability because outstanding engineers and technicians at the manufacturing site understand design concepts and are able to feed back site information on manufacturing to the design process.[1] Advanced techniques are cultivated and transmitted to younger employees in unified efforts extending from product design to actual manufacturing. Japanese manufacturing industries have long enjoyed a position of international superiority, but are now exposed to intense competition not only from the traditional industrial nations of Europe and North America, but also from a wide range of other countries.[1-3] As one background factor, although Japan was once considered simply a source of labor, its manufacturing industries steadily improved their technical capabilities, making the country a base for the production of high quality, high value-added products. However, the possibility that the superiority of Japanese manufacturing technology, or monodzukuri may be challenged in the near future is undeniable.

Given these circumstances, Japan's manufacturing industries must create new products which have an impact on world markets, achieve significant innovations in design and manufacturing processes, and dramatically improve product reliability in order to maintain and enhance their international superiority. For this, strengthening of monodzukuri backed by science and technology is necessary. The "White Paper on Monodzukuri 2006" presented the results of questionnaires completed by 300 listed companies as "Issues and Outlook for Japan as a Base of Innovation in Manufacturing Industries." More than half of the companies replying mentioned "The necessity of scientific knowledge in technical development is increasing annually.[3] In the strategy for promoting the "Monodzukuri Technology field" in the Third Science & Technology Basic Plan,[4] "monodzukuri" is defined as "value creation-type manufacturing" which aims at the development of science and technology so as to enhance the value of products (mono).[1] In the strategy for this field, "Reconstruction of science-based Japanese-style manufacturing" is mentioned as a basic policy.[1]

In monodzukuri measurement, various physical quantities related to product performance and manufacturing processes are digitized, and the results of data analysis are explained in scientific/technical terms. Thus, from the viewpoint of science-based manufacturing, it is one key element for promoting this policy. Because monodzukuri measurement is closely related to product functions and quality, research and development in this area cannot be carried out in a form which isolates measuring technologies. Rather, in R&D, monodzukuri measurement must be treated as part of a composite technology with the various other technologies that support the manufacturing process, such as design technologies and material/processing technologies. In other words, "monodzukuri measurement" is essentially different from the simple development of high-end measuring devices.[5]

Advanced measuring systems have now entered an era when anyone with sufficient funds can introduce state-of-the-art technology. Likewise, countries which were once viewed simply as a source of cheap labor are now completing plants equipped with more advanced measurement systems and production equipment than Japan's top companies. However, as a composite of design, manufacturing processes, and measuring and analysis technologies, "monodzukuri measurement" can only be materialized through the accumulation of technologies over many years, and must also be suited to the individual site and products, and therefore cannot be introduced simply by purchasing hardware. For this reason, "monodzukuri measurement" can be expected to occupy a key position supporting the international competitiveness of Japan's manufacturing industries in the future.

The aim of this article is to clarify the position of "monodzukuri measurement" and present proposals for directions in R&D on monodzukuri measurement, based on an understanding of the nature and importance of this key field.

2 What is monodzukuri measurement?

2-1 Conceptual framework of monodzukuri measurement

Monodzukuri measurement can be classified into three types, as described below. Figure 1 shows the positioning of the three types of monodzukuri measurement which will be discussed in this paper based on the stages of production in manufacturing industries. In the chart, measurement for operation and maintenance purposes is performed in the operation/use stage. However, in many cases, the measurement results are fed back to the function "monodzukuri measurement for elucidation of phenomena."

(A) Monodzukuri measurement for assurance of product performance

This type of monodzukuri measurement is performed at lines at the production site after the design and manufacturing processes have been determined in order to provide (a) assurance that products are being manufactured in accordance with specifications and (b) assurance that parts from separate production plants can be used, etc. Because a large number of measuring devices are used in lines at the production site, low cost is an

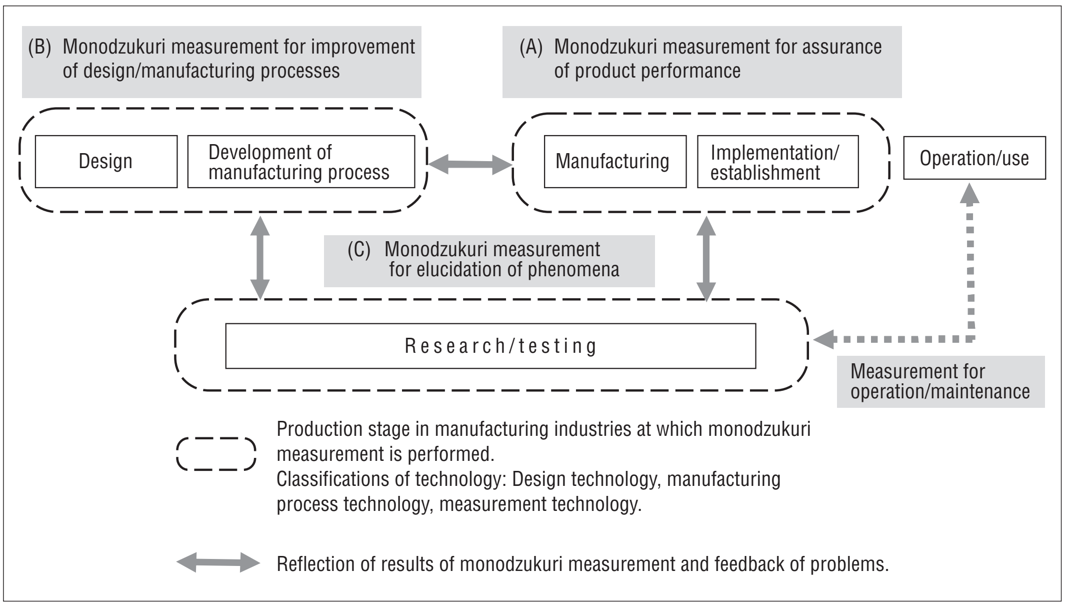

Figure 1 : Framework for monodzukuri measurement based on the stages of production in manufacturing industries

important requirement for these devices.

(B) Monodzukuri measurement for improvement of design and manufacturing processes

This monodzukuri measurement is performed to determine the design and manufacturing process in the design process and manufacturing process development stages. In particular, technologies for comparing design data and site data and in-process measurement technologies have attracted attention. Measuring devices are comparatively expensive, and multiple units are introduced.

(C) Monodzukuri measurement for elucidation of phenomena

This monodzukuri measurement function is performed in the research and testing stages in order to elucidate phenomena in the manufacturing process. For instance, in an example monodzukuri measurement of the joining mechanism in welding, accuracy in determining the joint reliability assurance period was greatly enhanced by elucidation of the phenomena in welding processes. Measuring systems of this type are generally installed in the research facilities or laboratories, and due to their extremely high cost, purchase by a single company or university may be difficult.

In this article, the above (A), (B), and (C) will be discussed in detail in Chapters 5-7, respectively.

2-2 *Conditions for progress in monodzukuri measurement*

(1) Digitization of physical quantities related to product performance and manufacturing processes

First, a key issue in monodzukuri measurement is identification of the physical quantities which express the fundamental performance of products. For example, in the development of a fuel cell vehicle or vehicle with improved crashworthiness, it is of first importance to determine which parameters should be measured.[5] In monodzukuri measurement, the various physical quantities related to product performance and manufacturing processes are digitized, the digitized data are supplied to those concerned, and discussions to improve the design/manufacturing process are facilitated by analysis of the data.

(2) Measurement based on a good understanding of the true nature of the technology

Because monodzukuri measurement is a composite technology involving design, the manufacturing process, and measurement, it is not appropriate to consider measurement as a technology independent from the design process and the manufacturing process. In other words, monodzukuri measurement technologies are not materialized in the measurement technology area alone. Measurement must be considered based on a good understanding of the true nature of the various technologies in the design/manufacturing processes. For example, when creating a technology map for a measuring device, the development region for the device is clarified by simply preparing a graph that shows measurement accuracy on the x-axis and the measurement range on the y-axis. However, in a technology map of monodzukuri measurement, the development region cannot be expressed adequately by these two axes. The map for monodzukuri measurement must be devised using parameters such as product performance and product cost rather than simple items of the type mentioned above.[5,6] Moreover, because monodzukuri measurement lies in this region, it is possible that there may be cases in which the development of new measuring devices is not necessary.

(3) Consideration of the uncertainty of measurement results

Internationally, measurement results always contain some uncertainty. For example, there is some uncertainty as to whether 1cm measured in another country is precisely the same as 1cm measured in Japan. Depending on the country, it is still not possible to assure the certainty of the centimeter unit as measured by local measuring equipment. However, in monodzukuri measurement, assurance that the shape and dimensions measured at plants in Japan and in other countries satisfy the same standards is necessary. This is referred to as traceability of measurement.[5,7]

(4) Building quality into the product as a corporate strategy

Manufacturing industries are strategically promoting the process of "building quality into the product" as a key corporate strategy. Total Quality Management (TQM) and quality engineering are concrete examples of this strategy. TQM is a systematic activity for the objective of managing the company's total organization effectively and efficiently, and supplying goods and services with quality that satisfies the customer in a timely fashion at an appropriate price.[8] Quality engineering is a type of engineering in which (a) the parameters that influence product quality and the manufacturing process are first identified by experimental and statistical techniques in the design stage, (b) next, deviations in the product performance are reduced by modifying the values of the parameters, and (c) finally, product performance is converged on the target performance by further adjustment of the parameter values.[9]

3 Monodzukuri measurement in Japan's Third Science & Technology Basic Plan

3-1 Monodzukuri technology field

Table 1 shows the system of Strategic prioritized S&T and Key R&D themes in the Monodzukuri Technology field.[1] Among these, the following will discuss Strategic prioritized S&T (1 technology of 2 in the field) and Key R&D themes (2 of 10 in the field) which are deeply related to monodzukuri measurement.

(1) Strategic prioritized S&T

One Strategic prioritized S&T which is taken up here is "Science-based 'visualization' technology for manufacturing that further advances Japanese-style monodzukuri technology." The objective of R&D in connection with this technology is to solve problems quickly and accelerate the creation of process innovation by the visualization of monodzukuri and by scientifically elucidating phenomena and problems which occur in the manufacturing process, enabling dissemination and accessability of the resulting information.[1] As background to the selection of

Table 1 : System of strategic prioritized S&T and key R&D themes in the monodzukuri technology field

<table>
<tr><td colspan="2">1. Situation recognition</td></tr>
<tr><td colspan="2">3. Strategic prioritized S&T (1)
Science-based visualization technology for manufacturing that further advances Japanese-style monodzukuri technology</td></tr>
<tr><td rowspan="4">2. Key R&D themes
Promotion of monodzukuri technologies (areas) serving as common infrastructure</td><td>(1) Enhancement of fundamental monodzukuri technologies based on IT</td></tr>
<tr><td>(2) Development of new measuring and analysis technologies/equipment and new precision processing technologies to meet the needs of monodzukuri</td></tr>
<tr><td>(3) Advancement of monodzukuri technologies in small and medium enterprises</td></tr>
<tr><td>(4) Monodzukuri technologies contributing to building huge mechanical systems</td></tr>
<tr><td colspan="2">3. Strategic prioritized S&T (2)
Monodzukuri process innovations to solve resource, environmental, and population problems and serve as flagship Japanese technologies</td></tr>
<tr><td rowspan="5">2. Key R&D themes
Promotion of monodzukuri technologies (areas) with the potential for innovations and breakthroughs</td><td>(5) Monodzukuri technology to produce world-leading high value added materials</td></tr>
<tr><td>(6) Monodzukuri innovation using robots, etc. to cope with Japan's declining-population society</td></tr>
<tr><td>(7) Monodzukuri innovation using biotechnology</td></tr>
<tr><td>(8) Energy saving monodzukuri processes</td></tr>
<tr><td>(9) Resource-efficient, environment-conscious monodzukuri technology</td></tr>
<tr><td>2. Key R&D themes
Human resources development/exploitation and preservation (transmission) and refinement of skills</td><td>(10) Promotion of the development and exploitation of human resources in monodzukuri</td></tr>
</table>

this Strategic prioritized S&T, Japan recognizes that it is necessary, at this moment in history, to take full advantage of new scientifically-based knowledge in monodzukuri technology.

(2) Important R&D themes in (1)

(a) "Development of new measuring and analysis technologies and equipment, and new precision processing technologies to meet the needs of monodzukuri"

The objective of this R&D theme is to develop more advanced/higher precision basic technologies supporting next-generation monodzukuri innovation and technologies that contribute to realizing a monodzukuri environment facilitating collaboration of workers as well as to "visualize" the technologies that ensure safety of facilities and huge mechanical systems. Concrete items include the development of measuring and analysis technologies/equipment, development of precision processing technologies, sensing, and monitoring, and technical development for realizing more advanced technologies.[1]

(b) Key R&D theme: "Monodzukuri technologies contributing to building huge mechanical systems"

The objective of this R&D theme is to develop and accumulate total technologies with international competitiveness which integrate all element technologies, including measurement, design, materials, processing, simulation, monitoring, and others, in order to manufacture and construct large mechanical systems such as aircraft, jet engines, rockets, satellites, nuclear power plants, and the like.[1]

3-2 Nanotechnology and materials field

The promotional strategy for the "Nanotechnology and Materials Field"[10] in the Third Science & Technology Basic Plan also includes one Strategic prioritized S&T (out of 10 in the field) and two Key R&D themes (out of 29) which are related to monodzukuri measurement technologies. The content of these items is outlined below.

(1) Strategic prioritized S&T

"Advanced nanocharacterization and nanofabrication technologies" is mentioned as one Strategically prioritized S&T, aiming not only at observation of shape and structure, but also the development of analysis/physical property measurement techniques with nanometer resolution, dramatic improvement in fabrication techniques, and integration with measurement.[10] As the background for selection of this item, advanced nanocharacterization and nanofabrication technologies will enable technical progress not only in the Nanotechnology and Materials field, but also in other fields of advanced science and technology such as the life sciences and IT, and in environmental measurement and clinical medicine, and is expected to play an important role in creating international competitiveness in industry, beginning with manufacturing.

(2) Key R&D themes

(a) "Cutting-edge nano-measurement and nano-processing technology"

The objectives of this theme are to enhance the level of research in the Nanotechnology and Materials field, including discovery of new phenomena and new functions by the development of new monodzukuri measurement/processing technologies, and to expand the range of industry and strengthen international competitiveness by developing new measurement, processing, and analysis systems.

(b) "Measurement, processing, and creation technologies making advanced use of electron beam technology"

The aim of this theme is to contribute to the discovery of new phenomena and elucidation of principles in materials and ecosystems by further development of electron/ion beam, X-ray, and neutron beam technologies, in which Japan has a high accumulation of technologies, and to enable advanced use of these technologies to realize a more advanced level in industrial fields and strength the competitiveness of industry.

4 Monodzukuri measurement in "Future Science & Technology in Japan toward the Year 2035"

In "Future Science & Technology in Japan toward the Year 2035," four surveys were conducted in order to provide useful information when studying priorities in the Third Science & Technology Basic Plan.[11] Among these, the "Delphi Survey" and "Survey of Development Scenarios for Key Scientific Fields" mentioned monodzukuri measurement. In the Manufacturing field[12] of the Delphi Survey, "Techniques for practical use of measurement of length, displacement, and surface roughness to the angstrom level and measurement to the femtosecond level in manufacturing processes" was mentioned as a theme in the "Nano-processing and micro-processing technology" region. In the Nanotechnology and Materials field[13] of the Delphi Survey, nano-measurement is understood as the basis of nanotechnology fields such as nano-processing and nano-creation. This study also described nano-measurement and nano-processing as essentially two sides of the same coin. The Survey of Development Scenarios for Key Scientific Fields mentioned "measurement technologies" in its development scenarios. This study described measurement technology in chemistry as a systematized technology consisting of a combination of a number of individual technologies, noting that the technologies which support it cover a wide range of fields, and went on to argue that this is not limited to chemistry, but is also true of measurement technologies in other fields of science and technology.[14]

5 Monodzukuri measurement for assurance of product performance

5-1 Issues for assurance that products conform to specifications

(1) Identification of measurement conditions and interpretation of measurement results

To provide assurance that products have been manufactured in accordance with specifications, it is necessary, first, to derive the measurement timing and items from the design specification, and then to interpret the measurement results. Figure 2 shows an example of the necessary objects of measurement when manufacturing

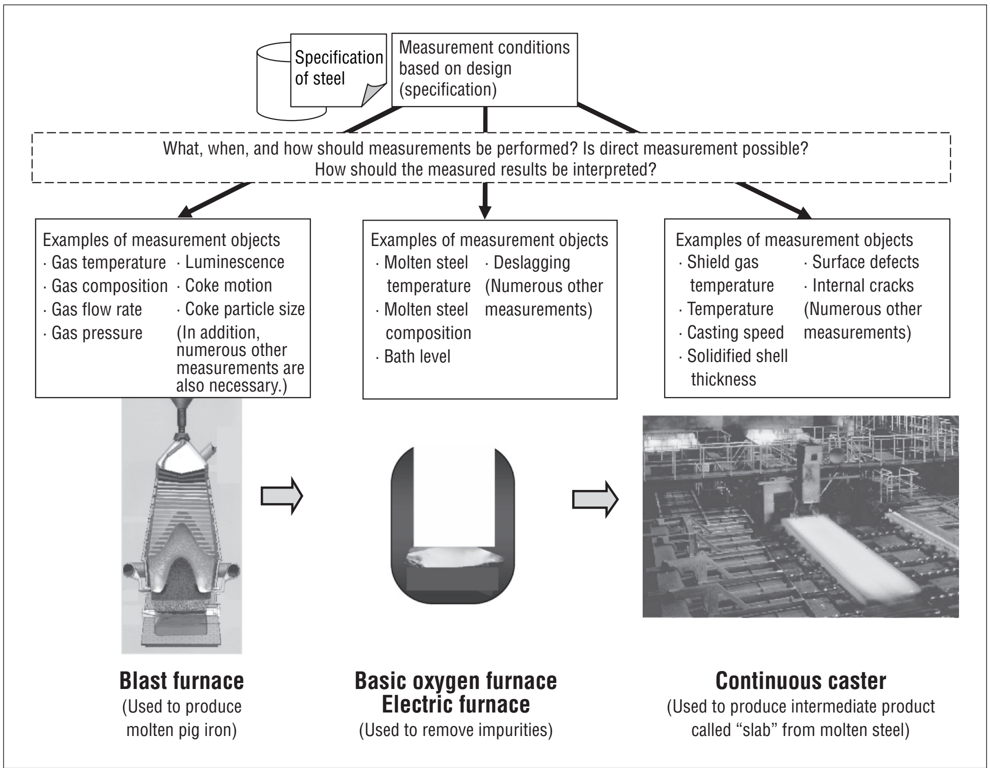

Figure 2 : Monodzukuri measurement for assurance of product performance; Example of manufacture of steel products

Prepared by the STFC based on references[15 and 16].

steel products. It is indispensable to derive the measurement conditions from the specification of the steel, which is determined in the design process. For example, in the manufacture of high quality steel, it is necessary to determine the timing of temperature measurements and the allowable limits of temperature as measurement conditions based on technical development extending over many years, and to interpret the measured results correctly.

(2) Selection of measurement method

As shown in Figure 3, even when simply measuring the diameter of a hole, measurement accuracy is higher when measurement is performed at 3 equidistant points than with 3 points in one part. Furthermore, because geometrical tolerances are applied to shape (See Figure 3.), measurement accuracy will differ depending on the positions measured. Thus, for high accuracy measurement, an appropriate measurement method must be selected, depending on the purpose. When measuring complex 3-dimensional shapes using a 3D measuring device, an angle exists between the surface being measured and the measuring pin of the device, and the position of the tip of the measuring pin in contact with surface will therefore change at the measurement location. For this reason, it is necessary to find a measurement method which is capable of measuring the surface shape with high accuracy. As mentioned previously, simply purchasing a high performance 3D measuring device does not guarantee that high accuracy measurement will be possible immediately.

(3) Separation and correction of error

- Correction of effect of temperature on measurement results

The temperature set as a standard in the specification when using machine tools and various types of manufacturing equipment is in principle 20°C. In design work, standard temperature can also be considered 20°C. However, because the temperature at production lines may reach 40°C, it is necessary to correct the measured results for temperature. Moreover, with increasing use of materials with different expansion coefficient in parts that require high, nanoscale accuracy, techniques for correcting for the effect of temperature on measurement results have become even more important than in the past.

- Calibration of measuring devices

Measuring equipment include devices that use mechanically complex mechanisms or multiple light sensors. The relative positions of the parts that comprise these devices change over time, if only slightly. To correct for these changes, it is necessary to calibrate the device before measurement. In many cases, tools called artifacts are used in calibration.[5]

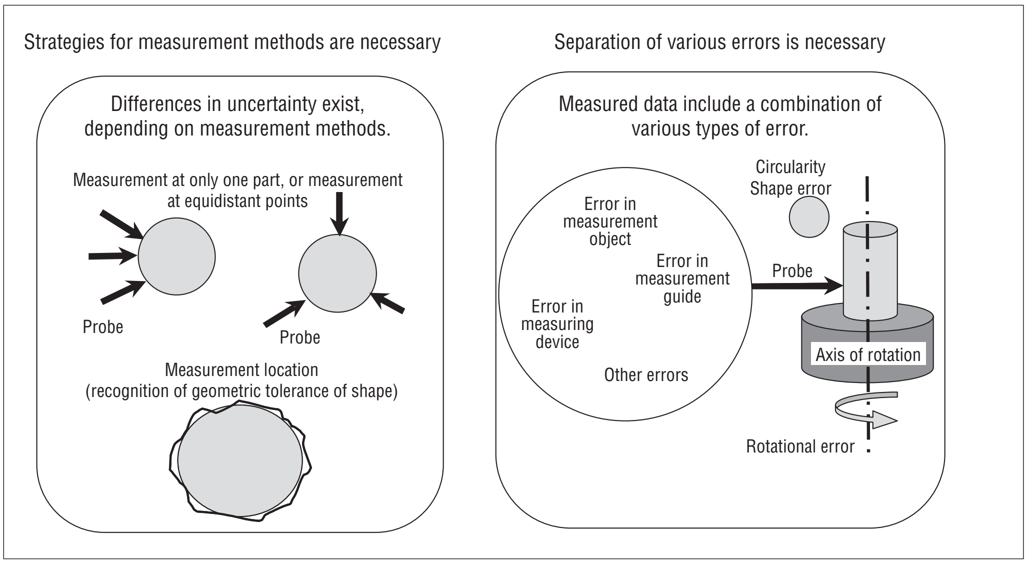

Figure 3 : Example of issues at manufacturing lines

Prepared by the STFC based on reference[17].

- Techniques for separating various kinds of error

In addition to error in the object of measurement, measured data also include error attributable to the measuring device, measurement guide, etc. It is therefore necessary to separate the error attributable to the object of measurement from the measurement results (See Figure 3.). Algorithmic methods based on numerical models of error are used in techniques for separating error.[5,17] Research and development on this subject takes advantage of applied mathematics.[17] Even in the measurement of circles, which appears simple at first glance, it is not possible to develop a measuring device without separation of error.

5-2 Issues for assurance of product quality under an international division of labor

With the progressive international division of labor and worldwide dispersion of manufacturing bases in today's global economy, it is necessary to secure international consistency in measurement standards in order to assure the quality of products which are manufactured using parts from different plants. This lends particular importance to Japan's efforts in international standardization in the area of monodzukuri measurement technologies. The Intellectual Property Strategic Program Promotion Network established in the Japanese Cabinet announced a "Comprehensive Strategy for International Standards" in December 2006, expressing the view that a strategic response to international standardization by Japan is necessary.[19] In international standardization, the viewpoint of healthy competition and cooperation with the Asian nations is important, as an increasing number of manufacturing bases under the international division of labor are expected to be located in these nations in the future. As part of this, it is desirable that Japan take the initiative in international standardization.[1,4] The following outlines issues for assurance of production quality under the international division of labor.

(1) Establishment of international traceability

To assure the absolute correctness of measurement results, it is necessary to establish traceability for physical quantities such as length.

For example, if a rotating shaft and bearing, each with a diameter and shaft hole of 20mm, are manufactured in separate countries, the methods of calibrating the measuring devices used to measure this 20mm must be consistent in the two countries. Problems will arise if the shaft or the bearing hole is larger than a true 20mm, exceeding the dimensional tolerance range, as it will be impossible to insert the shaft in the hole or the shaft will have excessive looseness, making it impossible to use these parts in products. In actuality, traceability cannot be called adequate in some countries where Japanese industries have established manufacturing operations.[5,7]

(2) Establishment of international notation system for parts

In part procurement spanning more than one country, parts which are different from the intended design may be produced if different methods of notation are used in each country. For this reason, the creation of standards for numerical notation of part dimensions, shape, and surface properties is important. It is necessary to incorporate a notation system for parts in standardization in the ISO (International Organization for Standardization). The ISO's TC213 (Geometrical Product Specifications: GPS) technical committee is creating a system of standards for accurate geometrical notation of the dimensions, shape, and surface properties of parts which is directly coupled with the functions of parts.[5]

6 Monodzukuri measurement for improvement of design and manufacturing processes

The selection of objects of measurement is determined by an analysis to identify which measurement locations will provide measurement results that are useful in improvement of the

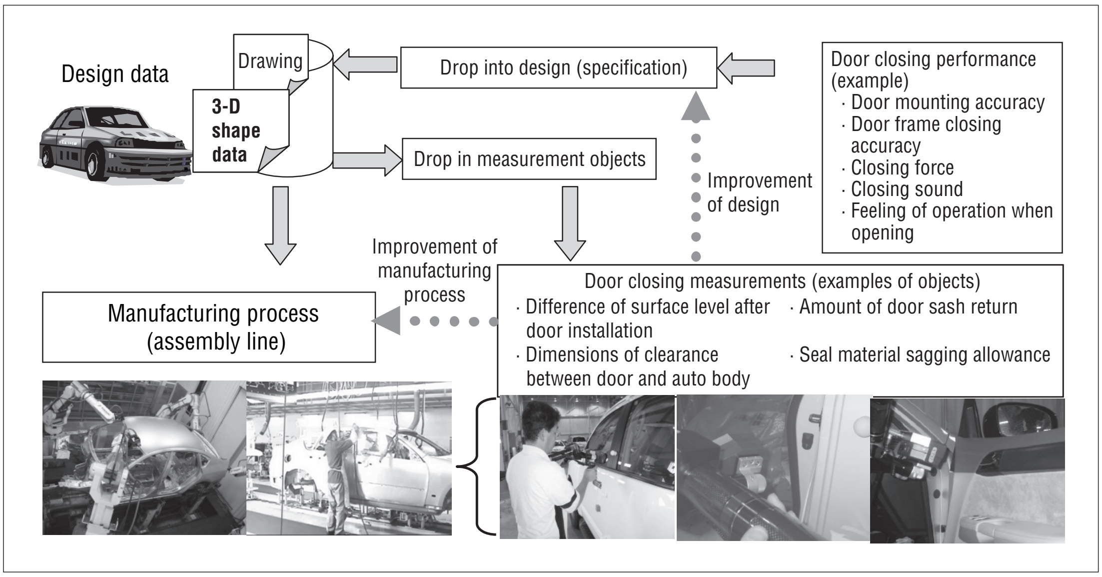

Figure 4 : Monodzukuri measurement for improvement of design and manufacturing processes: Example of measurement of automobile door closing

Prepared by the STFC based on reference [18].

design and manufacturing processes, based mainly on the design data. Without knowing the design, it is impossible to obtain useful measurement results, even if measurements are performed correctly. Thus, monodzukuri measurement for improvement of the design and manufacturing processes is performed as an integrated technology, including design, the manufacturing process, and measurement as such. Figure 4 shows an example of measurement of the closing of an automobile door.

In monodzukuri measurement for improvement of the design and manufacturing processes, technologies for comparison of design data and manufacturing site data and in-process measurement have attracted attention. The following describes these two technologies.

(1) Technology for comparison of design data and manufacturing site data

This technology compares, for example, design data and data obtained by measuring prototype products or work ("work" refers to assembled or processed products before completion) in the manufacturing process. If differences are found between the two sets of data as a result of the comparison, the cause is identified and the design and manufacturing process are improved to eliminate the cause. Because measurement of the surface and 3-dimensional shape are possible with this technology, considerable more information can be obtained than with point measurements, and various types of analyses are possible using this information. Figure 5 shows an example of a study in which 3D shape data on a prototype product measured using a laser measuring device and 3D shape data prepared in the design stage using CAD were compared, and the cause of a difference between the two data sets was identified.

(2) In-process measurement technology

In-process measurement refers, for example, to measurement of a part being machined with a machine tool as the machining process continues during processing. The incomplete part being machined is called "work." In-process measurement is necessary to avoid gage deviations which occur when the work is measured after being removed from the machine or deviations in the mounting position of the work. Because in-process measurement is performed while the machine is actually moving, the measuring device must satisfy specifications that minimize the effect of moving structural parts of the machine, such as the tool which may hinder measurement, vibration of the machine, and similar factors. Figure 5 shows an example of in-process measurement for analysis of the manufacturing process in a processing line.

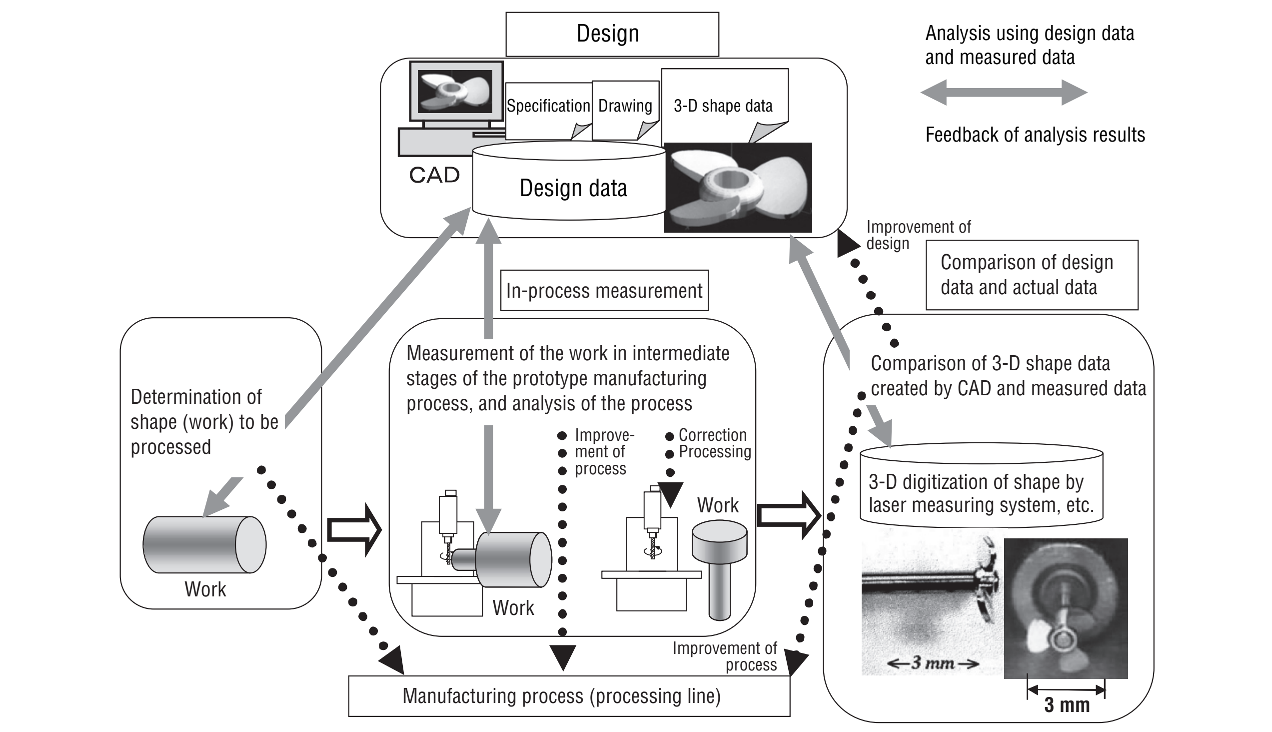

Figure 5 : Examples of comparison of design data and actual data and in-process measurement

Prepared by the STFC based on reference [5], referring to [6, 7], etc.

7 Monodzukuri measurement for elucidation of phenomena

Monodzukuri measurement for elucidation of various types of phenomena that occur in manufacturing processes from their mechanisms is also necessary. This requires a style of research and development in which measurement conditions are decided making full use of fundamental science such as solid state physics and material structural science, devices are created for these measurements, measurements are performed and a model is proposed, and finally the mechanism is elucidated. As an example of this type of research, Figure 6 shows the content of research to elucidate the joining mechanism in welding using the SPring-8, which is Japan's 3rd generation large-scale synchrotron facility.[20,21]

In order to elucidate the joining mechanism, welding researchers generally consider it necessary to measure the micro-phenomena associated with changes in the metal microstructure in the joint in time series with a temporal resolution of 0.05sec using the same moving heat source as in actual welding. This condition for resolution was derived theoretically based on metal microstructural science and joining science. To conduct experiments which satisfy this condition, R&D was carried out by creating an X-ray detector with 0.05sec temporal resolution and an experimental system for performing welding with a moving heat source inside an experimental hatch in the high-intensity beamline at SPring-8 (See Figure 6.). This research succeeded in observing the δ phase in the metallic microstructure which, among the micro-phenomena related to changes in the metal microstructure during welding, had not been well understood in the past. Measurement of the micro-phenomena associated with changes in the metal microstructure and elucidation of the joining mechanism will make it possible to establish stricter design specifications which satisfy product performance requirements. As a result, it will be possible to avoid unnecessarily high safety factors in structural design and to determine the period over which joint reliability can be guaranteed with higher accuracy.

On the other hand, similar research has also been carried out by physicists at the Lawrence Livermore National Laboratory in the United States.[22] Although that work has been praised

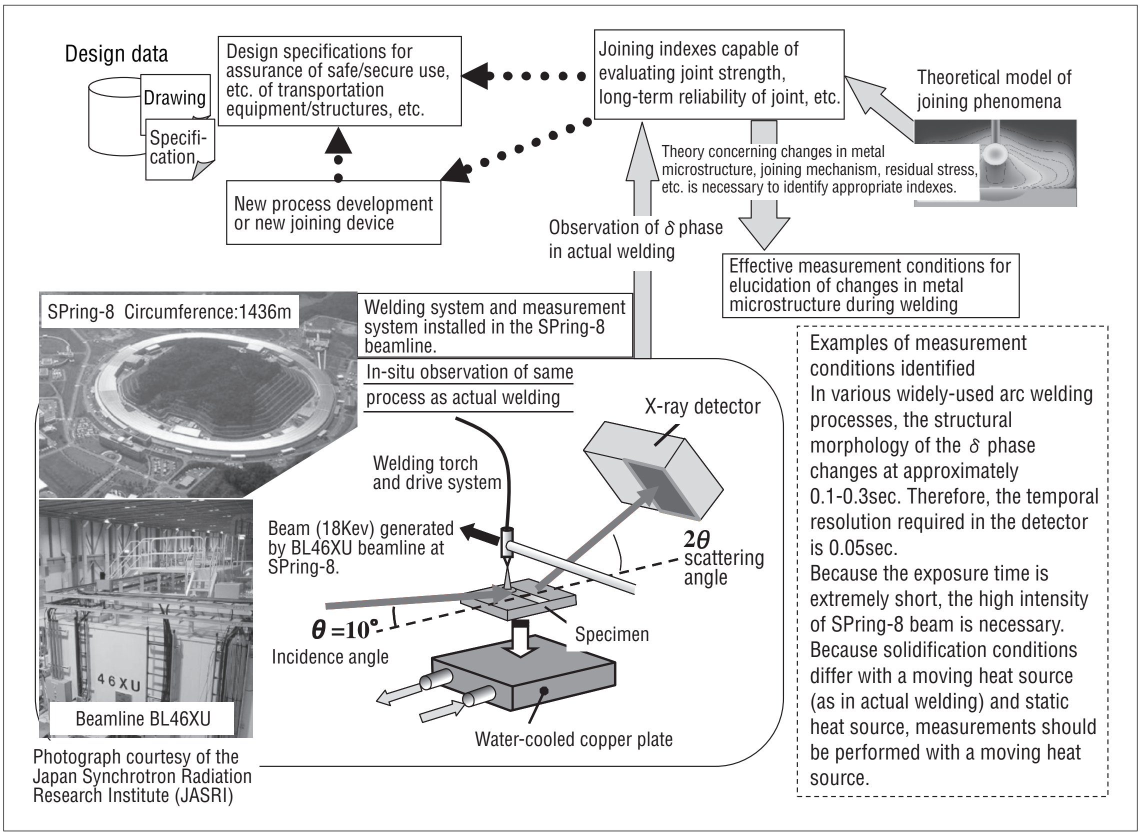

Figure 6 : Monodzukuri measurement for elucidation of phenomena: Example of elucidation of welding mechanism

Prepared by the STFC based on reference [21], referring to [20, 23], etc.

for its achievement in developing a technique for analyzing phase transformation in metals, a static heat source was used with the experimental measuring device, and not a moving heat source like that used in actual welding. Because the phenomena associated with changes in the metal microstructure are different with a static heat source, the results of this research is somewhat lacking in validity from the viewpoint of elucidation of phenomena in manufacturing involving joining by welding. It is more difficult to realize an experimental device with a moving heat source than with a stationary source. Thus, as described here, experimental research on manufacturing phenomena is the basis for R&D on monodzukuri measurement for elucidation of phenomena.

8 Important viewpoints for advancement of monodzukuri measurement

Although Japanese companies are now making daily efforts to enhance their international competitiveness in the face of fierce international competition, scientifically-grounded monodzukuri measurement will occupy an increasingly key position in maintaining the international competitiveness of Japan's manufacturing industries in the future. The following summarizes the key points when considering monodzukuri measurement.

(1) In R&D on monodzukuri measurement, treatment as a composite technology including design, the manufacturing process, and measurement is indispensable.

The above-mentioned measures for the three types of monodzukuri measurement discussed in this paper may be summarized as follows.

(A) Monodzukuri measurement for assurance of product performance

In monodzukuri measurement for assurance of product performance, it is important to determine the conditions for measurement, including measurement points, measurement methods, types of data, and the like. These are derived from the design specification. Analysis of measurement results must be based on the design/manufacturing technologies. Techniques for correcting for the effect of temperature on measurement results, calibrating measuring devices, and separating various kinds of error are also necessary.

(B) Monodzukuri measurement for improvement of design and manufacturing processes

For improvement of the design and manufacturing processes, one key point is comparison of design data and measured data and analysis of shape differences discovered thereby. In in-process measurement on processing lines, measurements are performed while machines are actually in motion; therefore, measuring devices must satisfy specifications that minimize the effects of moving structural parts of the machine, such as the tool, which may hinder measurement, machine vibration, etc. Integration of design, the manufacturing process, and measurement makes it possible to realize monodzukuri measurement for improvement of design and manufacturing processes.

(C) Monodzukuri measurement for elucidation of phenomena

Monodzukuri measurement is also necessary for elucidation of phenomena in the manufacturing process based on the mechanism of those phenomena. Here, it is necessary to determine the measurement conditions and conduct R&D to elucidate the mechanism of phenomena taking full advantage of fundamental science, such as solid state physics and material microstructural science.

(2) As a national project, monodzukuri measurement should be discussed based on an overview of the issues involved as a whole.

Large-scale competitive funding by the Japanese government for measurement is provided under MEXT's "Development of Systems and Technology for Advanced Measurement and Analysis" program (distributed mainly by the Japan Science and Technology Agency).[24] In the "8 sector budgeting method for research and development responding to policy issues" laid out in 2006 by the Bureau of the Council for Science and Technology Policy, this program is focused entirely on the monodzukuri field.

Under this system, the following two programs are being developed with the aim of promoting development of the world's first/world's highest level measurement and analysis technologies and systems supporting original research activities.

I. Development of Systems for Advanced Measurement and Analysis (System Development Program)
   Development of measurement and analysis systems which can respond to Japan's advanced research needs by implementing activities from development of element technologies to application research and production of prototypes.
II. Development of Technologies and Techniques for Advanced Measurement and Analysis (Element Technology Program)
   Development of original element technologies which possess novelty and can be expected to improve dramatically the performance of measuring and analysis systems.

In this program, until FY2006, proposals for development topics were accepted only for the research development area related to systems used mainly in laboratory research (general area). However, beginning in FY2007, proposals in the development area related to systems that are expected to see use in applied situations (i.e., manufacturing sites) in the future, and not only in laboratory research, were added as new development topics. Due to the strong demand for concrete benefits from measurement and analysis technologies/systems when development is completed, the objectives of this program are not limited to "fundamental research," but also include development. Assuming this program leads to the development of world's first/world's highest level measurement and analysis technologies/systems, it will support original research activities. Moreover, results which will be useful in monodzukuri can be expected from the elucidation of phenomena in science-based manufacturing processes. A framework for the above-mentioned "Development of System and Technology for Advanced Measurement and Analysis" program is considered to contribute to (C) Monodzukuri measurement for eludication of phenomena, in the above item (1) Monodzukuri measurement as a composite technology of design, the manufacturing process, and measurement.

Needless to say, these efforts alone cannot cover the entire research field of monodzukuri measurement as a composite of design, the manufacturing process, and measurement, as described above. To realize the Strategically prioritized S&T "Science-based 'visualization' technology for manufacturing that further advances Japanese-style monodzukuri technology," which was selected in the Monodzukuri Technology field, separate policies which contribute to R&D in monodzukuri measurement as a whole are necessary. Moreover, in the event that the development of new measurement devices is carried out in the future under such a program, first, it will be necessary to establish a phase which takes an overview of the issues in monodzukuri measurement as a whole and clarifies the specifications required in new measurement devices, and then to carry out R&D on devices based on the required specifications identified as a result.

(3) Industry, academia, and government must strengthen efforts in the areas of international standardization and establishment of traceability.

A necessary requirement for quality assurance in the global manufacturing economy is technology that supports international traceability by securing international consistency in measurement standards. Standardization activities are being carried out independently by various groups, including ISO standardization mainly by the academic community, creation of measurement standards by public research institutes, and creation of internal engineering standards by global corporations, among others. In the future, however, international efforts based on strengthened collaboration among industry, academia, and government will become necessary in order to strengthen Japan's international position. Likewise, from the viewpoint of healthy competition and cooperation with the Asian nations, it is desirable that Japan takes the initiative in promoting international standardization in the field of measurement to enable further progress in the international division of labor in the future.

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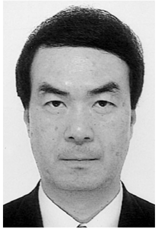

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