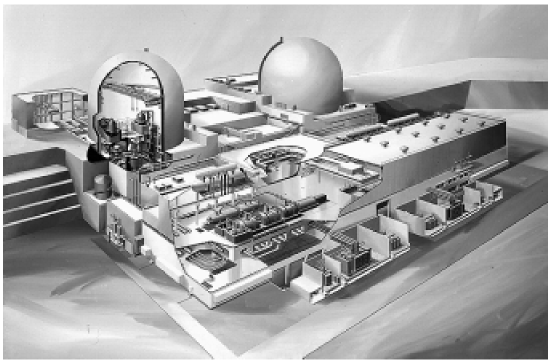

Towards Maintenance Service Supporting Secure Nuclear Energy

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With the recent deregulation of electric power supply, "maintenance optimization" has become important as a means of increasing economic efficiency while maintaining safety and reliability in nuclear power plants in Japan. Drawing upon an excellent track record of more than thirty years experience in activities ranging from the construction to maintenance of nuclear power plants, Mitsubishi Heavy Industries, Ltd. (MHI) makes every effort to provide advanced comprehensive engineering and highly reliable equipment, facilities, and on-site work, while positively carrying out various activities to meet customer needs from every perspective. Such service activities are supported by timely servicing through customer support and a wide range of support systems, and are expanded as activities of advancement developed in close cooperation with customers.

1. Introduction

Because of the primary importance of safety in the operation of any nuclear power plant, great attention has always been given to effective maintenance activities in nuclear power plants. In this regard, nuclear power plants in Japan have achieved a good track record compared with many other plants in the world. The concept of preventive maintenance, which seeks to prevent the occurrence of any trouble before it can occur in order to maintain the integrity and reliability of the equipment and facilities of a plant, has been a key factor to achieving high levels of safety and reliability. In recent years, proper preventive maintenance has become increasingly important in coping with the degradation of plant equipment due to aging, especially as older nuclear power plants that first started commercial operations in the 1970's reach thirty years of continued, long-term operation.

However, since deregulation of electric power supply was approved by the revision of the Electric Utility Law in 1995, improved economic efficiency has become increasingly important in assuring the price competitiveness of nuclear power plants as major producers of electricity. For this purpose, positive activities have already been initiated with respect to implementing advanced maintenance and advanced operation and servicing in order to realize the two seemingly conflicting requirements of improved safety and reliability and increased economic efficiency and operability, at the same time. To support these activities, more advanced comprehensive engineering and equipment and installations of higher reliability need to be provided (**Fig. 1**).

To cope with such changes in the operating environment, MHI believes that a major goal of its post-operational service activities is to provide services that allow customers to operate their plants with greater ease. Such services are to be performed in cooperation with customers to the extent possible in order to reflect and meet the needs of the utilities in these services more accurately.

2. Present State of Service Activities

Since the construction of The Kansai Electric Power Co., Inc. Mihama Unit 1, which first started commercial operation in 1970, MHI has accumulated extensive ex-

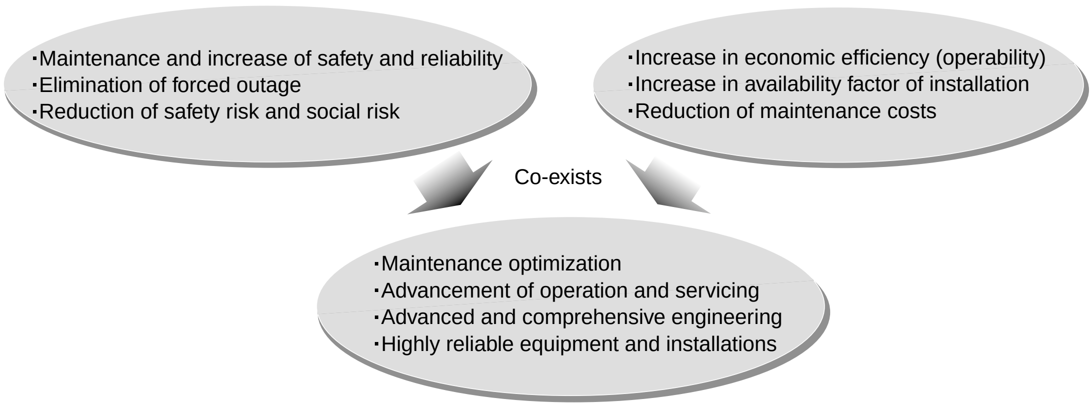


Fig. 1 Requirements of advanced maintenance

perience and an impressive track record on services ranging from the establishment of maintenance plans to the development of new technologies and execution of construction work. This has been done in close cooperation with utilities as customers and has drawn upon the comprehensive capabilities of MHI as a builder of power plants.

MHI has performed various activities to meet the recent needs of advanced maintenance and operation putting this experience and track record to good use in order to achieve the goals of:

(1) providing advanced comprehensive engineering, and
(2) providing highly reliable equipment, installations, and on-site work.

A brief overview is presented here of the current state of the activities being undertaken by MHI in the following fields.

(1) Establishment of maintenance plans and development of maintenance technologies
(2) Establishment of designs to enhance and plans to improve plants and equipment
(3) Customer service support

2.1 Establishment of Maintenance Plans and Development of Maintenance Technologies

2.1.1 Evaluation of the integrity of plants and equipment and the establishment of maintenance plans

(1) Plant Life Management (PLM) activities

Age-related degradation has become a matter of growing concern in the operation of older nuclear power plants. In response, the Ministry of Economy, Trade and Industry (formerly MITI at that time) established a policy on specific activities to address age-related degradation in nuclear power plants. This policy mandates that all major equipment that deteriorates over time is to be evaluated with respect to its integrity before thirty years has passed after the commencement of commercial operations, and further that the results observed are to be presented in a technical report on age-related degradation. This integrity evaluation is referred to as Plant Life Management (PLM) activities. Second and subsequent evaluations are to be conducted and reviewed every ten years, reflecting the latest knowledge in order to incorporate these advances properly in the maintenance activities of the plant (**Fig. 2**). Since the integrity evaluation in PLM is performed for all of about fifteen types of major equipment in nuclear power plants (approximately 2 000 items), it requires a considerable amount of operational effort. Consequently, evaluations must be undertaken not only to assure integrity in the short term but also to assure reliability and reduce maintenance costs in the long term, that is, throughout the service life of the plant for periods of as long as sixty years.

MHI carries out design evaluations based on (1) inspections and test databases of past operational experience, (2) study knowledge, and (3) the know-how of plant manufacturers to evaluate not only current integrity but also estimated degradation and possibility of age-related degradation in the future based on the latest knowledge and technologies. Since the applicable equipment involves a large number of design departments, MHI has established a department in-house that is dedicated to the transverse control of all the installations of an entire plant. The primary aim is to assure the consistency of the evaluation methods used between equipment and installations

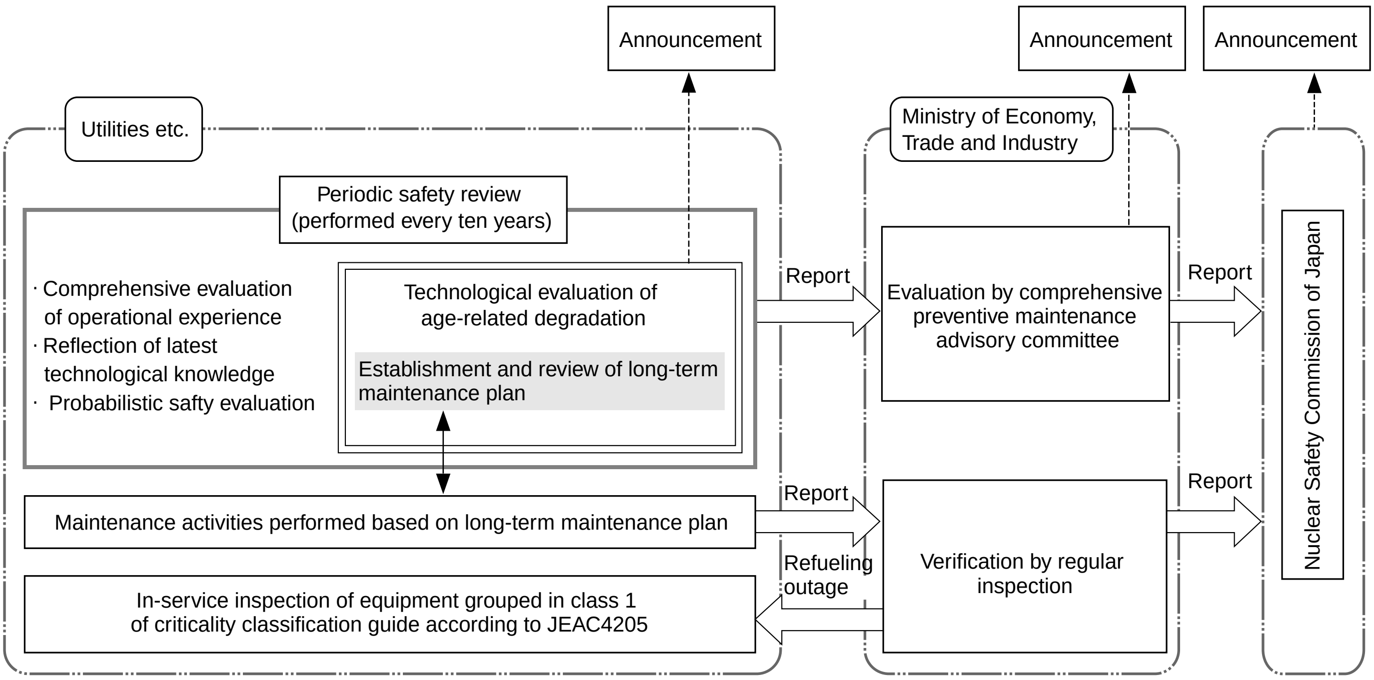


Fig. 2 Measure for comprehensive control of the age-related degradation of plant installations

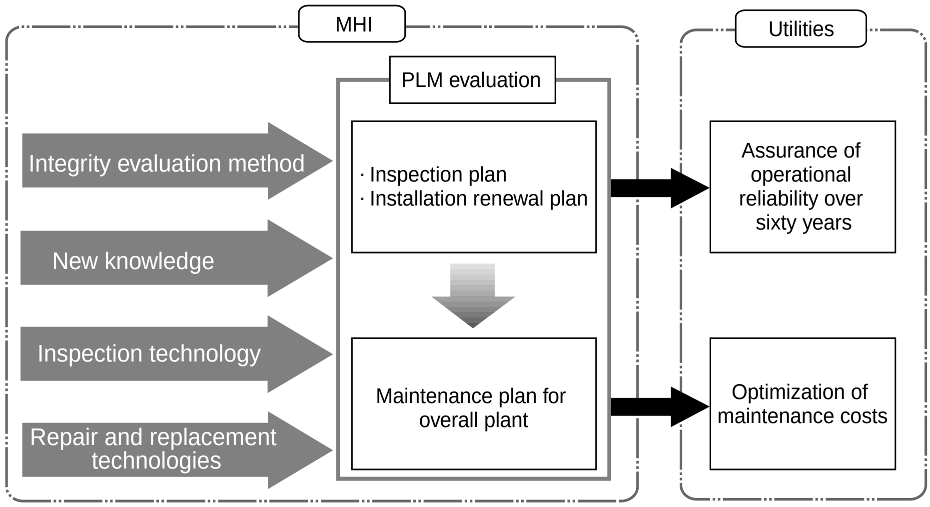


Fig. 3 Support system in PLM activities

and to summarize the information necessary to establish suitable maintenance plans, including inspection techniques and repair and replacement techniques in order to support customers from every perspective (**Fig. 3**).

(2) State of activities for comprehensive piping maintenance

In recent years, numerous problems have occurred with piping becomes evident as age-related degradation events and, therefore, proper maintenance must be performed against them. The modes of degradation and the causes of damage span a wide range. If maintenance is performed on similar parts each time a problem occurs, efficiency will be adversely affected and it will take a long time to complete necessary measures. Accordingly, MHI has proposes to its customers a comprehensive piping maintenance program as a comprehensive measure in which all piping is examined in order to establish an effective and reasonable maintenance regime.

The comprehensive piping maintenance program consists of the working procedures specified in **Table 1**.

Under the program, the operations comprising each step are advanced through the joint operation of MHI as a plant manufacturer and the user utility based on their respective roles. Together, they obtain fruitful results that achieve a high level of customer satisfaction through the joint conduct of operations aimed at effectively implementing the final maintenance plan while reflecting the specific needs of the user directly in the maintenance plan.

2.1.2 Development and verification of maintenance technologies

(1) Inspection technologies for steam generators

Since the inspection of large-sized equipment has a major impact on the refueling outrage process whereby plant operations are temporarily stopped, the need for increase in speed of the inspection is high to increase

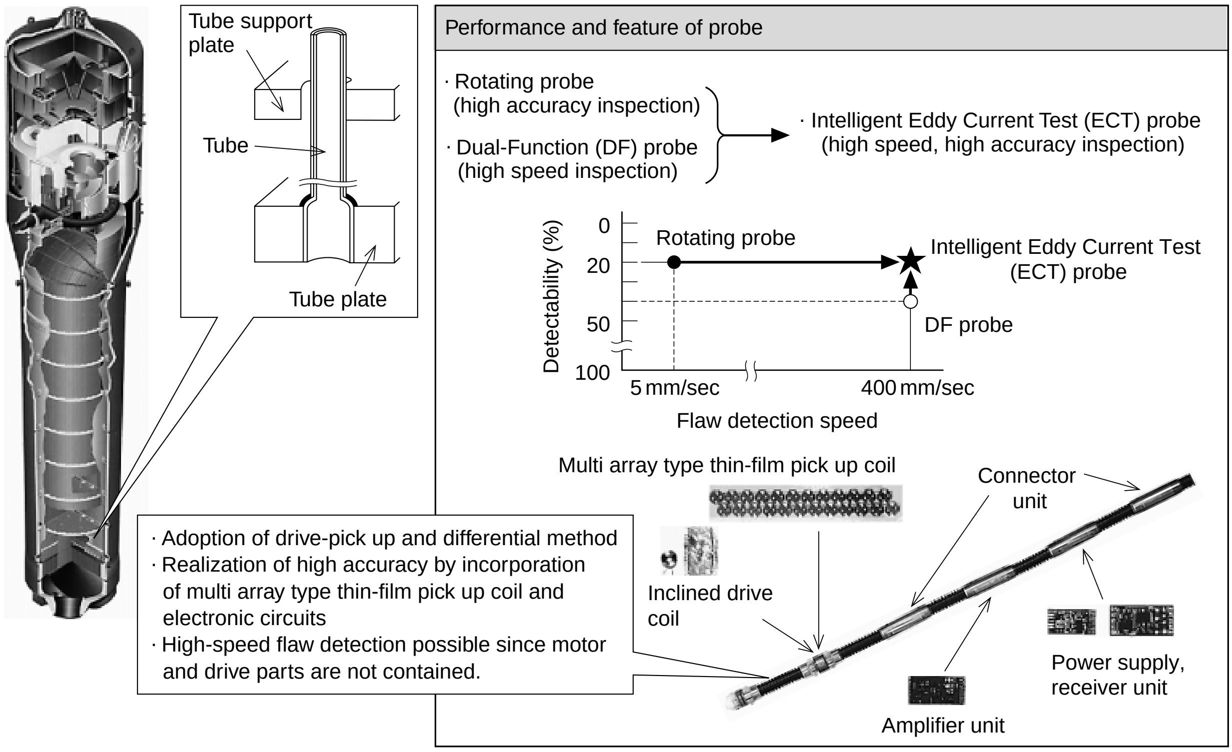
Table 1 Operating Procedure of Comprehensive Piping Maintenance Program

Item	MHI	UTILITY
(1) Classification and arrangement of actual events on piping. · Collection of the cases and study knowledge on piping in and outside Japan	○	—
(2) Arrangement of possible degradation events and screening conditions. · Preparation of FT (Fault Free) chart · Collection of experimental data on screening conditions.	○	—
(3) Preparation of extraction flow (for each degradation event) for applicable portions · Preparation of narrow-down procedure (flow chart) by conditions allowed to be narrowed down (temperature, flow velocity, material).	○	○
(4) Preparation of maintenance work sheet (piping isometrics), and extraction of portions suspected of being damaged based on extraction flow. · Preparation of piping isometrics (after confirming as-built state in tests). · Coloring of range in which damage is suspected for each degradation event.	○	○
(5) Determination of priority order of maintenance work to be done based on work sheets and reflection thereof in maintenance plan.	○	○

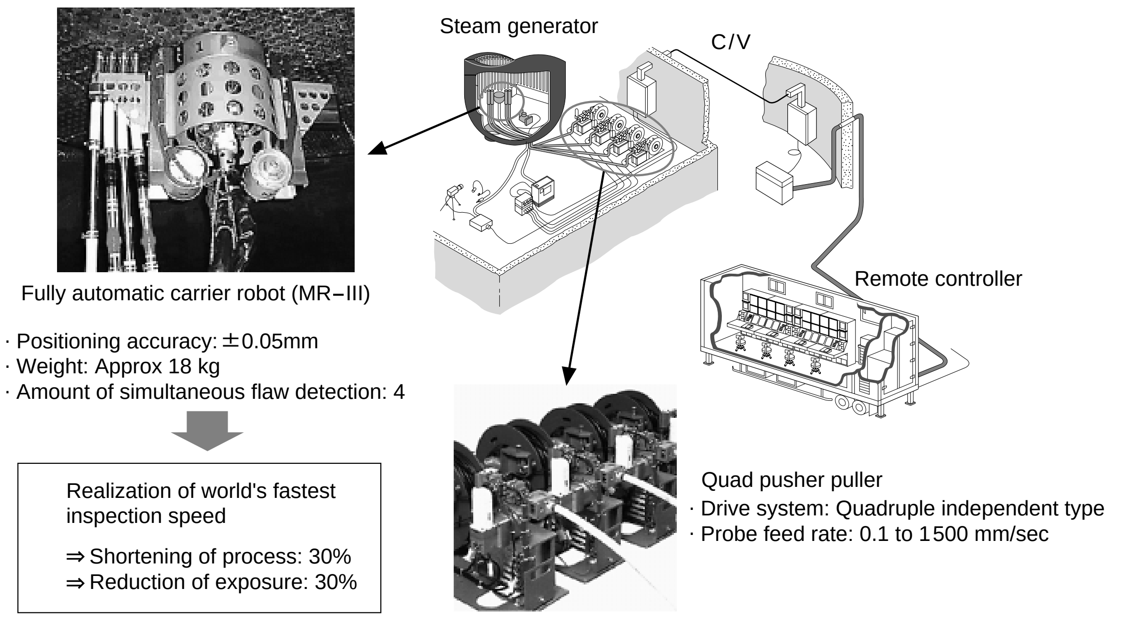
the availability factor of the plant. To meet this need, MHI has developed inspection technologies for tubes of the steam generator with a primary aim of increasing the speed of inspections.

One such technology is known as the intelligent Eddy Current Test (ECT). In a conventional inspection, a separate high-speed inspection and high-accuracy inspection were carried out since separate, dedicated ECT probes are used. In the newly developed technology, both high-speed and high-accuracy inspections can be performed with only one ECT probe. Thin-film coils for defect detection are arranged in an array shape and electric circuits are incorporated in the probe [**Fig. 4** (a)].

Another technology is the fully automatic flaw detection technique, which consists of a fully automatic carrier robot, a quad pusher puller, and a remote controller. A system has been developed to remotely detect four ECT probes simultaneously thereby achieving the highest level of accuracy and inspection speed in the world [Fig.4 (b)]. This fully automatic flaw detection system has been applied at The Japan Atomic Power



(a) Outline of intelligent Eddy Current Test (ECT) probe



(b) High-speed fully automatic ECT flaw detection system

Fig. 4 General outline of Intelligent Eddy Current Test (ECT) Probe, and high-speed fully automated ECT detection system

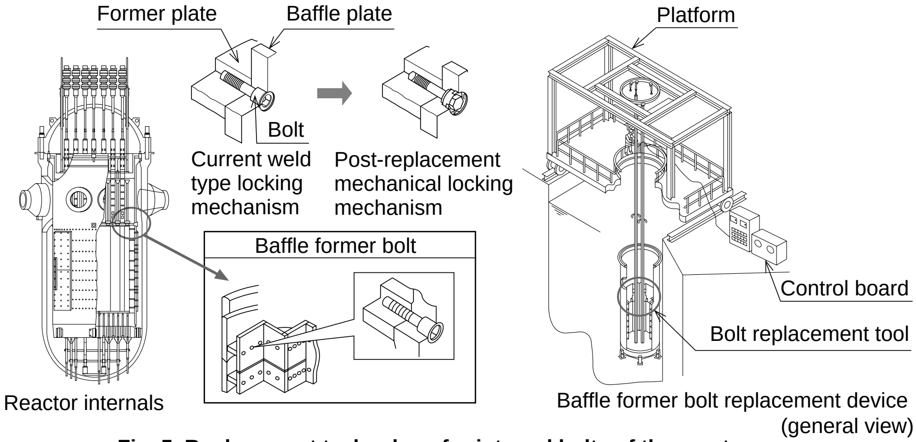


Fig. 5 Replacement technology for internal bolts of the reactor core

Company Co. Ltd. Tsuruga Unit 2, which recorded an all-time record for the shortest time required to complete a refueling outage (28.7 days) in July 2002. The use of this system contributed significantly to the achievement of this high-speed record.

(2) Reactor internal repair (replacement) technologies

Baffle former bolts inside a core are repaired or replaced, as necessary, as part of preventive maintenance in activities to apply lessons learned from cases of damage of overseas plants to domestic plants. In order to replace baffle former bolts, 600 or more existing bolts in water are sequentially removed under high radiation dose rate, and new bolts are installed. When installing new bolts, highly accurate bolt tightening control technique with ultrasonic method is adopted to prevent looseness. As a result, a high installation accuracy and high reliability are realized by remote control underwater (**Fig. 5**). Since this operation also greatly affects the refueling outage process, ways of shortening of the process were examined and careful training was conducted beforehand. As a result, a bolt replacement efficiency rate of as many as twenty bolts per day or more on average could be achieved in repair work done at the Mihama Unit 1 in October 2002, representing the highest on-site work rate level in the world.

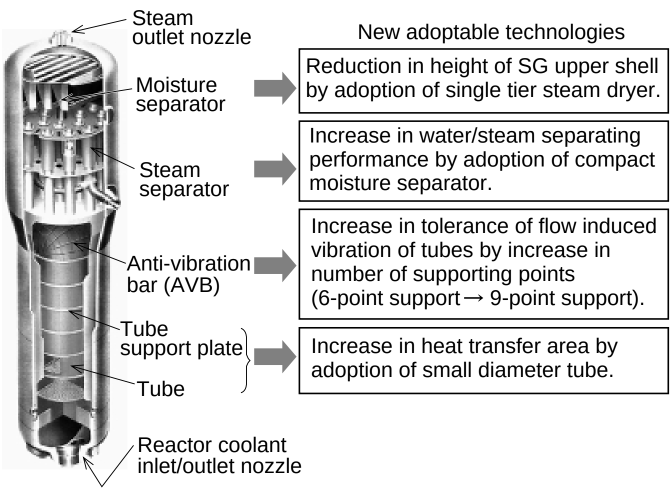


Fig. 6 Large-sized high-performance steam generator (SG)

There are also times when it may be more advantageous, from the perspective of long-term reliability and life cycle cost, to take more the drastic measure of replacing a set of equipment than to maintain it by replacing parts. To meet this need, MHI has developed replacement technologies and improvement design technologies for large-sized equipment. In addition to technologies to replace steam generators and reactor vessel heads, for which MHI already has established track records, MHI has recently developed and verified technologies for replacing reactor internals. In the future, the company plans to expand these technologies in actual work.

2.2 Improved design of equipment and scheme

2.2.1 Improved design of equipment for enhanced performance

The number of older plants that have been in commercial operation for more than twenty years are increasing. In the operation of these plants, it is important to assure the safe operation and effective utilization of the capacities of the plant and its installations. For this purpose, MHI actively takes measures to improve the design and increase the performance of equipment and installations whenever they are replaced.

(1) Primary system component

MHI has replaced steam generators and reactor vessel heads as part of measures against age-related degradation and preventive maintenance based on experiences in overseas plants. The replacement of steam generators has included adopting TT690 alloy with superior anti-corrosive characteristics as the material for tube, reducing the moisture of main steam, and developing a high performance steam generator with compact, high performance primary separators and increased heat transfer area (**Fig. 6**) to increase the efficiency of the turbine system. These latest designs have been adopted one after another. The replacement of reactor vessel heads has included improving material use and manufacturing methods as measures against stress corrosion cracking which was experienced in overseas plants.

(2) Turbine system equipment

Since an increase in the performance of the turbine system contributes directly to an increase in the performance of the plant, designs capable of providing a high level of efficiency are adopted when replacing equipment due to age-related degradation or in order to improve overall plant performance. In particular, designs are incorporated sequentially in the latest turbines in which a fully three-dimensional design blade is adopted and the LP turbine last blade is increased in length.

In recent years, turbine efficiency has been further enhanced by the development of new fully three-dimensional design blades taking into consideration wet steam characteristics, the adoption of new seal structures, and optimization of the shape of the blade rows entrance port (**Fig. 7**).

In addition, a specified amount of secondary system feed water is discharged outside of the system in order to control the quality of water in the secondary side of the steam generator. Since the recovery of heat from the blow-down system contributes to an increase in output of the plant, the effect of modifications and the materialization of the necessary contents of modification work are carefully examined for each plant.

2.2.2 Equipment improvement scheme for increase of plant output

In order to realize the economic improvement of nuclear power plants in the US, efforts have been made since the 1970's to increase the output of existing plants. In Japan, the controlled operation at rated thermal power was finally accepted in March 2002. With this as a turning point, efforts to improve output by increasing the efficiency of the plant and by increasing the output of the core itself have been attracting ever greater attention.

This means of increasing output is expected to provide more effect (10 to 15%) with the replacement of large-sized equipment however, since the major parameters of the primary and secondary systems will change, and it may affect plant design in the following areas:

- Reactor coolant pressure boundary components (by changes in temperature);
- Main Steam and Feedwater Systems (by changes in pressure and flow rate);
- Pressurizer-related installations (by increase in the amount of heat held by the primary system); and
- Equipment of the Residual Heat Removal System (by increase in core residual heat).

For future increases in output, the degree of increase that can be expected must first be identified for each plant together with the range and degree of effect on the installations of the plant. These results then need to be reflected in the latest installation improvements for each plant. MHI has been advancing such technical investigation as the evaluation of increases in output through the adoption of various kinds of measures and verifying and evaluating the safety and integrity of nuclear power plants based on experience gained overseas.

2.3 Customer Support

The establishment of the above-mentioned maintenance plans and the technical developments based on it must be promoted in a timely manner by sufficiently reflecting the ideas and intentions of customers. From this perspective, MHI employs the following service system to promote effective maintenance activities in corporation with customers.

(1) Customer-adhered support service

A dedicated service manager is posted at each power station so that information can always be promptly provided to customers in a manner most convenient for customers on-site and customer needs can be obtained at an early stage through close communications with customers.

(2) Support system that promises timely action

On the other hand, to realize the needs of customers, MHI has adopted the promotion system shown in

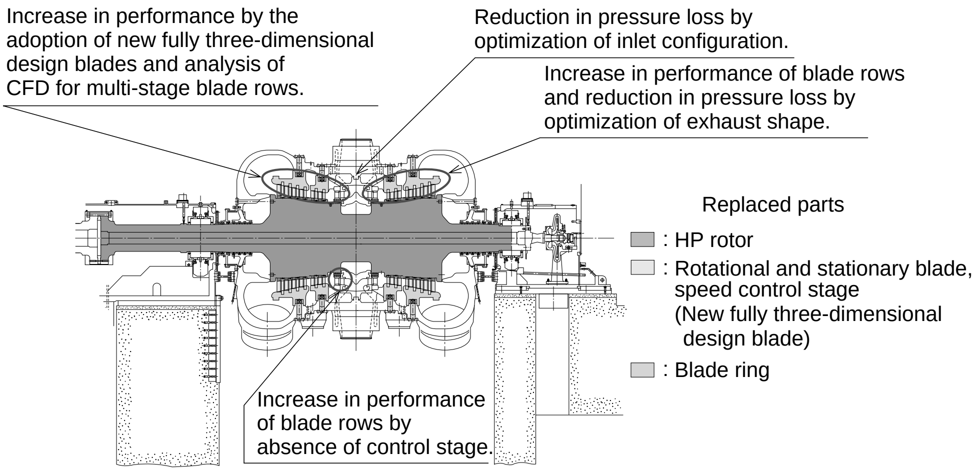


Fig. 7 High efficiency turbine (example of high-pressure turbine)

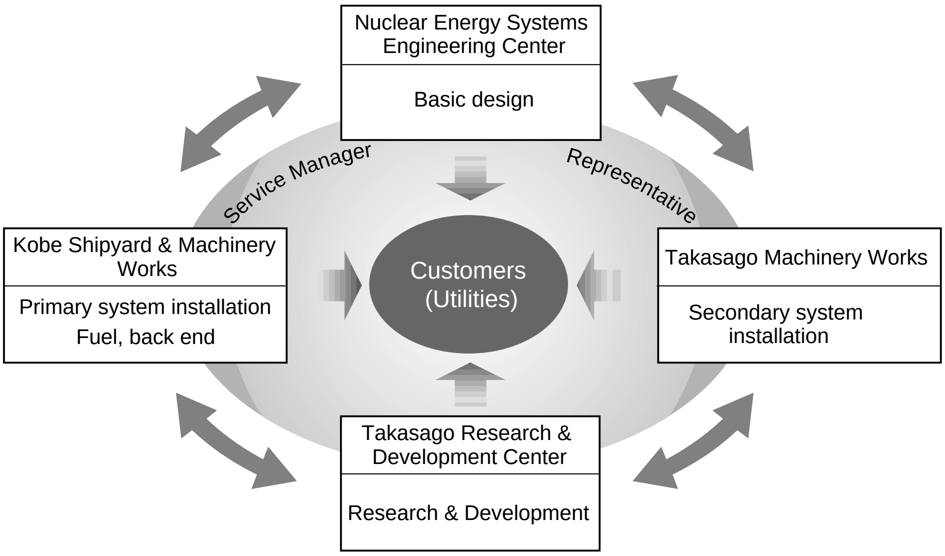


Fig. 8 MHI customer support system

Fig. 8 so that prompt action can be taken smoothly by any MHI works.

(3) Activities for advancement in cooperation with customers

MHI is moving ahead in the field of maintenance with preparations for the establishment of maintenance standards that address the age-related degradation of equipment. To evaluate the integrity of the equipment, further advances are necessary in inspection technology (quantification and increase in accuracy) and crack growth evaluation techniques need to be advanced. In addition, MHI believes that the risk of damage to equipment and the effects of such damage on safety must be discussed based on more quantitative maintenance data. From the perspective of "Maintenance optimization," MHI is also developing a risk-based maintenance technology as a technology for determining optimum maintenance measures based on maintenance data and estimated risk, and believes that it will to lead to the provision of more advanced servicing.

In order to promote the advancement and optimization of maintenance under such conditions, the customer utility and manufacturer need to undertake activities in cooperation with each other by sharing the operational experience of the utility and the technical knowledge of the manufacturer. MHI believes that vectors need to be matched to each other while discussing such issues through study meetings and promoting the better understanding between both parties.

3. Conclusion

MHI always strives to propose timely maintenance and improvement plans that reflect the needs of customers through the customer-adhered type customer support, and continually works to promote the development of the technologies that most effectively support such plans. Although this trend will continue to be pursued unchanged in the future, MHI seeks to provide careful, advanced engineering services that further increase the safety, reliability, and economic efficiency of nuclear power plants by sharing a wide range of maintenance information with customers.

MHI firmly believes that its mission and policy is to realize customer satisfaction that contributes to the activation and development of the atomic industry through these activities.

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