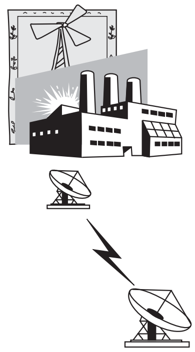


Power Systems: A Portal to Customer Services for Electric Power Generation

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With the recent deregulation of the electric power market, maintenance services of power generating equipment have also been undergoing significant change. This article introduces various customer services of Mitsubishi Heavy Industries, Ltd. (MHI) that accommodate this change, from the following two perspectives. (1) Feature of change in service: The service of power systems is shifting from the preventive maintenance to the minimum maintenance that is economical and reliable. (2) Notable technical factors such as high reliability, actual operating experience, novelty, etc.: In order to satisfy customer service needs, MHI has developed a range of new services including Plant Asset Management (PAM) as a new maintenance technology, the Mitsubishi Metallurgical Life Assessment System (Auto-MLAS) as a new inspection technology in pace with the times, and Remote Monitoring Support using IT technology.

1. Introduction

MHI has continuously striven to improve a wide range of technologies for power generating equipment, developing a wide range of new products that meet the needs of the times and providing them to the market in a timely manner.

However, the current deregulation of the electric power market has resulted in dramatic changes in the environment surrounding electric power systems. The field of maintenance services for electric power generating equipment has not remained unaffected by this trend, either. Preventive maintenance that had once been the prevalent approach of choice is being replaced by minimal service that seeks to ensure the reliability of the equipment as economically as possible. This has thus resulted in the need for new service technologies that have not been commonly known before.

This article introduces an overview of the efforts being made by MHI to develop corresponding customer services and some of the new maintenance technologies being developed that seek to keep pace with these changes.

2. Customer service support

MHI has designed, manufactured, installed, and maintained major equipments for entire thermal power generating plants and has delivered a great number of such equipments to customers in Japan and overseas. These equipments have been a major source of significant amounts of data, and MHI engineers have been able to accumulate extensive experience from these equipments, as well. This wealth of accumulated data and the technologies based on this extensive experience serve as the basis for the customer services provided by MHI. A brief introduction is given here of these data and related efforts.

2.1 Data accumulated

A look at major products for electric power generation delivered by MHI as an example shows that the company has delivered a total of 2 836 boilers, 1 459 steam turbines, and 401 gas turbines for as of April 2002. The large number of deliveries and data accumulated from these products serve as a major source of technical information that is important for the customer services provided by MHI (**Fig. 1**).

These data are managed in the form of a large database, with past specifications, operational information, and inspection and repair histories updated regularly.

2.2 Services by highly experienced skilled engineers

A significant amount of the data and information is accumulated in the form of hands-on experience of engineers who are respectively skilled in boilers, turbines, control, and operations. These engineers cooperate together in striving to meet customer needs for wide-ranged technologies related to power generation (**Fig. 2**).

2.3 Service based on technologies supported by managed data and experience

Various customer services performed based on technologies supported by well managed data and extensive experience are introduced below.

(1) Proposals for technical improvements, technical meetings, and thermal power generation seminars

An engineer is assigned to each customer who periodically provides that customer with technical proposals for improving the operation and maintenance of each power plant. Each proposal contains information on defects and failures, including those occurring in other plants of MHI, and repair plans that take into

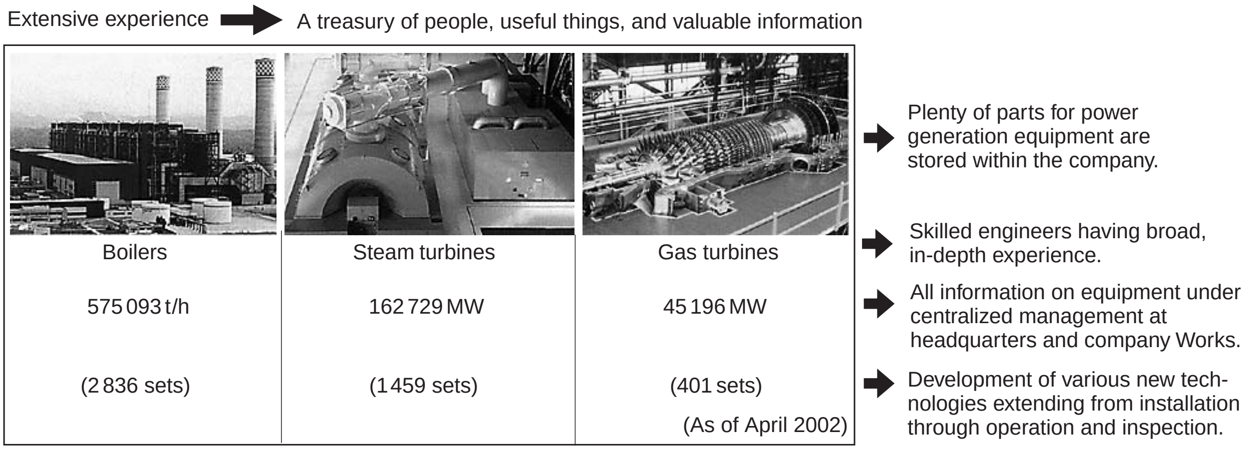

Fig. 1 Extensive experience extending throughout the world

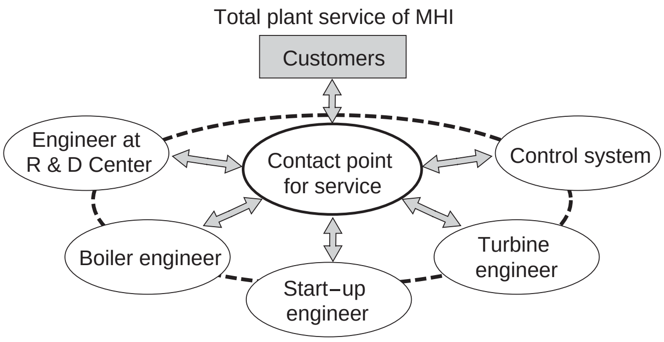

Fig. 2 Total plant services

account the individual needs of the customer.

In addition, MHI holds technical meetings and seminars on thermal power generation for customers in order that such information can be shared by all power plants for each company. This also facilitates the close and free exchange of information between customers and MHI.

(2) Finding the cause of defects and failures

When a defect or failure occurs, measures must be taken quickly to address the situation. In order to find the causes and prepare suitable countermeasures, complete analyses are necessary. Accordingly, MHI has the Works concerned and associated Research & Development Center investigate the causes drawing upon the extensive technical capabilities of MHI not only to address the problem but also to provide comprehensive customer services (**Fig. 3**).

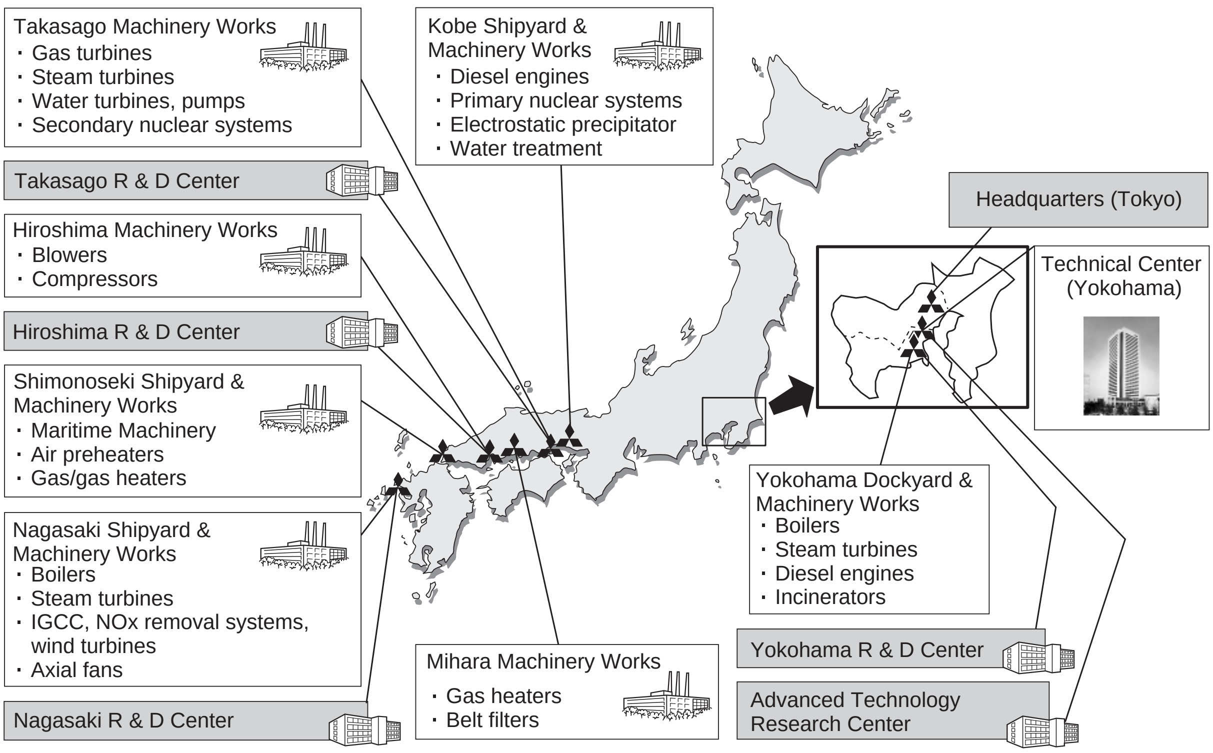

Fig. 3 R & D Center located adjacent to MHI Works

In the future, MHI intends to strive even more to enhance and make the most of these technologies supported by well managed data and extensive experience in order to provide services that fully meet and satisfy the needs of its customers.

3. Technologies that meet the needs of the times

The current trend toward deregulation of the electric power market has also resulted in the need for minimum maintenance that is both economical and ensures reliability of equipment. Accordingly, MHI is actively working to develop new products and service technologies that meet the most recent needs of the times, using its comprehensive and well developed technical capabilities. Several examples of these efforts are introduced in this article. These include Auto-MLAS, which realizes significant reductions in inspection times, and PAM, which is a method for planning maintenance strategies that optimize the economical inspection and maintenance of parts. MHI's Long Term Service Agreement (LTSA), which is increasing largely in combined cycle gas turbines for use overseas, and simulator based training are further examples of the positive efforts being made by MHI toward the technology transfer.

3.1 Auto-MLAS (MLAS: Mitsubishi Metallurgical Life Assessment System)

MHI has developed an Auto-MLAS method (For MLAS, refer to the later description) that can quickly assess the creep damage of low alloy steel used for the high temperature and high pressure parts of a thermal power plant, to the same level of accuracy as that achieved by a metallurgist. This method makes it possible to implement emergency or other suitable life extension measures according to the assessed residual life during the inspection period.

This method has also made it possible to reduce the time needed to complete an analysis and assessment from the former two or three months to just a few days. This is because microstructures obtained by a high resolution digital microscope (magnification ×1 000) can be automatically analysed by a computer image processor using this method. In the conventional technology, P (Precise)-MLAS, a metallurgist in a laboratory must examine replicas and carbon extraction replicas taken from the material surface by screening the location of inspection with an optical microscope (magnification 300×) , measuring the number density of creep voids with a scanning electron microscope (magnification 500×), and analyzing the distribution of the precipitates in the material with a transmission electron microscope (magnification 5 000×).

A brief description of the Auto-MLAS is outlined below (**Fig. 4**).

(1) Quantifying microstructure

In the welded heat affected zone of low alloy steel where creep-damage will be a problem, changes in microstracture appear during the first half of the material's life.

Observing this change with a microscope the martensite lath boundary (bamboo grass leaf-like

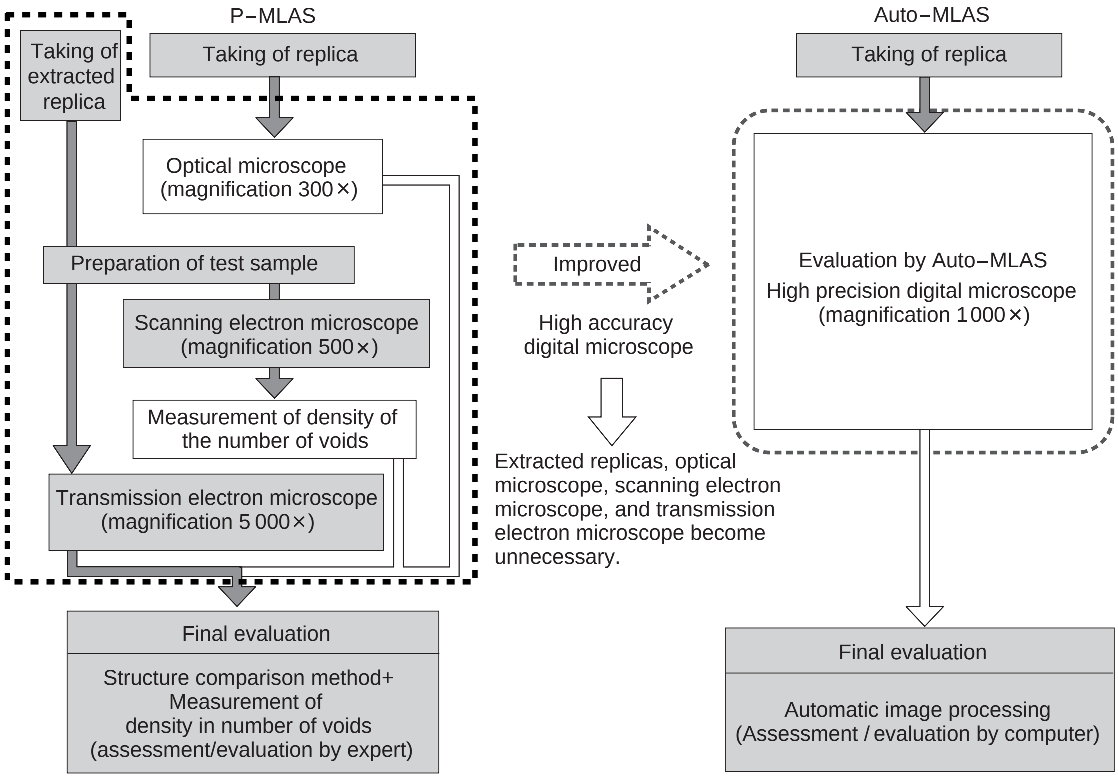

Fig. 4 Comparison of P−MLAS and Auto−MLAS

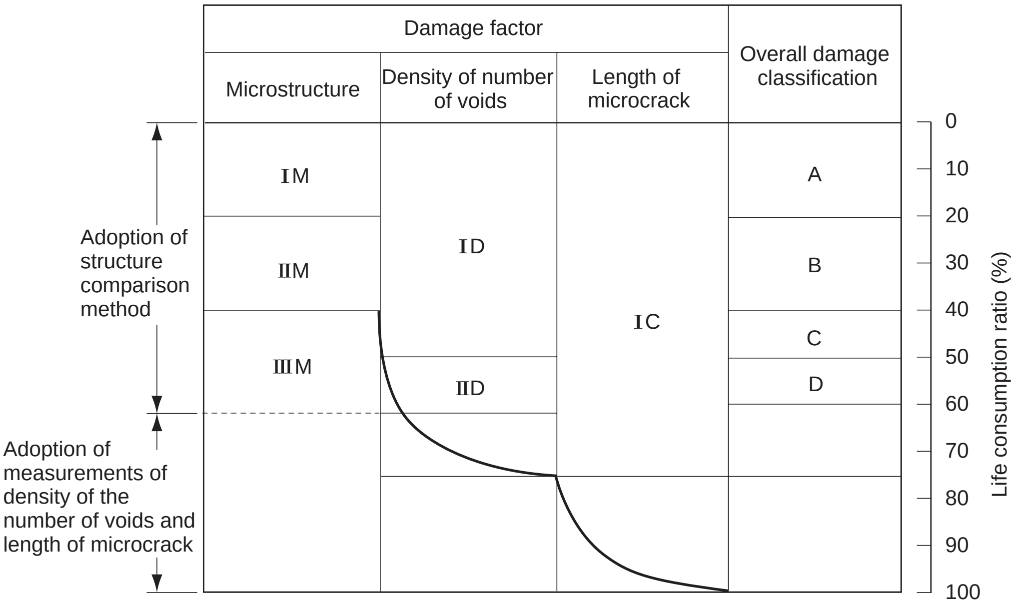

Fig. 5 Assessment diagram of Auto–MLAS

microscopic structure) comes to appear partly faded, with the progress of deterioration. The Auto-MLAS automatically distinguishes this deteriorated lath from sound lath structures with an image processor and assesses the extent of creep-damage from the percentage of sound lath remaining especially for the first half of the life of the material.

(2) Quantifying creep voids

Microstructural deterioration occurs during the first half of a material's life, while during the latter half, the increase in the number of voids (minute cavities produced at boundaries between crystalline grains) and their coalescence results in the growth of a crack, that is to say, physical damage progresses. The Auto-MLAS automatically counts the number of voids, distinguishing the cavity-like images like inclusions or dust particles on replica, calculates the number density of voids, and assesses the extent of creep-damage.

(3) Life assessment of material by Auto-MLAS

Fig. 5 shows a life assessment diagram of the Auto-MLAS. The extent of progress of damage is assessed classifying the percentage of sound lath remaining into three levels, and classifying the growth of voids into two levels, for the first half of the material's life.

For the latter half of the material's life, the life is assessed by the number density of voids prior to the formation of microcracks and by the measurement of the length of the longest crack once they form. The assessment system is installed as software in a computer, so that the life can be quickly assessed after observation of the microstructure of the subject material. In addition, the measuring accuracy of the Auto-MLAS has been verified to be equivalent to that of the conventional P-MLAS.

MHI uses numerous patents that it has developed, including for Auto-MLAS, in its comprehensive remaining life diagnosis technology that integrates the surface damage inspection technology based on Auto-MLAS with technologies related to impurity analysis and crack propagation analysis. Indeed, the diagnosis technology may be said to be the world's top class inspection technology (**Fig. 6**).

3.2 PAM (Plant Asset Management)

For boiler and steam turbine equipment, MHI has developed a maintenance strategy optimization system known as PAM (Plant Asset Management). Under PAM, the inspection and maintenance procedures for components are optimized resulting from maximize economic value of the plant based on the importance and the future operation plans of the plant and the cost of the maintenance cost. A brief summary of the PAM system is outlined below.

(1) Outline of PAM system

The PAM system has made it possible to select the most economical maintenance strategy (the optimum maintenance contents and timing) from among various candidate maintenance items (replacing, repairing, or inspecting components, etc.) by predicting the economic risk that each part can no longer be used due to the failure.

A flow diagram of this system is shown in **Fig. 7**. In the first step, a "qualitative PAM" is applied to all components in order to classify them into components with greater need for maintenance due to higher risks and those with lesser need due to lower risks. Components that have been predicted to have higher levels of risk are then subjected to a quantitative PAM that seeks to determine the most economic and effective maintenance strategy that indicates both the optimum maintenance contents and optimum maintenance timing for each respective component. The quantitative

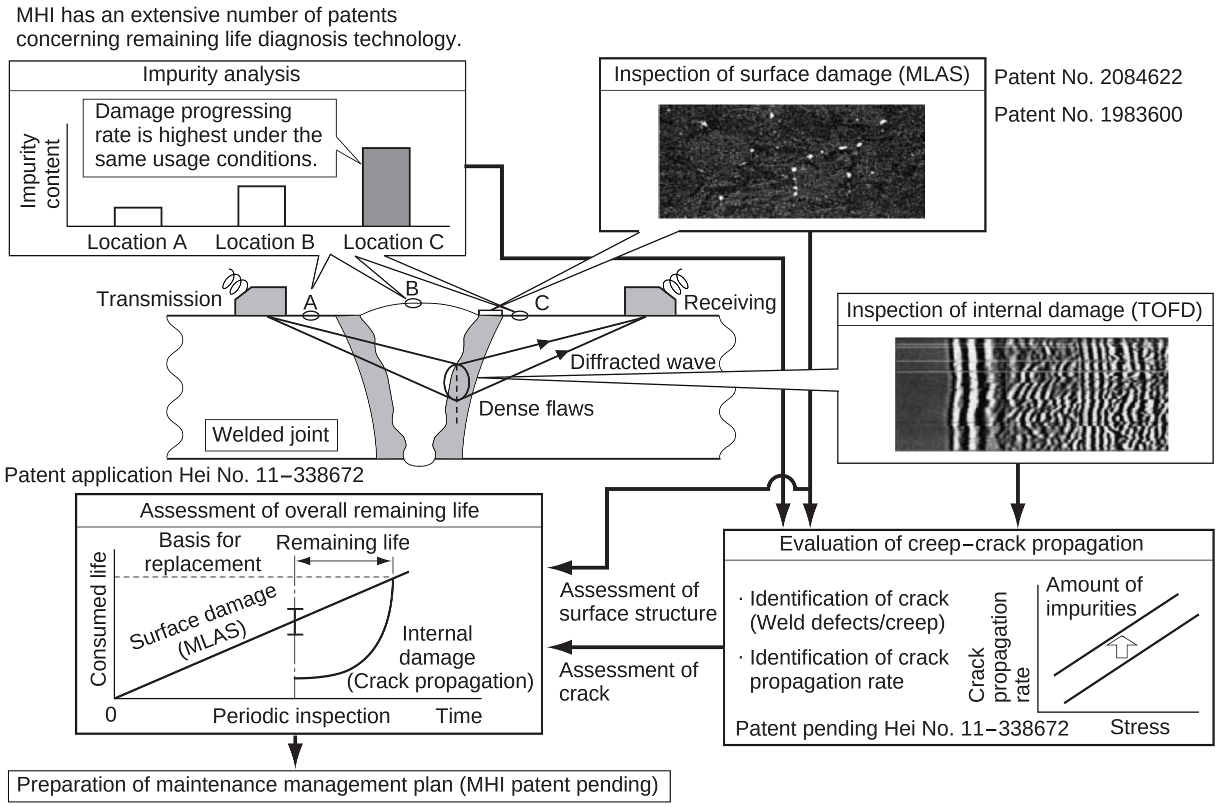

Fig. 6 Remaining life diagnosis technology

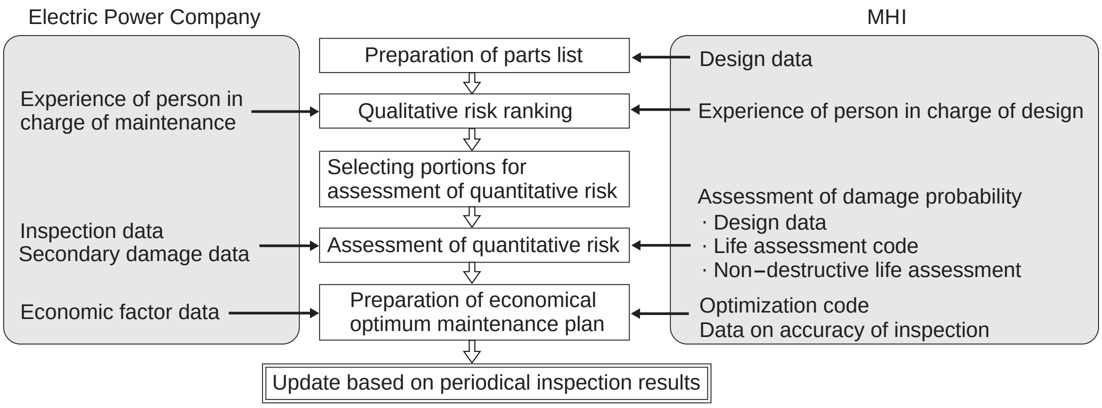

Fig. 7 System optimization plant maintenance strategy

assessment can respond to the changes in the importance of the plant, the future operation plans, and various restricting conditions (budget, etc.).

(2) Quantitative risk evaluation

The risk of a component is defined as the product of the cumulative probability that the component will fail before the plant is decommissioned and the amount of loss that would result due to the failure of the component (the sum of the cost to restore the failed component and the amount of loss due to forced stoppage of power generation). The probability of failure is obtained by applying the probabilistic life assessment technology developed and refined over many years by MHI and by considering the dispersion of the properties of the material and the fluctuation of the operating conditions. In addition, MHI has developed and applied the assessment code for the components that have already been inspected, the result of which can be used for the code to improve the accuracy of determining the probability of failure.

(3) Optimization of maintenance plan

As for the components assessed to have a high level of risk, a strategy for determining what kind of maintenance should be done and when it should be done most economically is obtained by the net present value method used for evaluation of investment projects. This system proposes the most economical contents and timing of the maintenance selected from several candidates as the optimum maintenance strategy.

This system has already been applied to some of domestic thermal power plants, and it is expected its scope of application will be extended in the future.

3.3 LTSA (Long Term Service Agreement)

Current changes in the environment surrounding the electric power market have led to a diversification in the range of need for after service care. LTSA can be pointed out as a typical example to meet such needs. The increase in such agreements is particularly notable in gas turbines for combined cycle plants overseas.

Mainly in the independent power producer (IPP) with gas turbine combined cycle (GTCC) equipment, there is a need for LTSA to set repair costs which can fluctuate greatly and comprise a substantial amount of the total cost of power generation. By controlling such costs, such agreements can help to ensure the profitability of the business.

In order to improve the rate of operation of a plant under an LTSA, specialists at remote monitoring centers described later monitor the trends of operational parameters to find a sign of any incident in them for 24 hours around the clock, thereby work to forestall any problems and prepare for prompt and emergency action in the event of an incident. The LTSA provides overall support for electric power generation, including the supply of necessary parts and the planning and implementation of optimum periodic inspections.

3.4 Training service using simulators

(1) Need for technology transfer

The deregulation of the electric power market in Japan will become full-scale in the future, with the result that the environment surrounding the electric power market will become more severe due to competition among existing electric power companies and newcomers. Furthermore, it is anticipated that ever-greater reliability will be required in electric power supply than up to now. In addition, the first baby boom generation to be born after World War II will retire within five years from now.

Under such conditions, new ways of actively and positively conveying technology using IT and other means will be required in the future, although most technology transmission has been done through OJT (On the Job Training) in Japan in the past (**Fig. 8**).

(2) Training service for customers

Training seminars on boilers, turbines, and their control systems are held for customers at the respective MHI Works. Simulators are actively used in many of these seminars.

Twenty years ago, computation took several hours for a several minute simulation, even in a simplified plant model. However, advances in simulation technology have progressed remarkably in recent years to the point where the simulation of a sophisticated plant model can be done more quickly than real time.

At present, the use of a precise simulator for both the static and dynamic characteristics of a plant can facilitate the understanding of even quantitative operational variables during training. In concrete terms, trainees can, for example, verify the changes in temperature at various locations in boiler caused by the variations of each one percent in fuel consumption (**Fig. 9**).

In addition, MHI has increased training effectiveness by combining simulations with Computer Aided Instruction (CAI) containing a collection of many questions on thermodynamics such as enthalpy. CAI has been developed for higher-level maintenance staff personnel and electric generation operators engaged in thermal power generating plants. The purpose of such instruction is to let trainees effectively understand the essence of design concepts and acquire know-how for judging situations properly and coping with different situation ever more effectively.

4. Remote monitoring technology utilizing IT

A brief introduction is given here of the remote monitoring support centers of MHI. The power system products of MHI function through the joint efforts of the Nagasaki Shipyard & Machinery Works, Kobe Shipyard & Machinery Works, Yokohama Dockyard & Machinery Works, and Takasago Machinery Works, with each product allotted to each MHI Works. Therefore, each MHI Works has its own remote monitoring support center.

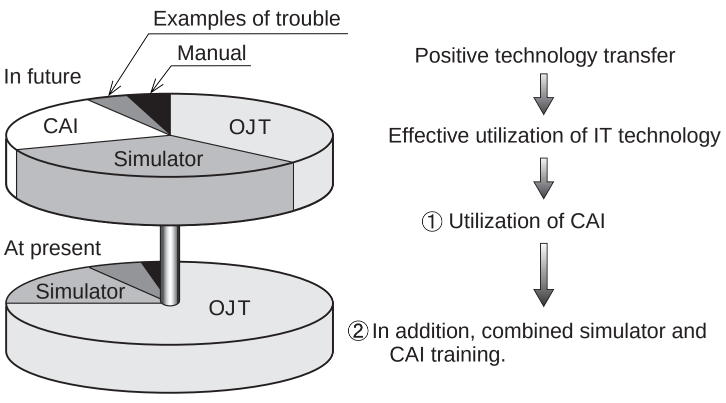

Fig. 8 Positive technology transmission

Fig. 9 Typical power plant simulator

4.1 Remote monitoring center

MHI supports the monitoring and maintenance of products delivered to customers from remote monitoring centers installed in the following four MHI Works using various IT technologies including the Internet, which has advanced rapidly recently. Each center organizes its own systems and places strong emphasis on security.

(1) "Remote Operation and Maintenance Assistance Center" of the Nagasaki Shipyard & Machinery Works

This Center was established for the purpose of monitoring the operational state of power generating equipment delivered to domestic and overseas customers, through networks such as private lines and the Internet. It provides also customers with various services including support menus.

In addition, the Center also provides the support services on the web in real time to assist in detecting irregularities in advance, restoring normal conditions, and managing maintenance data for periodic inspections for boilers, as well as for monitoring and collecting data.

(2) "Remote Monitoring Center" of Takasago Machinery Works

Always determining the operational state of combined cycle power generating equipment used mainly with gas turbines, this Center conducts technical services that provide information on the optimum maintenance and technical support of the operation of power systems. This includes information on deterioration damage of high temperature parts and the combustion vibration of combustors, the high level diagnoses of operation phenomena, and the like. In addition, the Center responds quickly to take various actions to prevent problems before they occur and support efforts to restore operations to normal in the event of a problem.

The Center also operates a continuous operation trend management system to control sophisticated phenomena, which are generally said to require higher experiences and knowledge. The system is organized so as to place emphasis on deviation- monitoring that determines the normal characteristics of each machine and piece of equipment and detects any machine or equipment behavior that deviates from normal conditions.

The Center is organized so that usual operation statuses are determined and analyzed and a global network of service groups can respond quickly to take actions beforehand for preventive measures and make decision in keeping with them on measures through the timely sharing of information.

The Center established the Mitsubishi Power Systems, Remote Monitoring Center, otherwise known as the MPS-RMC, in America in March 2002. The Center is always connected with MPS-RMC through IP-VAN lines so that the stream route of information is ensured and the cooperation of both the Centers and MPS-RMC contributes to the stable supply of electric power generated by customers worldwide (**Fig. 10**).

(3) "Customer Support Center" of Yokohama Dockyard & Machinery Works

A remote operation support system was developed at the Yokohama Dockyard & Machinery Works prior to the establishment of the present Center that automatically informed engineers concerned about problems via E-mail. The system was developed by MHI and commenced operation in 2000, connecting diesel generating stations installed in Niigata and Yamagata prefectures with the Yokohama Dockyard & Machinery Works.

When the Customer Support Center was established in December 2002, this system was extended and reorganized so as to accommodate services for all the power generating gas and diesel engines delivered by the Yokohama Dockyard & Machinery Works and to provide technical consultation and support that corresponds to the operational status of the equipment and systems.

Quick diagnoses are made by the Center of failures using data monitored on cylinder interior-pressure that changes on an order of micro-

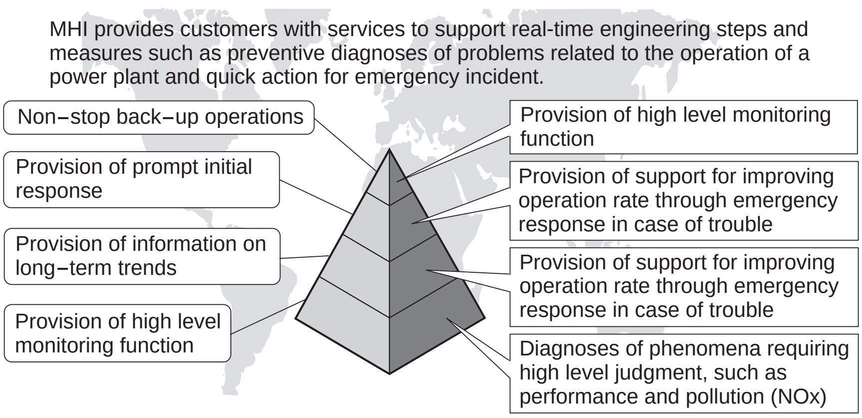

Fig. 10 Overall engineering service

seconds, combining the remote operation support system with a combustion diagnosis device (patent pending) (**Fig. 11**).

5. Other new technologies

MHI is also striving to provide customers with new technologies for power generation, as another major form of customer service. Examples of other technologies that relate to boilers, turbines, and diesel engines are introduced here.

5.1 Boilers

(1) A wide range of technologies other than those described above is also currently available to respond customer's requirements . The recent technologies are as follows: combustion technologies of various fuels such as Orimulsion(R), low grade coal, residual oil, RPF (Refuse Paper and Plastic Fuel), RDF (Refused Derived Fuel), etc.; NOx reduction technologies such as premixed combustion, in-furnace De-NOx systems, and high fineness pulverizers; as well as CO_2 reduction technologies, such as biomass and waste-firing.

(2) With the deregulation of the electricity market, equipment needs to be more reliable than ever in order to ensure the high availability of power plants to reduce power generation costs. To meet this trend , MHI is striving to develop new inspection technologies aimed at achieving higher levels of accuracy.

Other life assessment and defect detection technologies in addition to the Auto-MLAS method described in 3.1, include the "Time Of Flight Diffraction (TOFD) method", the "phased-array UT (Ultrasonic testing) method", the "welded part creep-damage assessment method based on an intergranular fracture resistance distribution model", and the "Helical skip UT method". MHI has developed and is practically using a boiler maintenance management system that manages the maintenance histories of boilers as a comprehensive management system that integrates these individual technologies.

In addition, the "catalyst regeneration" and "on-site regeneration of creep-damaged pipe welds" can be pointed out as technologies aimed at extending the useful life of equipment.

5.2 Turbines

(1) Typical examples of newly developed elemental turbine technologies include combustor technology for gas turbines, rotor and stator blades-cooling technology, Thermal Barrier Coating (TBC) technology, high performance fully three-dimensional airfoil technology for steam turbines, and Integral Shroud Blade (ISB) end blade technology. These new technologies are being tested to verify their long-term reliability. This is being done by practical operations carried out at the "T" point gas turbine combined cycle power generation plant verification facility at the Takasago Machinery Works, after being thoroughly verified by actual pressure combustion and the actual loading test stands of MHI (**Fig. 12**).

Fig. 11 "Customer Support Center" of Yokohama Dockyard & Machinery Works

Fig. 12 "T" point

These most advanced and verified technologies are also applied to existing machines to meet customer needs for improved economy and reliability.

5.3 Diesel engines

(1) The Kobe Shipyard & Machinery Works has acquired the sole sale and manufacturing rights to the Swirl Injection Principle (SIP) cylinder lubricating system in Japan, in cooperation with A. P. Moller, the world's largest Danish shipowner, and the Hans Jensen Lubricators company.

The Mitsubishi SIP cylinder lubricating system is an epoch-making lubricating system that remarkably reduces the consumption of cylinder lubricating oil and simultaneously minimizes the wear of cylinder liners and rings, compared with conventional injection systems. This system jet-injects cylinder oil directly to the inner liner wall of a cylinder at a high pressure and high injection rate utilizing air swirls produced inside a cylinder (**Fig. 13**).

It is reported that application of the system to an

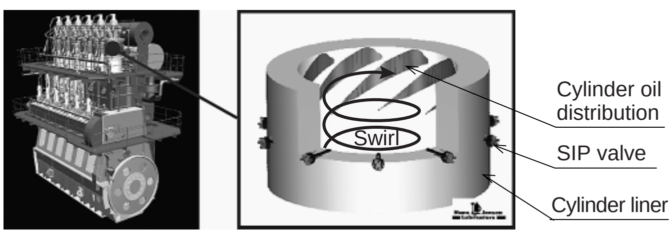

Fig. 13 Mitsubishi SIP cylinder oil injection system

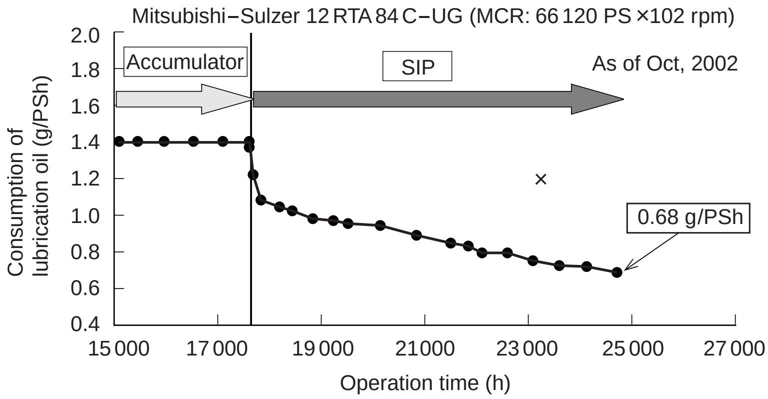

Fig. 14 Graph of cylinder oil consumption

in-service ship built by MHI has resulted in the consumption of cylinder lubricating oil to be reduced by as much as 50% or more (**Fig. 14**).

Since the reduction in the consumption of cylinder lubricating oil also results in reduced PM (Particulate Matter) emissions, an engine equipped with the Mitsubishi SIP cylinder lubricating system may be called an environmentally friendly engine.

Combining the SIP system with its own originally developed drive system, MHI has completed the Mitsubishi SIP system as a total system to reduce costs, ensure safe voyages of ships that are valuable assets for customers, and protect the environment.

(2) DOCTOR DIESEL

Kobe Shipyard & Machinery Works has developed a software application known as "DOCTOR DIESEL" that can be used to diagnose the state of a remote marine engine at a control room on land via satellite communication.

Information on about forty different kinds of performance parameter data measured in the engines operating onboard ships voyaging throughout the world is received by a server installed at the MHI Works via Inmarsat communication satellites. "DOCTOR DIESEL" then diagnoses the operational state of each engine based on the data received, and relays the results of the diagnosis back to each respective ship.

6. Conclusion

MHI intends to continue to strive to provide customers with ever better, ever more comprehensive services that effectively meet their needs in the future giving careful consideration to the changes in the electric power market and various environmental concerns. These aim at realizing further technology innovation and utilizing the merits of the extensive experience and expertise of the company as an overall manufacturer of boilers, turbines, diesel engines, and control systems for electric power generating plants.

POWER SYSTEMS HEADQUARTERS


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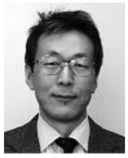
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