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DEVELOPMENT OF ADVANCED GAS TURBINE

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ABSTRACT

There is a strong demand for efficient and clean power generation systems which can cope with the energy shortage and the global environmental problems.

As one of the measures to meet this demand, Tohoku Electric Power Company, in cooperation with the three domestic gas turbine manufacturers, has been developing since 1989 the key technologies for the next generation high efficiency gas turbine of a 1,500°C class of firing temperature.

The aim is to achieve over 55%(LHV) thermal efficiency in a LNG combined cycle power plant.

In this research, Tohoku Electric Power Company have developed: (1) advanced cooling schemes for 1st stage vanes and blades, (2) heat resistant materials for 1st stage vanes and blades and (3) high temperature low NOx combustor, which are the key technologies required for realizing a 1,500 °C class high efficiency gas turbine with a potential for practical use.

1. INTRODUCTION

At present, a great variety of approaches are being employed in the world to cope with environmental problems like global warming.

Under these circumstances, a high thermal efficiency combined cycle power generation system, which uses a clean fossil fuel like LNG, is now being considered as one of the measures for solving these problems.

Recently, Japanese gas turbine technology has made a lot of progress and can put to practical use large turbines having firing temperatures as high as 1300°C class. The gas-steam combined cycle plant with this kind of turbines achieves thermal efficiency in the range of 51 to 54%(LHV).

This means that the new technology can improve the thermal efficiency of the conventional power generation system by 15 to 20 percentage points.

2. OPERATIONAL EXPERIENCE WITH HIGASHI NIIGATA THERMAL POWER STATION No.3

In Octorber of 1985, Tohoku Electric Power company started full commercial operation of Higashi Niigata Thermal Power Station No.3, the first Japanese large capacity combined cycle plant.

This plant is a combined cycle with a total outptut of 1090MW, consisting of two trains, each train being a multi-shaft type combination of three gas turbines, three heat recovery steam generators (HRSG) and one steam turbine.

The gas turbine employed has the firing temperature of 1,150°C. Heat losses of this gas turbine were reduced by the long size llast stage blade. And also the advanced cooling technologies were applied to the hot parts. Further a premixed type dry low NOx combustor was developed, in which low NOx emission was achieved without any water or injection into the combustor.

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The thermal efficiency of this plant was as high as 48% (at gross LHV), which is much higher than 44%, conceived as the limit of the conventional steam power generation at that time.

Since the beginning of commercial operation, the plant availability has been kept high.

Fiscal year	1985	1990	1993
Operating hours (hr)	8,185	8,760	8,760
Plant loss factor (%)	1.6	1.4	1.4
Total plant availability (%)	56.8	77.5	80.6
Gross thermal efficiency (% : LHV)	47.78	48.75	48.72
Net thermal efficiency (% : LHV)	47.02	48.06	48.02

Table 1 Operational Experience at Higashi Niigata No.3

Annual average gross thermal efficiency has been continuously maintained at a level of 48% (LHV) (Table 1), and no failures such as damage of facilities have been experienced so far under high temperature operating condition. In addition, througb appropriate operational controls, such as scheduled replacement of gas turbine hot parts, the reliability has been kept high.

3.BACKGROUND OF THE RESEARCH AND DEVELOPMENT

At the time Tohoku Electric Power company started to investigate the development of advanced gas turbines, our technical level had the limitation of a total plant thermal efficiency of 48% (LHV) which was achieved at the Higashi Niigata Thermal Power Station No.3. This limitation was due to the metal materials and cooling technology for blades and vanes.

The history of gas turbine development is one of aiming for higher efficiency tbrough higher firing temperature, and the world's target of the development of industrial gas turbines in those days was 1,300 °C class.

Under those circumstances, Tohoku Electric Power company decided to start the development of the required key technologies for the realization of a 1,500 °C class gas turbine. It was hoped that this would enable us to achieve a target of over 55% (LHV) total plant thermal efficiency.

For this purpose we made separate contracts with Hitachi Ltd., Mitsubishi Heavy Industries, Ltd. and Toshiba Corporation, which were representative of Japanese gas turbine manufacturers with excellent technology at that time, in order to proceed with the research, effectively utilizing their know-how for gas turbines and their facilities as much as possible. This research and development continued for 6 years from April of 1989 to March of 1995. In this research we developed: (1) advanced cooling schemes for 1st stage vanes and blades (2) heat resistant material for 1st vanes and blades and (3) high temperature low NOx combustor, which are key technologies required for realizing a 1,500 °C class high efficiency gas turbine with a potential for practical use.

4.OUTLINE AND RESULTS OF KEY TECHNOLOGY

4.1 Development of Advanced Cooled Turbine Vanes and Blades

The evolution of Turbine Inlet Gas Temperature as well as the 1st stage vanes and blades configuration, and cooling schemes eitbr used or studied are shown in Fig.1 and Fig.2.

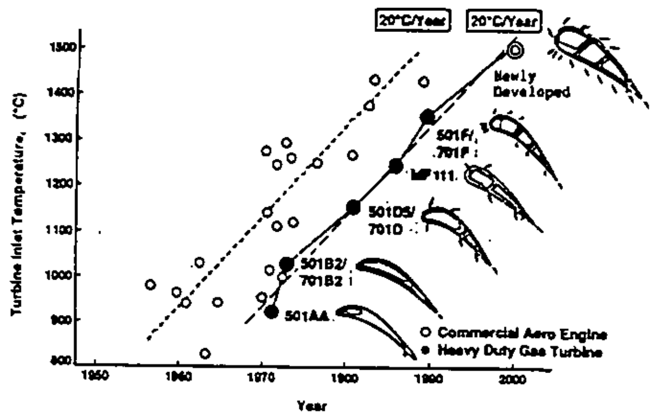


Fig.1 Evolution of Turbine Inlet Gas Temperature and Cooling Scheme of 1st Stage Vanes

In this research, the air cooling system using an advanced cooling structure was developed. The major details are as follows:

1. Film cooling of blades & vanes
2. Internal cooling structure by combining the full coverage film cooling (FCFC) for whole of the airfoil surfaces (Fig.3)
3. Serpentine flow passage structure with turbulence promoters such as angled or V-shaped staggered ribs etc.(Fig.4)

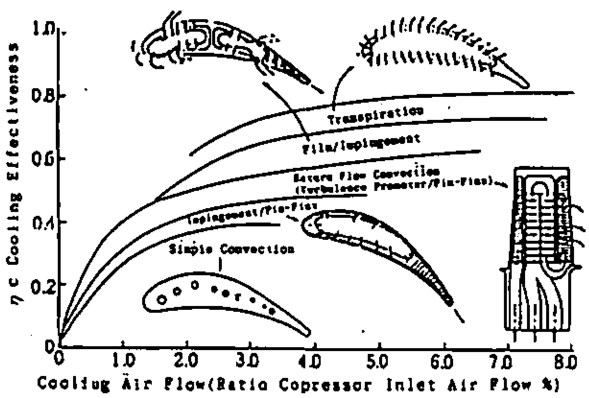


Fig.2 Cooling Scheme of Typical 1st Stage Blades

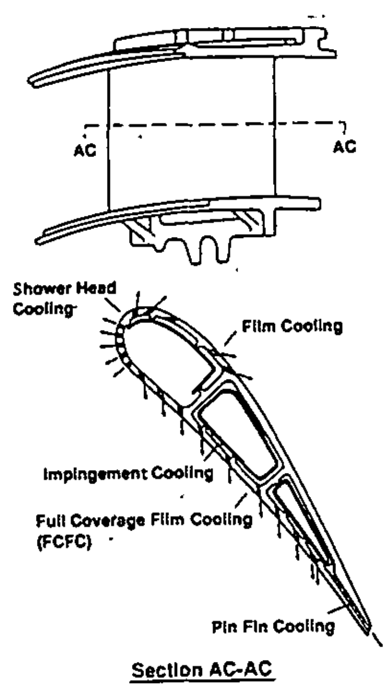


Fig.3 Cooling Scheme of 1st Stage Vane with FCFC

At the same time, the cooling scheme using steam, which has about 1.4 times the heat transfer coefficient of air (about two times for specific heat) as a cooling medium (Fig.5) was developed. Tohoku Electric Power Co., designed the 1st stage vanes employing the closed steam cooling system. The steam is delivered from HRSG and returned to the cycle at high pressure steam turbine.

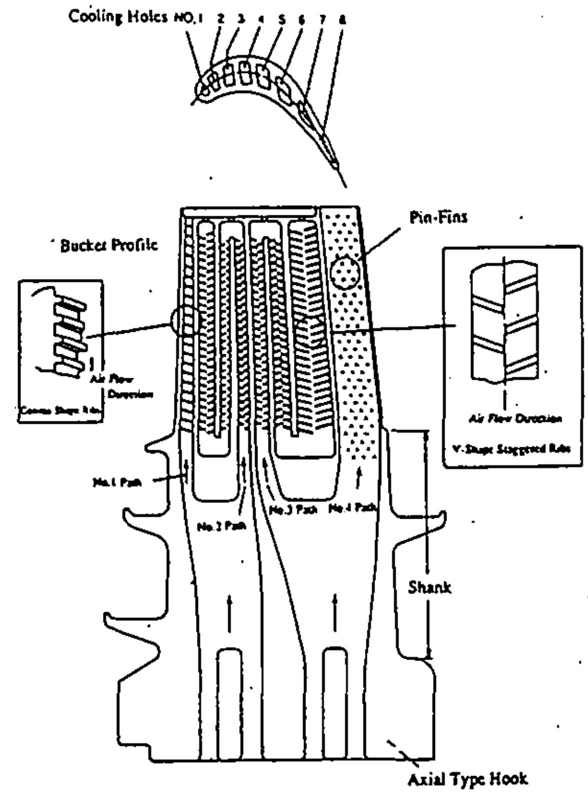


Fig.4 Cooling Scheme of 1st Stage Blade with Advanced Cooling Structure

Fig.5 Steam Cooled Turbine Vane

Tohoku Electric Power Co., manufactured the steam cooled 1st stage vanes model on a trial basis by incorporating improvements such as a combination use of the film air cooling from the results of thermal stress analysis.

To verify the developed cooling scheme for the 1st stage vanes and blades, under a 1,500°C class actual machine temperature condition, high temperature cascade test in the stationary condition, as well as high temperature demonstration unit (HTDU) test in the rotating condition were conducted with approximately 1/2 scale 1st stage vanes and blades built in a small size test gas turbine. (Fig.6)

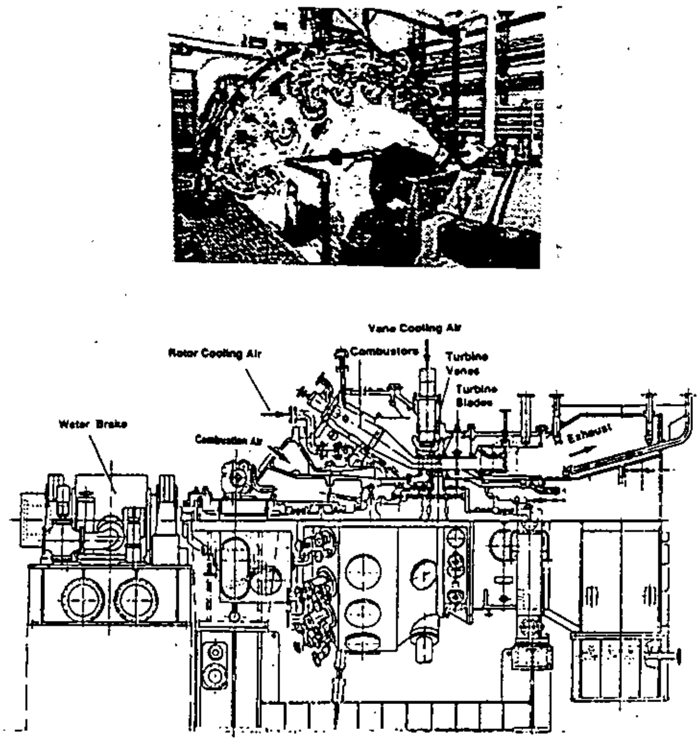


Fig.6 High Temperature Demonstration Unit

As a result of those tests, the expected performance has been verified under the condition equivalent to the actual machine at full firing temperature of 1,500°C class.

4.2 Development of Heat Resistant Materials

For the hot parts directly exposed to high temperature combustion gas, such as the 1st stage vanes and blades, use of the Directionally Solidified (from now on referred to as DS) alloy as well as the Single Crystal (from now on referred to as SC) alloy, which are already in practical use for small blades of aero-jet engines, is much more likely in industrial gas turbines than the conventional cast (from now on referred to as CC) alloy normally employed in the large size industrial gas turbines (Fig.7).

In addition, it is a promising technology, to develop a new heat resistant material, using the Thermal Barrier Coating (hereafter referred to as TBC) that protects metallic material against high temperature combustion gas with ceramic coat and has excellent heat resistant properties.

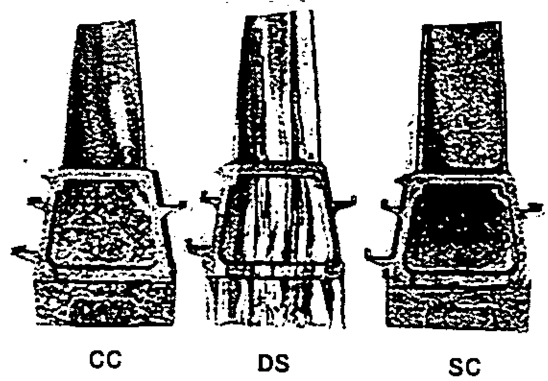


Fig.7 Heat Resistant Materials for Turbine Blades

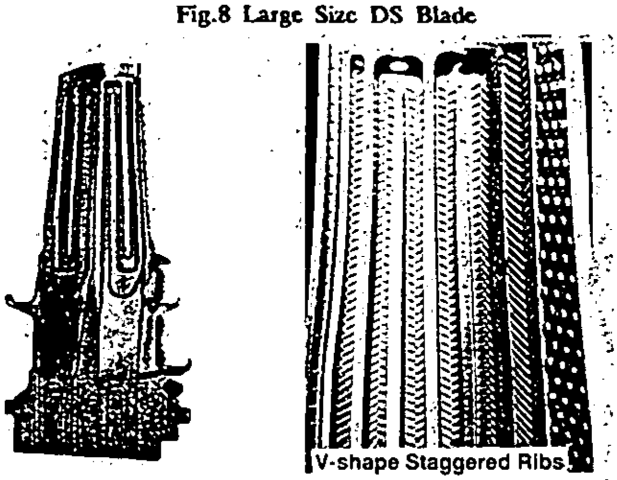
In this research, the core,the mold, casting condition, casting procedure plan and heat treatment process were examined; and the manufacturing technique for large size DS/SC blades was developed,finally 200MW class large size DS blades and 50MW class SC blades have been made the trial casting (Fig.8,Fig.9).

As for DS/SC blades, the result of trial casting of blades did not show any structural abnormality, such as casting defect, equiaxed grain.

The crystal direction was acceptable and the strength including tensile strength, fatigue strength and creep rupture strength was also satisfactory, so the manufacturing technique for large size blades has been established.

Tohoku Electric Power Copany's Research & Development Center evaluated creep strength and high temperature fatigue strength. This evaluation was performed

Fig.8 Large Size DS Blade



(Suction Side) (Magnified Photo of Cooling Passages)

Fig.9 Large Size SC Blade with Advanced Cooling Structure

using test pieces of both raw materials and trial casting blade made of DS/SC alloy. As the result Research & Development Center accumulated the data, and in addition, examined the creep life evaluation parameters and also accumulated the basic data on structural changes (Fig.10).

The expected performance was confirmed as a result of having verified the heat resistance and durability under a 1,500°C class actual machine temperature condition by conducting a high temperature cascade test in stationary condition and HTDU test in rotating condition and by applying the TBC to model vanes and blades.

In addition, to verify the durability of the TBC in field the operating condition, Tohoku Electric Power Co., installed TBC

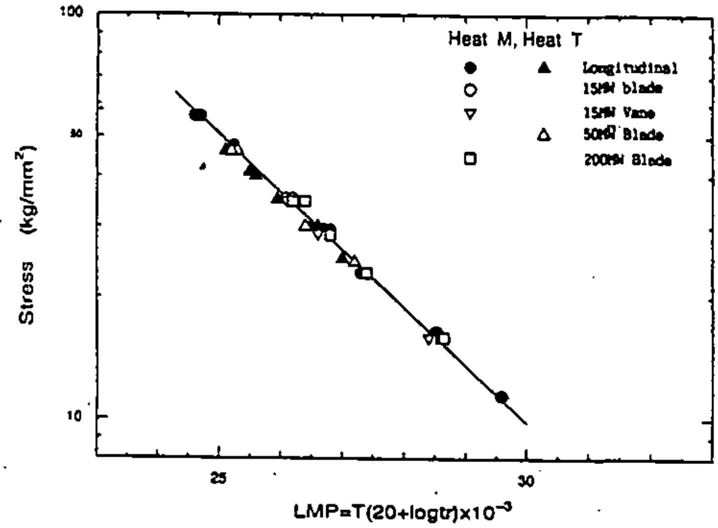


Fig.10 Creep Rupture Strength of CM247LC

coated vanes and blades in an operating gas turbine.

The TBC was found to be in good condition even after about 22,000 hours of operation.

From these results, it was concluded that the TBC can be applied to actual machines. (Fig.11)

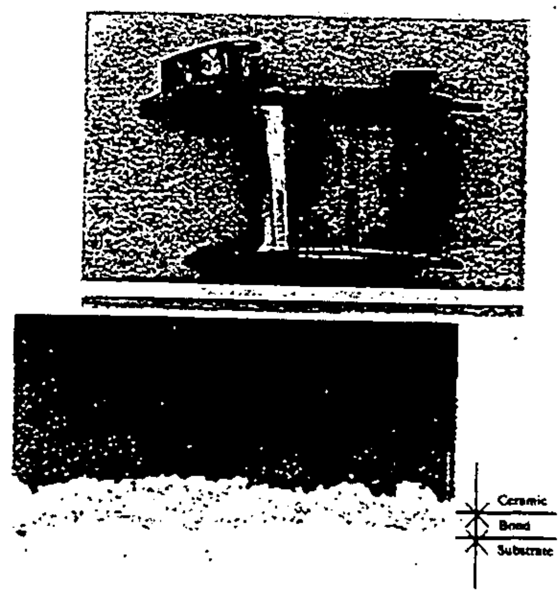


Fig.11 TBC Coated Vane of Existing Gas Turbine

4.3 Development of High Temperature Low NOx Combustor

The nitrogen oxide (NOx) produced during combustion process increases exponentially with the rise in combustion temperature.

Because of this, Tohoku Electric Power Co., developed a combustion system capable of repressing the production of NOx to the conventional level, even under a 1,500°C, class of high temperature combustion.

At Higashi Niigata Thermal Power Station No.3, Tohoku Electric Power company succeeded in the development and commercial operation of a dry type low NOx combustor for the first time in the world by using this lean premix combustion system in 1989.

In this research, Tohoku Electric Power Co., achieved further lower levels of NOx by increasing the rate of premixed combustion based on the above mentioned dry type low NOx combustion system (Fig.12), and in addition, developed a new cooling system to replace the air cooling because the increased premixed combustion results in the lack of combustor cooling air.

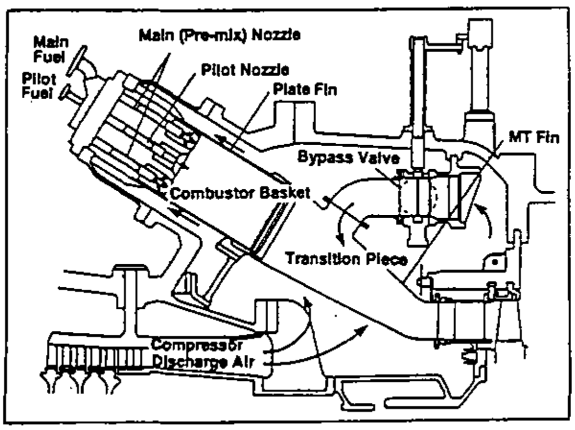


Fig.12 Overview of Pre-mix Low NOx Combustion System

Tohoku Electri Power Co., made a model combustor,and confirmed the air mixing characteristics inside the combustor, the vibration /acoustic characteristics of combustion system and ignition/flame propagation ability by carrying out various tests using the above mentioned model combustor and numerical analysis.

Moreover, Tohoku Electri Power Co., verified the NOx production characteristics, combustion stability, pattern factor and wall surface cooling performance by conducting high temperature combustion tests at atmospheric pressure and at higher pressures, about 12 ata.

5. PLANNING AT HIGASHI NIIGATA THERMAL POWER STATION No.4

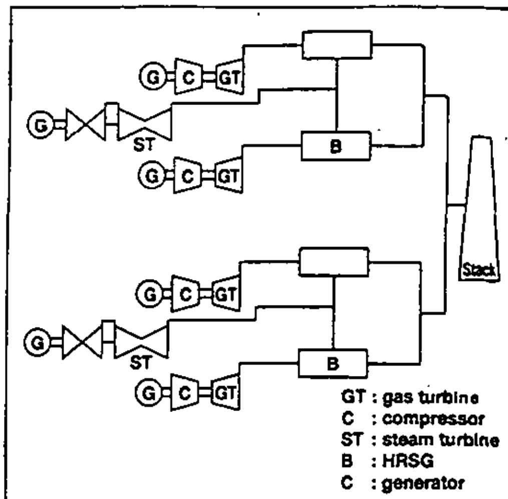
Tohoku Electric Power Co., are planning to apply the key technologies developed during this research and development to the field machines. The first application will be to the Higashi Niigata thermal power station
No.4 (total output is 1,610 MW), which is expected to start commercial operation in the year from 1999 to 2000 and is located next to the Higashi Niigata Thermal power station No.3 .

Tohoku Electric Power Co., are aiming at realizing a high efficiency large capacity combined cycle power plant and achieving the world wide highest class thermal efficiency of over 55% (LHV).

5.1 Configuration of Plant

Higashi Niigata thermal power station No.4 is planned as a combined cycle, consisting of two trains, each train being a multi-shaft type combination of two gas turbines, two HRSG and one steam turbine (Fig.13).

The gas turbine unit output is planned to be 270MW (at an atmospheric temperature of -1 °C)which will be one of the largest class machines to go operation in 1999, with increase in TIT to 1450 °C.



Total power output (at Ambient Temp. -1°C)		1,610MW
Plant thermal Efficiency (Gross, LHV)		55%
Turbine system	Steam Turbine	2
	Gas Turbine	4
Turbine Inlet Gas Temperature		1,400°C class

Fig.13 System Configuration of Higashi Niigata No.4

Also the steam turbine output is planned to be 265MW since the reheated triple pressurization of steam cycle is enabled by the adoption of a multi-shaft type. The total output of No.4 will be 1,610MW.

5.2 Configuration of Gas Turbine

The gas turbine planned for adoption at Higashi Niigata thermal power plant No.4 is planned to be operated at the TIT of 1,450°C and a unit output of 270MW, which will be one of the largest class machines to go operation in 1999.

For the cooling system of turbine hot parts such as 1st stage blades and vanes, the FCFC is adopted as the air cooling system. Also, for the cooling structure inside the blades and vanes, turbulence promoters of which form is optimized in serpentine cooling air path are arranged to increase the cooling efficiency.

Thus the TIT of 1,450°C is compensated for with approximately the same amount of cooling air as that used in the conventional 1,300°C class gas turbine.

5.3 Configuration of Heat Resistant Materials

Nickel base super alloys are used for all blades and vanes. Also a large size DS blade is used for 1st and 2nd stage blades in order to improve the creep strength.

On the other hand, the metallic materials are protected against hot combustion gas by applying TBC onto the 1st and 2nd stage blades and vanes.

5.4 Configuration of Combustor

For combustor, the steam cooled premixing combustor developed to reduce NOx more by improving the multi-nozzle type low NOx combustor,which is already put into practical use in the conventional 1,300°C class gas turbine, was adopted.

The closed loop steam cooling system will be applied to the combustor.

The steam that cooled the combustor is recovered and used as a part of steam for driving steam turbine,thus preventing reduction in thermal efficiency.

6.CONCLUSION

The Higashi Niigata thermal power plant No.4 is a large capacity combined plant with the maximum class thermal efficiency in the world, which Tohoku Electric Power Co., plan to construct integratedly based on the "Development of Advanced Gas Turbine" in that Tohoku Electric Power Co., have been engrossed for the last six years.

In future, Tohoku Electric Power Co., will attempt to confirm its plant reliability by conducting technical verification at each step of design, manufacturing, shop test and trial operation etc.

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