Latest Technology of Highly Efficient Coal-Fired Thermal Power Plants and Future Prospects

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Against the background of soaring crude oil prices, coal, which has a comparatively low unit price per calorific power and a steady price with less fluctuations, is expected to be used more widely in the future. On the other hand, the annual electric power generated in Japan by thermal power plants using fossil fuels such as coal, LNG and petroleum in 2005 was approximately 60% of the total power, so that control of CO_2 emissions from thermal power plants is the most important factor for limiting greenhouse effect gas emissions. Since coal amounts to about 25% of the annual power generation, it is necessary for countermeasures against global warming to take measures to limit CO_2 emissions through highly efficient power generation.

1. Status of highly efficient coal-fired power generation technology

For conventional thermal power plants, each unit capacity has been increased and high-temperature and high-pressure steam conditions have been promoted to improve the thermal efficiency as shown in **Fig. 1**.

The Hirono No. 5 Thermal Power Station of Tokyo Electric Power Company is a coal-fired thermal power plant adopting the ultra super critical (USC) conditions of 24.5 MPa × 600/600°C, the highest level in the world, and has continued highly reliable operation since it started commercial operation in July, 2004.

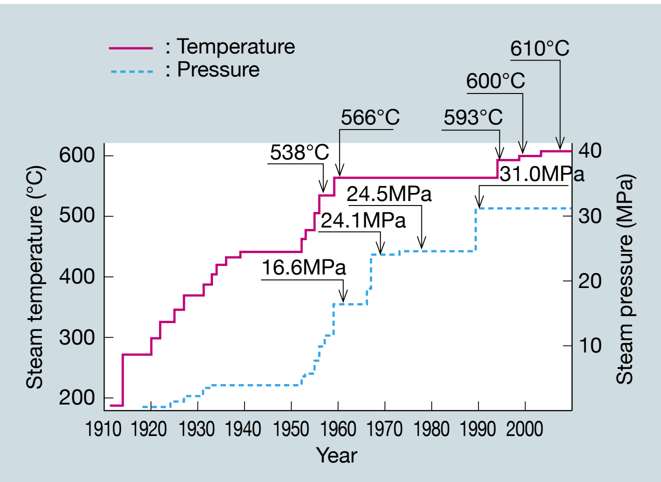

Fig. 1 Trends of steam conditions in thermal power plants
The current steam conditions are improved to a pressure of 31 MPa and a temperature of 610°C.

This most sophisticated coal-fired thermal power plant has the efficiency of 43% at generator terminal (HHV base), and reduces CO_2 emissions intensity by 3% of conventional plants.

1.1 Turbine

Figure 2 shows the world's largest 600 MW class turbine which is a two-casing type and consists of a combined casing for a high-pressure turbine and an intermediate-pressure turbine, and a single low-pressure turbine casing. The high-pressure and intermediate pressure turbines adopt high-temperature materials and cooling structures of proven design, to withstand the high-temperature steam conditions, and the blade rows and overall frame size are optimized in order to secure the performance and reliability of the shaft dynamics, realizing a compact design. Further, high-performance and highly reliable technology is used in the

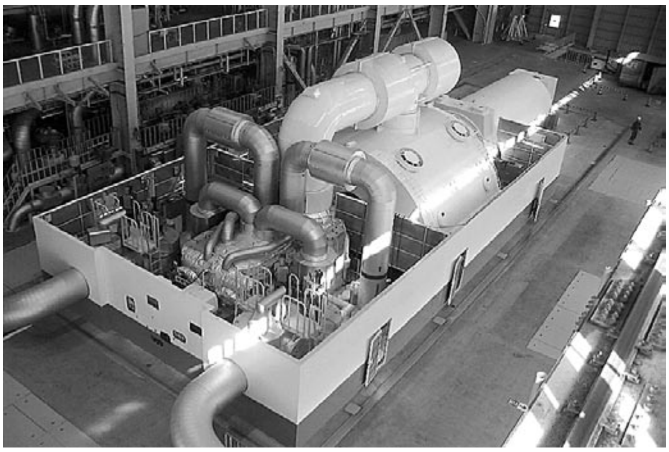

Fig. 2 External view of Hirono No. 5 steam turbine

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low-pressure turbine, such as a 48-inch steel ISB (integral shroud blade), a high-performance exhaust hood, and a bearing base structure directly supported by the foundations.

As for the high-temperature materials, the new 12Cr forged steel is used for the high-and-intermediate-pressure turbine rotor, 12Cr forged steel is used for the inner casing, and 9Cr steel for the turbine inlet valves and inter-connecting piping between the valves and the casing. The longitudinal center section of the rotor as well as the blade grooves at the intermediate-pressure inlet section are cooled by passing steam from the control stage outlet to the intermediate-pressure turbine along the rotor. In addition, a thermal shield is installed so that the inner surface of the outer casing at the intermediate-pressure turbine is not directly exposed to the 600°C reheat steam, and cooling steam from the high-pressure turbine exhaust is led into a space between the thermal shield and the outer casing.

1.2 Boiler

The boiler shown in **Fig. 3** adopts low NOx and low unburned carbon combustion technology applying an A-PM (advanced-pollution minimum) burner and MRS (Mitsubishi rotary separator) pulverizer for Mitsubishi circular firing in addition to the vertical-tube furnace using high-temperature material and rifled tubes.

2. Development of the next generation, advanced ultra super critical plant (A-USC)

With the limitation of CO_2 emissions becoming an urgent problem in recent years, increasing efficiency by further increasing steam conditions (higher in temperature and higher in pressure) of thermal power plants are an effective means of reducing CO_2 emissions. As in Europe and America, there is also a movement in Japan to promote, as a national project, the development of 700°C class A-USCs, with the net power plant efficiency aimed at 46% (HHV base). However, there are many issues to overcome such as the development and production of new materials suitable for high-temperature and high-pressure use, the development of manufacturing technology and a design which is reliable and economically feasible. The development schedule is foreseen as shown in **Fig. 4**. A period of nine years is set for the project starting from the elementary development including material development, to verification tests such as field tests. A period of five years is allotted for demonstration tests, with the details not yet determined.

2.1 Material development

In order to withstand the 700°C steam conditions, it is necessary to develop materials unlike conventional materials, materials with ultra high-temperature strength. Since the ferrite steel and austenite stainless steel used in conventional USC are not suitable for 700°C temperatures, the application of Ni or Fe-Ni-base alloy with sufficiently high allowable stress as the main materials of A-USC boilers and turbines is indispensable.

Turbine manufacturers have independently developed various materials as candidate materials for turbine rotors, and MHI has developed LTES700R, a Ni-base alloy with low-thermal expansion.

As for boiler materials, Ni-base alloys such as Alloy617, CCA617, Haynes230, Alloy740 and Nimonic263 in addition to HR6W, an Fe-Ni-base alloy currently under development in Japan, are candidates.

The development of these materials requires the storage and evaluation of long-term creep data and thermal fatigue data in addition to knowledge about their characteristics over long-term use under high temperatures for enhanced reliability. In addition, since expensive Ni-base alloys are used, it is important to minimize scope by optimization and to establish a design method that ensures economic efficiency.

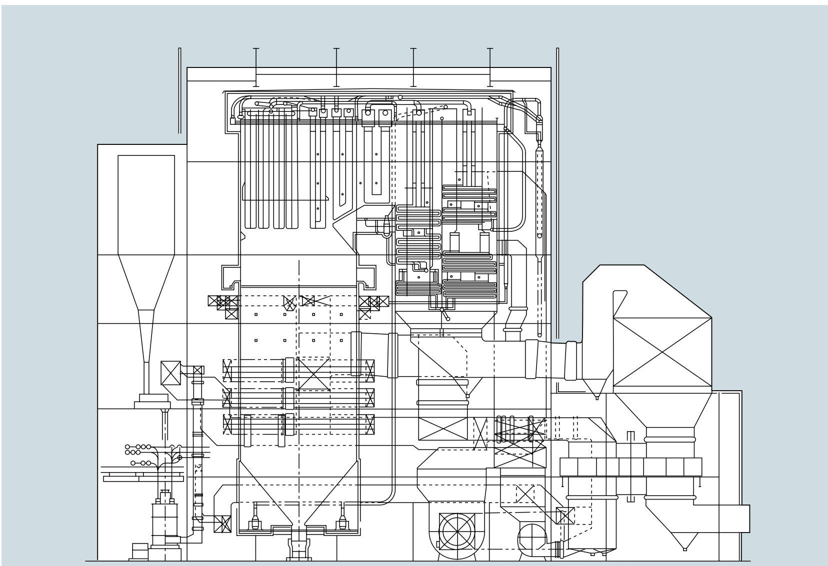

Fig. 3 Side view of Hirono No. 5 boiler

2.2 Development of manufacturing technology

In order to apply these materials, the development of manufacturing technology including processing, welding, and inspection is required.

(1) In order to use Ni-base alloy for turbine rotors, the manufacturability of large steel ingots of Ni-base alloy has to be improved. From the economic point of view, it is necessary to establish welding and inspection technology for the welded sections to realize a welded rotor using Ni-base alloy in the high-temperature section, and high Cr steel at both ends, which are exposed to comparatively low temperatures.

(2) An Ni-base alloy or an Fe-Ni-base alloy should be used instead of ferrite or austenite steel for the main steam pipes and reheat steam pipes, and bending technology for materials used under high temperature and high pressure is required. In addition, overall verification is needed, such as the development of weld materials for joints made of these materials and dissimilar metals, the establishment of welding methods, the optimization of welding conditions, knowledge of the material structure, strength and toughness of the joints, heat treatment processes and weld inspection methods.

2.3 Consideration of structure

(1) Since Ni-base alloy and Fe-Ni-base alloy will be used for the main steam pipes and reheat steam pipes, the thermal expansion will be larger than for conventional ferrite steel, calling for attention to the piping routes and system configuration.

(2) Since the valves will be exposed to high temperature and high pressure steam, it is necessary to secure structural reliability such as the operating and shut-off performances of the sliding sections and the durability of the sealing section under high thermal stress conditions.

(3) Since the desuperheaters (attemperators) within the boiler are exposed to low-temperature spray water under high-temperature steam under a cycling thermal stress environment, attention must be paid to the structure and the nozzle material.

(4) The turbine also needs its structure developing which includes cooling and reducing the thermal stress in the high-temperature section in addition to material

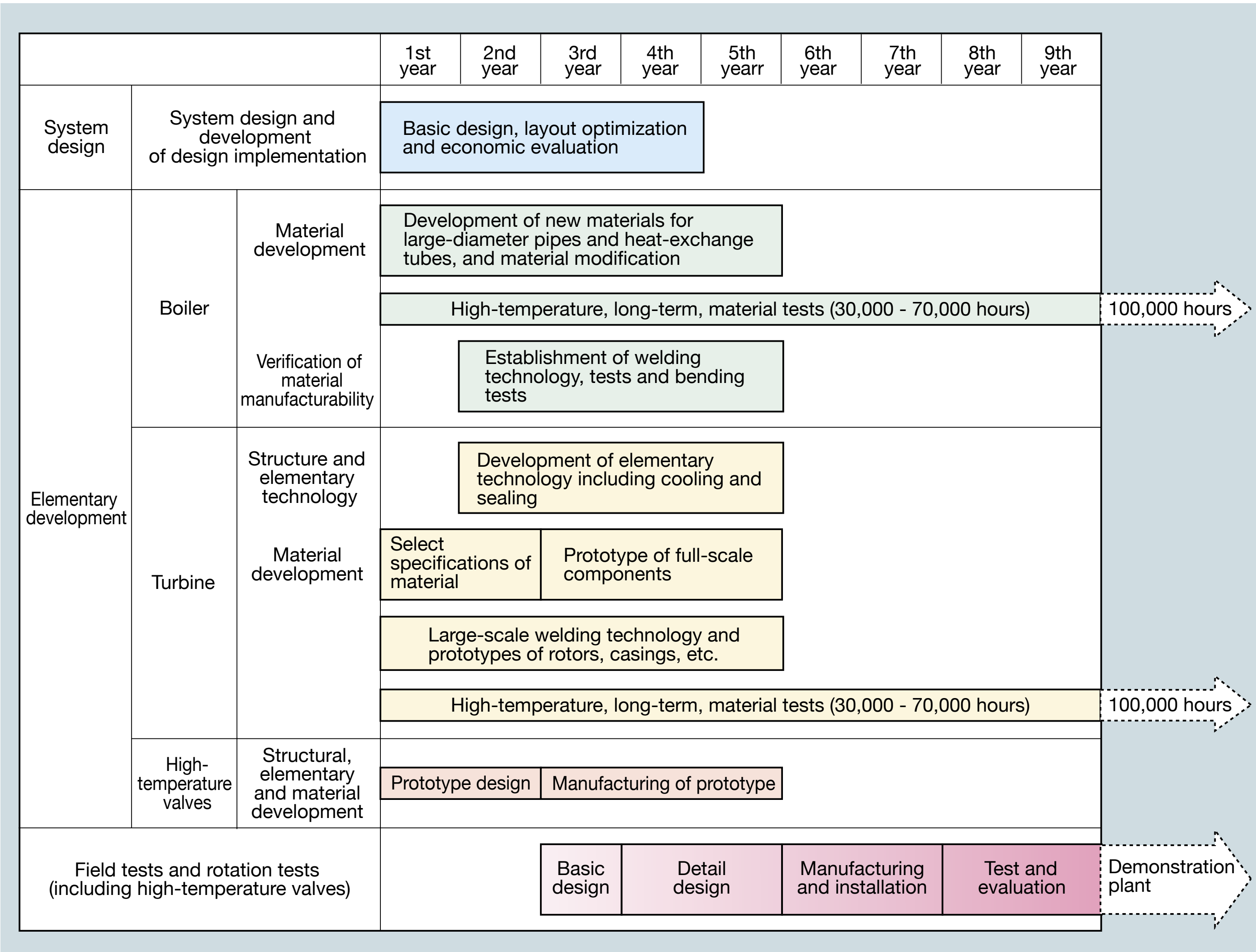

Fig. 4 National project schedule for A-USC technical development (plan)

development. Study of a cooling system suitable for the strength of the Ni-base material is also necessary.

3. Conclusion

The continuous research and development of new materials and manufacturing technology, which are indispensable to Japan's energy security for coal-fired thermal power and to realize the high steam conditions of A-USCs, is an urgent issue. Thus, innovative technical developments are required to improve the thermal efficiency of thermal power plants and to ensure CO_2 reductions, contributing to the prevention of global warming.

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