Hitachi's Activities in Fusion Device and Particle Accelerator Development

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OVERVIEW: Taking advantage of its extensive technical expertise developed as a general manufacturer of electrical equipment including electrical machinery, superconducting and very-low-temperature equipment, and system technologies, Hitachi continuously works on the research and development of experimental fusion equipment and accelerators for fundamental scientific research, which require cutting-edge technologies. In the fusion area, Hitachi has collaborated on design review and research and development work for both the International Thermonuclear Experimental Reactor and the Japan Atomic Energy Agency's next-generation JT-60SA facility, and has worked on remodeling the National Institute for Fusion Science's Large Helical Device to improve its performance. In the field of accelerator equipment, Hitachi delivered sector magnets for RIKEN's SRC and approximately 400 large magnets of various types for the Japan Proton Accelerator Research Complex run jointly by the JAEA and High Energy Accelerator Research Organization.

INTRODUCTION

NEARLY half a century has passed since Hitachi first became involved in research and development into experimental fusion devices researched as a potential new source of energy and into the accelerators used for fundamental scientific research

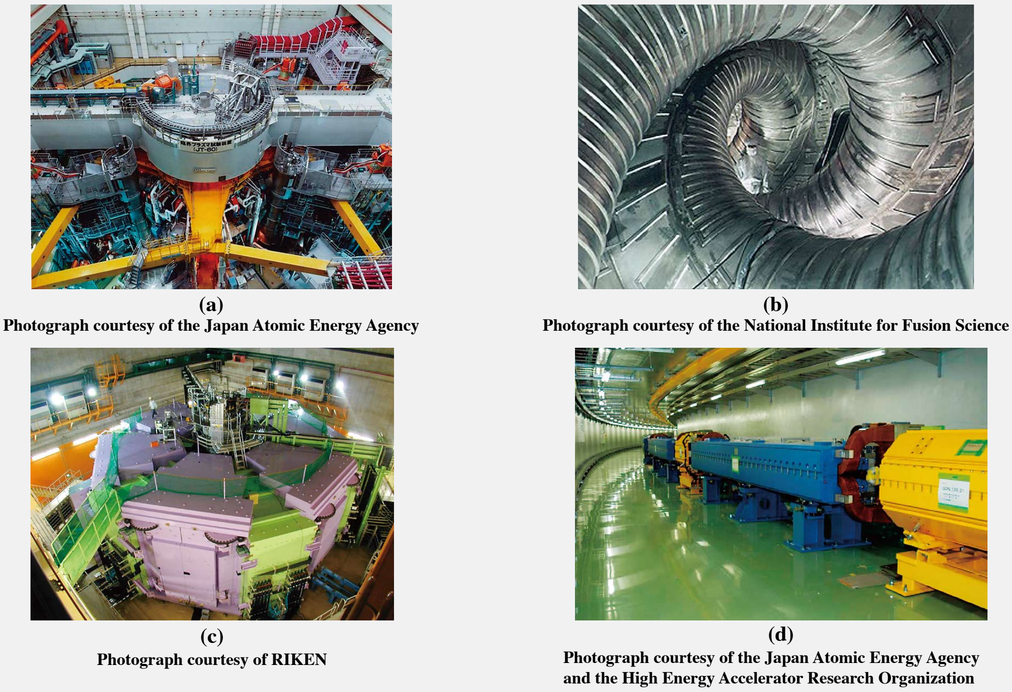


Fig. 1—Equipment Delivered by Hitachi for Fusion and Accelerator Applications.
The photographs show: a view of the JT-60U critical plasma examination device for the Japan Atomic Energy Agency (JAEA) (a), inside of the Large Helical Device (LHD) vacuum vessel for the National Institute for Fusion Science (NIFS)(b), a view of the Superconducting Ring Cyclotron (SRC) for RIKEN (c), and 50-GeV synchrotron for the JAEA and the High Energy Accelerator Research Organization (KEK)(d).

and to probe the mysteries surrounding the origin of the universe. In both cases, this research was undertaken through national projects sponsored by the Japanese government. During this period, Hitachi has manufactured and delivered a number of research devices under the guidance of research institutes and academic institutions based on its technical expertise in the manufacture of electrical equipment accumulated through its role as a producer of generators, transformers, and similar (see Fig. 1). Hitachi has contributed to these fields in its role as a general electrical equipment manufacturer. Although this research initially involved the use of laboratory-scale equipment, it has since grown to the extent that it uses equipment similar in scale to power generation plants. Hitachi applied its fundamental technologies from electrical equipment production to fields such as superconducting and very-low-temperature technology, production technology for large structures, ultra-high vacuum technology, and electromagnetic analysis technology. Hitachi also supplies the system technologies that bring these different technologies together.

This article discusses Hitachi's past performance and recent efforts in the fields of fusion and accelerator technology.

INVOLVEMENT IN FUSION EXPERIMENTAL EQUIPMENT

Developments in the Field of Fusion Research

Fusion is a reaction where two lighter nuclei such as hydrogen are combined to form a heavier nucleus and release a large amount of energy. Solar energy is produced by fusion reactions. In order to use fusion reactions as an energy source, attempts to control plasmas (the fourth state of matter) began in the 1950s around the world and led to the construction of various types of experimental fusion equipment. Recently it was decided to build the International Thermonuclear Experimental Reactor (ITER)[1] in Cadarache in France as part of an international collaboration on next-generation fusion development. Fusion research is about to embark on a new chapter in its history.

Hitachi has been part of this field from the earliest stages of fusion research and has designed and manufactured experimental equipment in Japan. This has included the coils and vacuum vessels used in the main reactor bodies, NBIs (neutral beam injectors), controllers, and power supply systems.

TABLE 1. Experimental Fusion Equipment Manufactured by Hitachi
The table lists examples of major items of experimental fusion equipment manufactured by Hitachi in the past.

Year of completion	Customer / equipment name	Specification		Type
		Major radius (m)	Magnetic field (T)	
1972	JAERI/JFT-2	0.9	1.5	Tokamak
1974	JAERI/JFT-2a	0.6	1.0	Tokamak
1976	Nagoya University / JIPP T-II	0.91	3.0	Tokamak / Helical
1978	Tohoku University / Asperator NP-3	0.8	0.5	Helical
1980	Kyoto University / Heliotron-E	2.2	2.0	Helical
1980	Energy Research Laboratory, Hitachi, Ltd. / HT-1	0.35	1.5	Tokamak
1982	Nagoya University / NBT-1M	1.4	1.7	Bumpy torus
1984	The University of Tokyo / REPUTE-1	0.82	0.3	Reversed field pinch
1985	JAERI/JT-60	3.0	4.5	Tokamak
1986	Kyushu University / TRIAM-1M	0.8	8.0	Tokamak
1987	Energy Research Laboratory , Hitachi, Ltd. / HT-2	0.41	2.5	Tokamak
1988	Nagoya University / CHS	1.0	1.5	Helical
1991	JAERI/JT-60U	3.4	4.2	Tokamak
1998	NIFS/LHD	3.9	2.9	Helical
1999	Kyoto University / Heliotron-J	1.2	1.5	Helical

JAERI: Japan Atomic Energy Research Institute

Primary Devices

Hitachi has manufactured the primary devices used in most of the experimental fusion systems in Japan (see Table 1). And in the engineering research and development carried out during EDA (engineering design activities) at ITER, the company contributed to development and was able to accumulate technical expertise through the manufacture of a real-scale vacuum vessel sector model in 1997 and an Nb_3Al insert coil in 2000. In addition to the production of new equipment, Hitachi conducts regular maintenance and inspection work on other equipment currently in operation, such as the Large Helical Device (LHD) and Heliotron-J. This includes making improvements to the equipment to enhance its performance.

It recently delivered a subcooled-helium generator used to lower the temperature of the liquid helium supplied to the LHD's superconducting helical coil (see Fig. 2). By lowering the temperature of the supplied liquid helium from 4.4 K to 3.2 K, this helped increase the intensity of the generated magnetic field by approximately 4%[2].

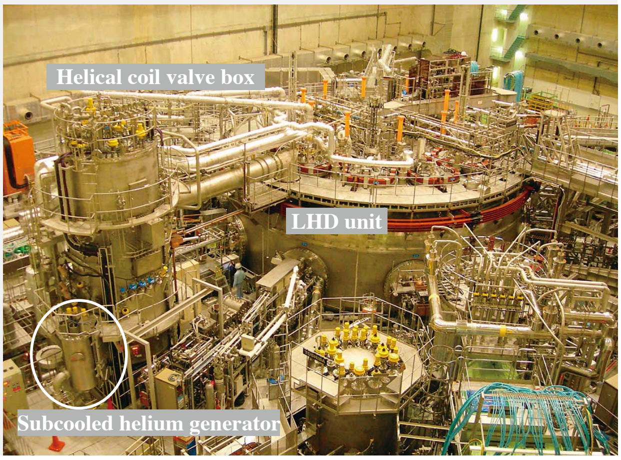
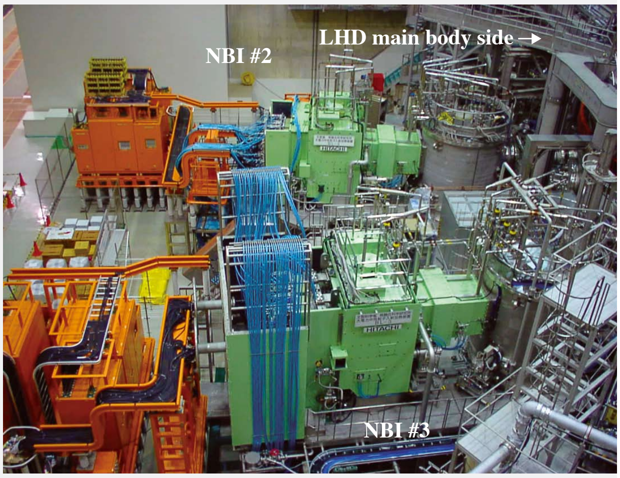


Fig. 2—LHD Helical Coil Subcooled Helium Generator.
A subcooled helium generator was added to lower further the temperature of the liquid helium used to cool the superconducting helical coil (photograph courtesy of the NIFS).

NBI

An NBI heats plasma by injecting a high-speed neutral beam into the plasma in experimental fusion equipment. Hitachi's NBI development began in 1977 when it became involved in the detailed design of an NBI for JT-60. In 1985, for the Heliotron-E, Hitachi delivered three NBI units that incorporated a number of systems that would become standard features in future NBIs, including a 30-kV 35-A bucket-type ion source. Hitachi also delivered 14 NBI beam line units for the JT-60 with a beam energy of 75 kV, incident power of 20 MW, and pulse width of 10 s. The units were the highest rated systems of their type at that time.

After 1990, Hitachi worked on the development of negative ion sources and DC (direct current) high voltage technology to provide the higher energy, higher power, and higher efficiency required in the next generation of large devices. NBI units were supplied for the JT-60U in 1995 and for the LHD in 1998 and 2000 (see Fig. 3).



NBI: neutral beam injector

Fig. 3—NBI used in the LHD.
The NBI can generate a stable negative ion current of 40 A or more per ion source (photograph courtesy of the NIFS).

Future Development of Experimental Fusion Equipment

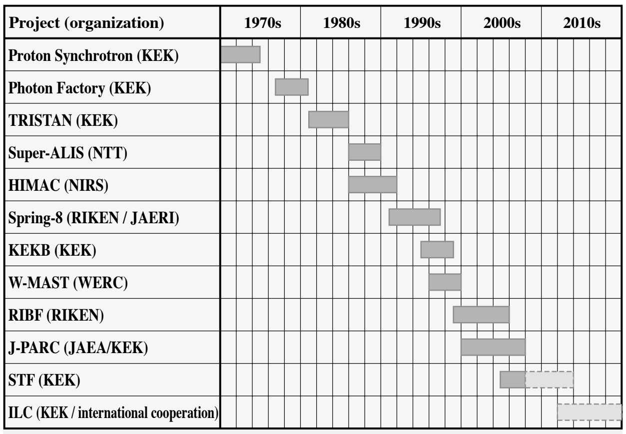
Experimental fusion equipment to be built in the future includes the ITER mentioned earlier and the JAEA's ITER satellite tokamak JT-60SA which represents the next generation of experimental devices in Japan and upgrades the JT-60U to use superconductors throughout[1]. Hitachi intends to collaborate on these projects based on the technical expertise it has developed in the past.

INVOLVEMENT IN ACCELERATORS

Developments in the Field of Accelerator Technology

The quest for sub-atomic particles picked up pace at the end of the 19th century and led to the development of various particle accelerators such as the inventions of the electrostatic accelerator developed by Cockcroft and Walton in 1930s and the cyclotron by Lawrence and others. Since then, accelerators have become a powerful research tool for advanced science and are now widely used for research into elementary particles, space, matter, life sciences and numerous industrial applications.

A wide variety of accelerators are now available for research purposes, including high-energy accelerators used to explore the origin of elementary particles, space and matter, high-intensity beam accelerators that generate large amounts of secondary particles for use in experiments, and accelerators for research into the use of radiation. Hitachi has actively participated in projects run by research institutes both in Japan and overseas and is also involved in applying this technology in medical and industrial applications. Fig. 4 lists some of the major research accelerators with which Hitachi has had an involvement and the following sections describe these in more detail.



Super-ALIS: Superconducting Atsugi Lithographic Synchrotron Radiation
NTT: Nippon Telegraph and Telephone Corporation
HIMAC: Heavy Ion Medical Accelerator in Chiba
NIRS: National Institute of Radiological Sciences
Spring-8: Super Photon Ring-8 GeV
KEKB: KEK B-factory
W-MAST: Wakasa-wan Energy Research Center Multipurpose Accelerator System with Synchrotron and Tandem
WERC: The Wakasa Wan Energy Research Center
RIBF: Radioisotope Beam Factory
J-PARC: Japan Proton Accelerator Research Complex
STF: Superconducting RF Test Facility
ILC: International Linear Collider

Fig. 4—Hitachi's Past Record of Manufacturing Accelerators. Hitachi has had an ongoing involvement in the construction of the major accelerators used for research in Japan.

Accelerators for High Energy and Nuclear Physics Research

Japan's domestic development of large-scale accelerator facilities started at the beginning of the 1960s. In 1971, the National Laboratory for High Energy Physics of the Ministry of Education [now known as the High Energy Accelerator Research Organization (KEK)][3] was established and construction began on a proton synchrotron, the country's first full-fledged large-scale accelerator. Hitachi supplied a total of 110 bending magnets and quadrupole magnets. The company then went on to manufacture beam line equipment and various electromagnets for the Photon Factory. In 1980s, it produced more than 800 large electromagnets of various types for the TRISTAN accelerator and established know-how in the manufacture of resistive magnets for high-energy accelerators.

Meanwhile, Hitachi pursued the development of superconducting magnets for accelerators and manufactured solenoids for the AMY detectors used in the TRISTAN accelerator and QCS magnets used at the collision point. A superconducting solenoid supplied to the University of Tsukuba in 1984 was incorporated into the CDF (Collider Detector at Fermilab) detector of a large-scale joint international research project at the Fermi National Accelerator Laboratory in the USA which led to the detection of the top quark in 1995. Hitachi also manufactured various types of equipment in the late 1990s including 712 resistive magnets for the KEK B-factory (KEKB) and QCS magnets used at the collision point.

In the field of heavy ion accelerators, Hitachi also manufactured superconducting sector magnets for the SRC (superconducting ring cyclotron) in the final stage of RIKEN's[4] RI (radioisotope) beam factory in 2003[5]. In December 2006, the SRC succeeded in generating its first beam and went into operation.

Application of Secondary Beams

In 1995, Hitachi manufactured magnets for RIKEN's Super Photon Ring-8 (Spring-8) storage ring and vacuum chambers for beam lines, thereby gaining experience in the manufacture of large-scale vacuum systems. Since the beginning of 2000s, the company has worked on the construction of a high-intensity proton accelerator [Japan Proton Accelerator Research Complex (J-PARC)] and manufactured a combined total of 416 large magnets for the 3-GeV synchrotron and 50-GeV synchrotron and RFQ (radio frequency quadrupole). In addition, Hitachi was in charge of manufacturing the modular power supply for Linac and the resonant power supply for the 3-GeV electromagnet. Beam operation commenced at J-PARC in December 2008.

Research into Applications for Radiation

As to a powerful tool for fundamental scientific research and industrial applications, Hitachi has also worked on the development of a synchrotron system which uses the high-intensity synchrotron radiation generated when the trajectory of fast-moving particles is bent. The company manufactured the Super-ALIS superconducting accelerator system for generating SOR (synchrotron orbital radiation) for Nippon Telegraph and Telephone Corporation in 1988 and

Fig. 5—Wakasa-wan Energy Research Center Multipurpose Accelerator System with Synchrotron and Tandem.
Ion beams are widely used in materials science, biology, medical research, and elsewhere [photograph courtesy of the WERC (Fukui Prefecture)].

Fig. 6—Cryostat for Superconducting Cavities Used in Advanced Accelerators.
Hitachi is involved in the development of equipment for use in future high-energy accelerators (photograph courtesy of KEK).

the HIMAC synchrotron system, including the power supply and control system, for the organization now known as the National Institute of Radiological Sciences (NIRS) in 1992. The Wakasa-wan Energy Research Center Multipurpose Accelerator System with Synchrotron and Tandem (W-MAST) was completed in 2000 (see Fig. 5). The technology has also been used in a particle therapy system that uses the generated beam as a treatment for cancer.

Future Development of Accelerators

In 2001, the KEKB accelerator demonstrated CP violation in B-meson decays. This led to two Japanese scientists, Makoto Kobayashi and Toshihide Masukawa, winning the Nobel Prize in Physics in 2008. Since entering the 21st century, the field of elementary particle physics has experienced an unprecedented upsurge in activity directed toward updating the standard model. One current example is the International Linear Collider (ILC) project run jointly by a number of countries on which work has already started. Use of quantum beams such as synchrotron radiation, RI beams, and neutron beams is becoming increasingly important and they have become essential tools for the development of science and technology. With an awareness of these trends, Hitachi has strengthening its involvement in the development of advanced accelerators. One example is the cryostat for superconducting cavities shown in Fig. 6 which is currently under development by KEK.

CONCLUSIONS

This article has discussed Hitachi's past successes in the fields of fusion and accelerator technology and its current activities in these areas.

Hitachi will continue to participate in projects where it can play an important role as a general manufacturer of electrical equipment, further develop its accumulated technologies, and work on medical applications for this technology such as superconducting magnets for MRI (magnetic resonance imaging) machines and the particle therapy system.

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