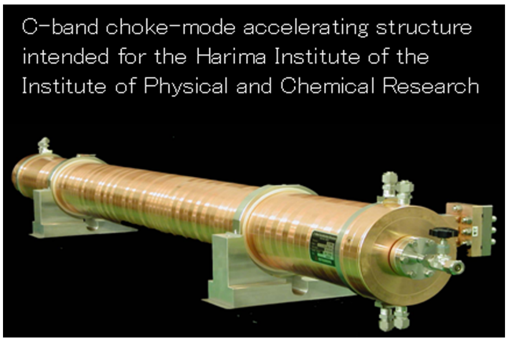
Particle Accelerator Products for Advanced Research and Technology Development



MACHINERY & STEEL STRUCTURES HEADQUARTERS
ADVANCED TECHNOLOGY DEPARTMENT

In the fields of nuclear physics and elementary particle physics, accelerator cavities and structures are used to accelerate particles (primarily electrons, positrons, and protons) to high energies. Mitsubishi Heavy Industries, Ltd. (MHI) has been developing a variety of production technologies in order to provide accelerator cavities and structures needed for new research and experiments. Described here are a superconducting accelerator cavity, conventional accelerating structures, and their derivatives intended for medical use.

1. Superconducting accelerating cavity

1.1 Characteristics

The superconducting accelerating cavity requires that liquid helium be used as a refrigerant to cool the niobium cavity to achieve superconductivity. These cavities are used mainly in accelerators that are operated at high electric fields and in continuous-wave mode. This is because high-frequency losses in superconducting accelerating cavities are as small as one hundred thousandth to one millionth of the loss in normal-conducting accelerating structures that use copper.

1.2 Applications

The superconducting accelerating cavity is used mainly in accelerators intended for large-scale research, because such accelerators need a large refrigeration system to maintain superconductivity. MHI developed and supplied a superconducting crab cavity intended for an electron-positron collider (KEKB) for a high-energy accelerator research organization (KEK). KEK contributed toward a validation test that was performed for the 2008 Nobel Prize in Physics (**Figure 1**).

MHI has also been developing a 1.3-GHz superconducting accelerating cavity for the International Linear Collider (ILC) project, which is a linear electron-positron collider project that aims to further understanding of particle physics, and the Energy Recovery Linac (ERL) project, which is involved in research for the next generation of synchrotron light sources.

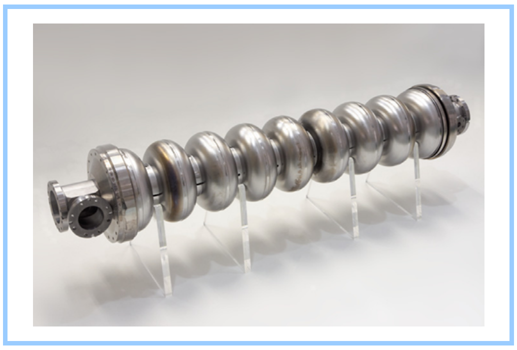


Figure 1 Superconducting accelerating cavity intended for ILC R&D (Courtesy of KEK)

1.3 Production technologies

Because superconducting accelerating cavities cannot achieve a high enough electric field if even small amounts of impurities are present in the niobium or if there are any defects or bumps on the inner surface of the cavity, the following production methods are used:

(1) High-precision forming technology: A technology to precisely form the hemispheric cells that constitute the cavity (**Figure 2**).

(2) High-precision electron-beam welding: A technology to precisely weld cells directly using an electron beam in an ultra-high vacuum so as to reduce the intrusion of impurities and smoothen the inner surface of the cavity when cells connect to assemble the cavity.

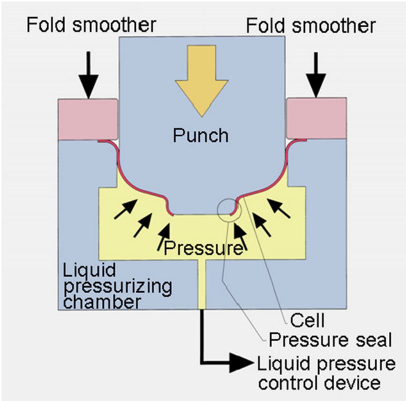


Figure 2 Outline drawing of the hydroforming method, utilizing counter pressure fluid, of the large-diameter thin-wall cell used in the superconducting accelerating cavity

2. Normal-conducting accelerating structure

2.1 Characteristics

Normal-conducting accelerating structures operate at room temperature and therefore require less auxiliary equipment and less maintenance than superconducting cavities. These structures have greater high-frequency loss than superconducting accelerator cavities and are therefore not appropriate for continuous-wave operation, but they can achieve a high electric field in pulsed-mode operation.

2.2 Applications

Normal-conducting accelerating structures are supplied to KEK and to Spring-8, both of whom use them for beam injection into large-scale ring accelerators. They are currently being mass-produced and are the main accelerators used by the X-Ray Free Electron Laser (XFEL) project, which is currently under construction by the Institute of Physical and Chemical Research (RIKEN). They are also used as intensifiers of the main accelerators by the Japan Proton Accelerator Research Complex (J-PARC). J-PARC is a high-intensity proton accelerator constructed jointly by KEK and the Japan Atomic Energy Agency (JAEA), which conducts neutrino experiments and promotes the industrial use of neutrons. They are also used in medical equipment and in electronic sterilization systems.

2.3 Production technologies

Because normal-conducting accelerating structures require precise resonant frequencies, the following production technologies are used.

(1) An ultra-precise lathe to achieve a surface roughness of <0.1 μm and an error of <3 μm (**Figure 3**).

(2) Low-strain multilayer and intermaterial brazing technologies (Figure 3), realized by using one of the largest vacuum brazing furnaces in Japan (accepting work pieces 1.2 m in diameter and 3 m in length).

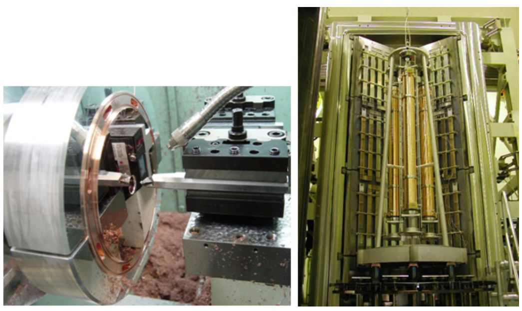


Figure 3 Cell for the C-band accelerator tube under high-precision processing (left) and the brazing furnace (right)

3. Application to medical equipment

3.1 Characteristics

The MHI-TM2000, which is a highly advanced radiotherapy machine with its own accelerator technologies that has been on the market since last year (see **Figure 4**), is acknowledged as patient-friendly equipment. Downsizing the accelerator is a key aspect in creating a high-precision compact irradiation head that can be driven to rotate in pan and tilt directions and compensate for the mechanical distortion caused mainly by its weight. The mechanical distortion problem was solved by using an ultra-light and compact C-band (5.7 GHz) accelerator for which the length was reduced to one third of the conventional structure. This C-band accelerator can realize the application of a high-power klystron, which offers stability and a higher frequency.

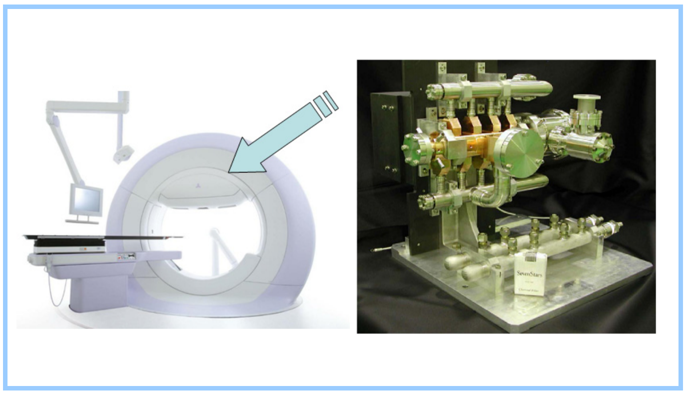


Figure 4 TM2000 radiotherapy machine and the C-band accelerator tube

3.2 Applications

TM2000 machines are distributed to hospitals both at home and abroad for clinical treatment.

3.3 Production technologies

This machine contains various MHI elemental technologies such as image processing, technologies for normal-conducting accelerating structures explained in article 2 and technologies for precise-positioning machine tools.