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The Cryogenic Department of Suzuki Shokan Co., Ltd. (SSK) has been providing superconducting and very-low-temperature machines to the domestic market in a variety of domains since 1971. After the discovery of High-Temperature Superconductors (HTS) and their operating temperature near the boiling temperature of liquid nitrogen (LN2), the number of applications using superconductors drastically increased and the role of SSK in designing and manufacturing these very-low-temperature and superconducting machines became more important as it attracted a higher number of users. These machines, at once necessary only in a few specialized industries, are now finding new applications every day thanks to the HTS and the ease of use they made possible.

In these few pages, we will present some of the products SSK deal with.

1. Liquid nitrogen circulation cooling system

In the recent years and after the discovery of HTS, it was made possible for various devices to run at a temperature near the boiling temperature of LN2. When cooling down a large-scale machine, where it may seem usual to immerse the part to cool into a bath of LN2 (immersion cooling), it is actually more effective to circulate the cryogen, brought to a subcooled state, through a piping system and have the part to cool down exchange heat with the cold pipes through heat exchangers. To bring

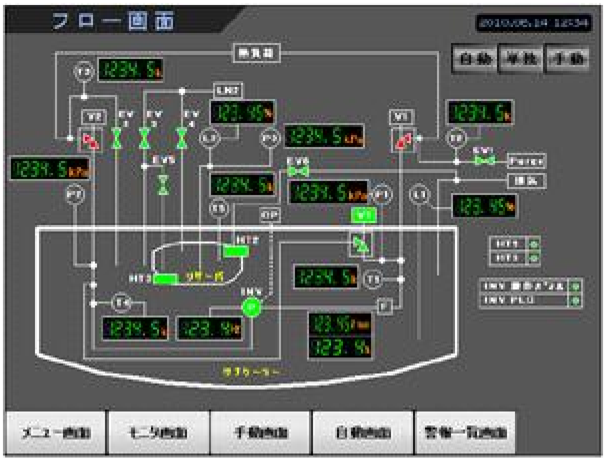

Fig. 1. LN2 circulation cooling system (bath-cooled type) for spectrometer. Circulating LN2 temperature: 78 K, Cooling power: 2 kW, Flow: 5 L - 20 L/min, ΔP: 0.3 MPa.

LN2 to the subcooled state, one has to either apply a pressure larger than the saturation pressure of the liquid at this temperature, or cool down the liquid phase to a temperature lower than the temperature corresponding to the saturation pressure of its gaseous phase. The use of subcooled LN2 allows to have a bubble-free cryogen, meaning better heat exchange properties and no vibration through the system.

Subcooled LN2 circulation cooling systems are largely employed in the cooling of HTS power transmission cables. In a totally different domain, they are also necessary for synchrotron radiation monochromators: the silicon (Si) crystals diffracting the incident beam are submitted to a large quantity of energy becoming heat; the elevation of temperature and the creation of a gradient in the crystal can affect its optical properties. By using subcooled LN2, one prevents the linear thermal expansion of the crystal, meaning the optical properties are preserved, and keep a good thermal conductivity (Si is as its best around 100 K). Compared to usual immersion cooling, subcooled LN2 has the additional advantage to prevent the vibrations coming from the boiling of the liquid phase.

The LN2 used in the circulation loop can be cooled down either by cryocoolers or by another LN2 bath (possibly pumped down below atmospheric pressure to reach even lower temperatures).

The figure 1 represents a subcooled LN2 circulation cooling system which was manufactured for the cooling of a spectrometer. After having removed the heat from the user's machine, the circulating LN2 in a subcooled state (78 K, pressurized) is cooled down through a heat exchanger in contact with a 77 K bath of LN2 at atmospheric pressure. The 77 K LN2 vaporizes as a result, and has to be regularly resupplied, for example from a cold evaporator (CE) tank installed on the premises. This SSK-specific model proposes a CPU-based fully automated operation from the precooling of the equipment still at room temperature to a stable and normal operation.

The device presented in figure 2 has the same purpose as the one illustrated in figure 1, but the circulating LN2 is cooled down by cryocoolers. By the use of

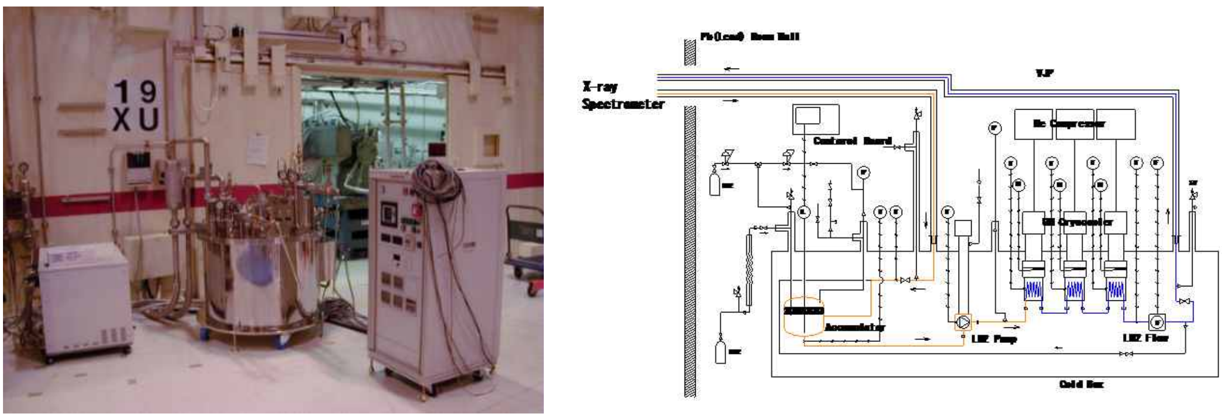

Fig. 2. LN2 circulation cooling system (cryocooler-cooled type) for spectrometer. Circulating LN2 temperature: 66 K - 81 K, Cooling power: 0.3 kW - 1 kW, Flow: 5 L - 15 L/min, ΔP: 70 kPa.

heater-controlled cryocoolers, it becomes possible to control the temperature of the circulating LN2 from 66 K to 80 K. Depending on the model, one of these cryocoolers can provide a cooling power between 300 W and 1 kW. SSK has already provided more than 30 of these to organizations such as Spring8 or KEK. These machine are inspected twice a year, but other than that, are permanently running.

For larger-scale applications such as superconducting power transmission cables, the choice remains the same between both methods.

In the case of a bath-cooled circulating LN2, depending on the properties of the HTS cable, pumping the gaseous phase of the LN2 bath will have for effect to decrease the temperature of the liquid phase. The pumping speed, the quantity of supplied LN2, the design of the heat exchangers, etc. are parameters with which SSK have to deal in order to make possible the design and manufacture of cooling systems in a very large range of cooling requirements.

In the case of cryocooler-cooled circulating LN2, the necessary cooling power is usually of the kW order and makes necessary the use of bigger cryocoolers. These cryocoolers, based on the Brayton or Stirling cycles, do provide an adequate cooling power but would still need to be optimized in terms of efficiency, reliability, size or cost.

SSK has participated to numbers of domestic HTS power transmission cable projects and supplied the cooling systems. Recently, SSK designed and manufactured a cooling system used at the Asahi electric power station for TEPCO. Shown on the figure 3, it is composed of 6 Stirling cryocoolers and 2 LN2 pumps to ensure high reliability and constant operation. Maintenance of the cryocoolers was also made possible without stopping operation.

2. Helium gas circulation cooling system

A HTS conductor exposed to an outer magnetic field sees its current flowing properties reduced, making it necessary to lower the operation temperature to the 20 K – 30 K range. It is possible to opt for a direct conduction cooling with cryocoolers but the temperature gradient formed inside the machine, the transmission of

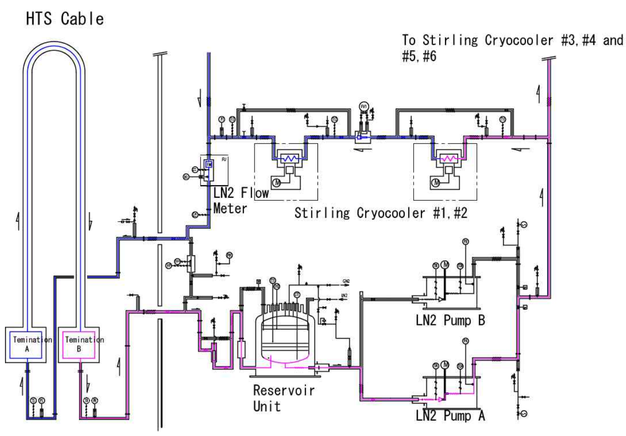

Fig. 3. Cooling system used at the Asahi power station managed by TEPCO. Circulating LN2 temperature: 66 K – 80 K, Cooling power: 5 kW @ 70 K, Flow: 30 L – 60 L/min, ΔP: 250 kPa.

Fig. 4. He gas circulation cooling system for NMR sample cryo-probe. Operation temperature: 〈20 K, Mass flow: 0.1 g/s, Cooling power: 3 W.

vibrations coming from the cold head or the effects of the magnetic field on the cryocooler itself are many problems the circulation of helium gas can solve at once.

The figure 4 illustrates a case where a small portion of the high-pressure Hegas exhausted by the cryocooler's compressor was actually used for circulation cooling. About 1/60 of the gas supplied by the compressor was actually rerouted to the circulation circuit. This small portion was successively cooled by the returning gas, the cold head's 1st stage and then the 2nd stage before being sent 5 m away through an insulated flexible pipe to cool down the cryo-probe of a NMR system, located in a high magnetic field. Inside the insulated flexible pipe, the returning gas had for purpose to shield the cold circulating He gas from room-temperature radiation and heat invasion.

The figure 5 represents a cooling system used for a 3 MW HTS motor. He gas, temporarily stored in a buffer tank, is driven into the cryostat through the use of a room-temperature compressor, allowing the controls of the pressure and the flow. Once inside the cryostat, the circulating He gas is first precooled by the returning gas; further cooling is ensured by heat exchangers placed at the cold heads of cryocoolers. This kind of high-torque slow-rotation HTS motors are expected to play a great role for gearless propulsion motors in a very near future.

3. Helium-free superconducting magnets

With the progress made in the conception of cryocoolers and the steep decrease of liquid helium availability,

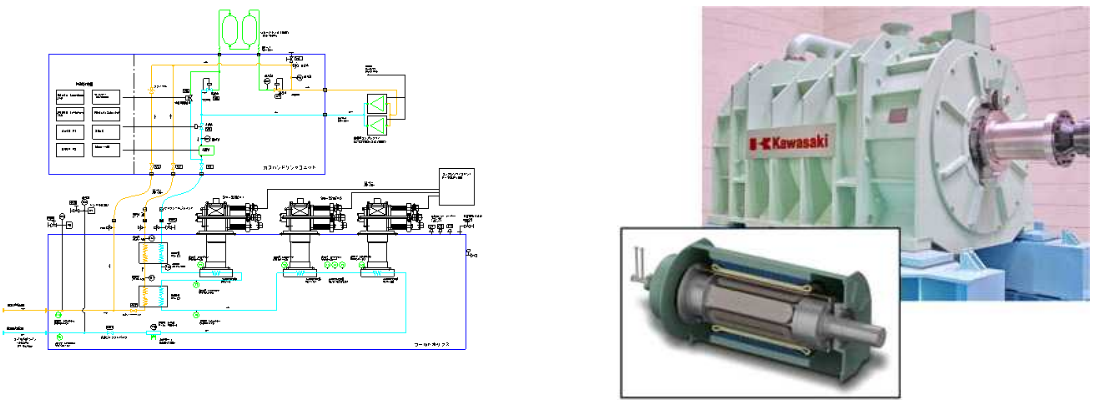

Fig. 5. He gas circulation cooling system for HTS motor. Operation temperature: 〈20 K, Mass flow: 6 g/s, Cooling power: 200 W @ 20 K.

it has become quite usual for customers to ask for He-free superconducting magnets. SSK has been manufacturing and still manufactures superconducting magnet systems with cooling based on cryocoolers conduction cooling or recondensation of liquid helium. In recent years, a New-Zealand company represented by SSK in Japan, HTS-110 Ltd., proposes all types of HTS coil systems for practical use (see figure 6). Thanks to these systems, the advantages of HTS (compactness, reliability, ease of use) are brought to life even in lower fields and reveal markets which could not exist with conventional superconducting magnets.

4. Conclusion

The applications of very-low temperature and superconducting machines are still limited to a portion of the industry. In order to boost the development of superconductors, the

Fig. 6.1. HTS dipole magnet.
Taking advantage of the HTS, this high-speed ramping magnet performs a cycle (0, 7 T, -7 T, 0) in less than 320 s. Used in Kerr effect measurement devices.

Fig. 6.2. 200 MHz 4.7 T NMR magnet.
Equipped with a compact SSK-made GM cryocooler, it is expected to be used on any kind of production lines for automated and systematic quality control.

low-temperature technologies have to evolve beforehand. So far, it was thought that as long as the machine was cold, everything was fine; but with the multiplication of devices and of new technical challenges, it became clear that the notion we call quality is not as simple as it was for past and present machines. To the usual energy saving, reliability and cost issues, the system also has to be a silent and invisible actor. It is through the optimization of cooling techniques that the superconducting applications can evolve further. SSK contributes to the evolution of these two intertwined domains.

SSK has already found brilliant partners in Korea and provides products combining the strengths of both countries to its users. From now on more than ever, SSK wishes to go one step further in the cooperation between our two countries and contribute to the mutual development of low-temperature and superconducting technologies.