Present status of STQ system in BigRIPS and RI-beam delivery line

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The BigRIPS in-flight separator and RI-beam delivery lines are characterized by superconducting triplet quadrupoles (STQs) with cryocoolers. Because the STQ with cryocoolers is a "stand-alone" superconducting magnet with a large cold mass but subject to small heat loads,[1] we adopt a unique thermal cycle operation in which we operate the cryocoolers continuously and never warm up the magnets.[2] Most of the cryocoolers have been continuously operated since 2006 to maintain the liquid helium level in the STQ cryostats. The scheduled maintenance of the cryocoolers is performed yearly, and the constant monitoring of the operational status by the RIBF cryogenic operators facilitates the detection of an abnormal state before losing the helium from the STQ cryostats. The total operation time of the cryocoolers exceeds 140,000 hours.

Two cryocoolers maintain the liquid helium levels in the STQ cryostat. One is a 4K cryocooler system, which re-condenses the evaporating helium gas in the He vessel. Originally, a Gifford-McMahon/Joule-Thomson (GM/JT) cryocooler system, model SG308SC of Sumitomo Heavy Industries, Ltd (SHI), was used as the 4K cryocooler system with a cooling capacity of 2.5 W at 50 Hz. Another cryocooler is a shield cooler system that cools the thermal shield surrounding the He vessel and power leads. A single-stage GM cryocooler system, SHI model UV110CLR, is used as the shield cooler system with a cooling capacity of 90 W at 80 K.

Although these products have worked well for more than 15 years, aging degradation of the cryocooler system owing to impurity accumulation in the coolant helium gas after long-term continuous operation is recently becoming noticeable.[3,4] Furthermore, the manufacturer of the cryocoolers, SHI, has stopped not only shipping these models but also the repair service of the compressor unit in 2022. We then started the replacement of cryocooler systems for STQs.

We replace the discontinued cryocooler unit with a new product without warming up the magnet. Because the original GM/JT cryocooler is mounted on the STQ cryostat with the Wilson seal, a new 4K cryocooler with the same interface can be mounted without modifying the cryostat. We chose a new re-condensing type 4K cryocooler system, TRG-418D_R, manufactured by TAIYO NIPPON SANSO. It uses a 4K GM cryocooler, SHI model SRDE-418D4, which is a two-stage GM cryocooler with a cooling capacity of 1.8 W at 4.2 K. Although it is the one of the most capable 4K cryocoolers in the market, its cooling capacity is smaller than that of the original GM/JT cryocooler, so that we need to reduce the 4K heat load.

To reduce the 4K heat load without modifying the cryostat, we lower the temperature of the thermal shield. Because the GM cooler head V110 of the shield cooler system UV110CLR is integrated in the cryostat, we only replace the compressor unit U108 with the SHI model F-70L with a higher flow rate.[4] We have finished replacement in 17 STQ systems till December 2023. The replacements reduced the temperature of the thermal shield from 4° to 13°, and the estimated reduction of the 4K heat load is in the range of 0.1 to 0.6 W for these 17 STQ systems.[5]

We have replaced the GM/JT cooler with the new recondensing unit TRG-418D_R in 4 STQ systems till December 2023. Figure 1 shows the TRG-418D_R on the STQ20 cryostat as an example. We have not observed any significant degradation of cooling capacity occurring in the GM/JT cryocoolers so far.[5] We consider the new recondensing unit to be more reliable than the GM/JT cryocooler and suitable for continuous operation of STQ systems. The full-scale replacement will finish by 2027.

Fig. 1. New 4K cryocooler system on the STQ20 cryostat.

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