DESIGN OF A CRYOGENIC REGULATION VALVE BOX FOR SRF OPERATION AT TPS

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Abstract

A 3-GeV light source named Taiwan Photon Source (TPS) at National Synchrotron Radiation Research Center (NSRRC) is under construction, and is scheduled for commissioning in 2013/2014. An SRF module of KEKB type has been selected for the TPS as the accelerating cavity of its storage ring. The SRF valve boxes, as part of the cryogenic transfer system, stabilize the cryogenic operational conditions required for various needs of SRF operation. The SRF operation requires a large dynamic variation in the cryogenic loading that challenges appropriate sizing of the cryogenic regulation valves to minimize the pressure drop and concurrently to maintain a fine regulation of pressure. Here, we report our design considerations for an SRF valve box with emphasis on highly stabilizing the helium pressure for SRF operation with a dual-return valve scheme. The estimated fluctuations of pressure due to finite accuracy of the valve opening decrease to a tenth of what is obtained from the conventional single return-valve scheme.

INTRODUCTION

Two 500-MHz SRF modules of KEKB type will be in operation [1] during the commissioning and in the initial user phases of TPS. A third SRF module might be installed subsequently to support the machine operation with a maximum top-up beam current up to 500 mA or even more. SRF module(s) of harmonic or other new design might be installed in TPS after machine commissioning, strongly dependent on the scientific requirements from the users of the light source. The TPS consequently reserves four short straight sections for SRF operations, and each of them is shared with either some short insertion devices or diagnostic or feedback beam-line components to maximize the number of user beam lines. A dedicated cryogenic plant (700 W, 4.5 K, Linde) has been manufactured to support the SRF operation at liquid-helium (LHe) temperature. The cryogenic transfer system connects the 4.5-K cold box and LHe main dewar of the cryogenic plant with the SRF modules, including the cryogenic distribution valve boxes (DVB), associated cryogenic transfer lines, and the cryogenic regulation valve boxes (called SRF valve boxes hereafter) are under production (A/S Scientific).

The layout of the cryogenic transfer system to support the SRF operation at TPS is illustrated in Fig. 1. The cryogenic plant will be located behind the long straight section in the middle of the four short straight sections reserved for SRF operation to minimize the lengths of helium-transfer line. With this cryogenic layout, the individual SRF valve boxes provide the function not only to operate their own SRF modules but also to maintain the cryogenic service to its downstream SRF modules whenever it becomes necessary. Independent cool-down or warm-up of any specific SRF module is allowed for trouble-shooting, but maintaining the other operational SRF modules at cold and avoiding any unexpected thermal oscillation due to the existence of a warm end along the cryogenic piping. Implementing a second or back-up cryogenic plant to service SRF modules from the far end of each of wings is straightforward. Here we present our design considerations for the cryogenic-regulation valve boxes to support the SRF operation in a highly stable, easily maintainable, and conveniently operable manner.

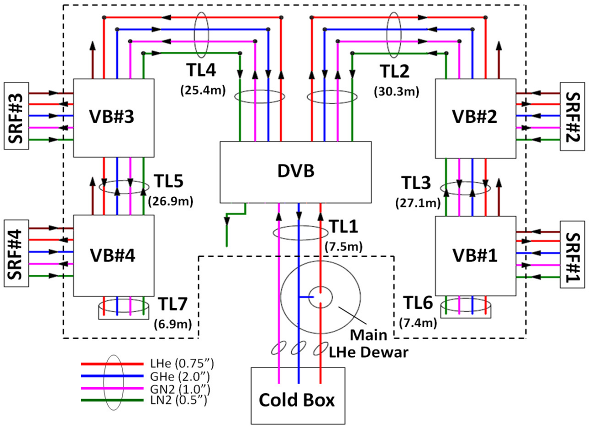

Figure 1: Layout of the cryogenic transfer system for SRF operation at TPS [2].

DESIGN CONSIDERATIONS FOR SRF OPERATION

The 500-MHz SRF modules of both Cornell and KEKB types are not expected to withstand a large operational pressure under warm conditions. The warm KEKB cavity must be operated below 1.3 bara which forces operating the cold cavity below 1.3 bara under some concerns for cryogenic safety. Our routine operational pressure of an SRF module is expected not to exceed 18.3 psia (1.26

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bara). The suction line pressure is at 1.05 bara and the vendor-promised pressure drop from the cold box inlet at cold gas return to its outlet warm end is less than 200 mbar but larger than 150 mbar under a full load (~700 W at 4.5 K). In the worst case (full load), the feasible operational pressure of SRF module is about 1.26 bara (18.3 psia) in a tight margin near the venting pressure of the mechanical safety-relief valve at 0.3 barg (19.05 psia), which brings a risk of contamination to the cryogenic system. In addition, the available budget of the pressure drop for the return line for cold gaseous helium including its cryogenic regulation valve for pressure regulation is less than 10 mbar in the worst case and no more than 60 mbar in the best case. This criterion might cause difficulty in regulating the LHe bath pressure if the allowed pressure drop for the CGHe return valve is too small.

The routine operation of SRF module requires strictly maintaining its liquid helium (LHe) bath pressure and LHe level precisely. Variations of the LHe level unavoidably result in fluctuations of CGHe pressure, because the CGHe return pressure and LHe level of a cryogenic system such as an SRF module are intrinsically coupled together. The cold gaseous-helium (CGHe) return valve and the liquid-helium supply valve inside the SRF valve box are implemented to regulate the liquid-helium (LHe) bath pressure and the LHe level of the SRF module. The fluctuations of the LHe bath pressure modulate the resonant frequency of the cavity. The fluctuations of helium pressure for the SRF operation at TLS are routinely regulated within a few mbar. The resulting variation of the cavity frequency can be partially compensated by the cavity frequency (tuner) loop of the low-level RF system, but a highly stable light source must stabilize the SRF operational pressure from sources of turbulence.

The cryogenic losses of the SRF module and its cryogenic-transfer system determine the required rate of LHe mass flow for transfer from the cryogenic plant to the SRF module. The cryogenic loss of the SRF module nevertheless heavily varies with operational mode, for example roughly 60 W for routine operation at an RF gap voltage 1.6 MV (with nominal $Q_0 = 1\times10^9$) and about 165 W for CW RF processing mode at an RF gap voltage 2.4 MV (with a degraded $Q_0 = 5\times10^8$), which conflicts the proper sizing of the cryogenic CGHe return valve inside the SRF valve box. A compromise between a fine resolution required for precise regulation of pressure during routine operation and a small pressure drop during CW RF processing is difficult to fulfil. We therefore propose to implement a dual-return valve scheme to stabilize the SRF operational pressure with sufficient fine resolution but with extremely small valve pressure drop. The flow distribution ratio between two CGHe return valves cannot be unique; a competition of mass flow rates between two valves must be avoided. To stabilize the flow distribution ratio during routine SRF operation might be a challenge for the control loop of the dual-return valve scheme. A possible solution is either to decrease the feedback bandwidth of the large CGHe return valve or even to operate the large CGHe return valve in a manual mode. An optimal operational scheme must be determined experimentally by trial and error during commissioning. Figure 2 illustrates the detailed diagram of SRF valve box. For diagnostic purpose, a Venturi flow meter, in addition to pressure transducers and temperature sensors, is implemented inside the SRF valve for the CGHe return line from the SRF module. All these can be serviced as flow meters and compared with each other. The KEKB SRF modules require a small rate of cooling (~3K/h) to minimize the thermal stress eventually created by an inhomogeneous temperature distribution during a rapid cooling. Slow cooling is readily achieved on cooling the SRF module with its LHe transfer line together, but implementing a heater on the LHe transfer line in the SRF valve box provides extra convenience that is under evaluation.

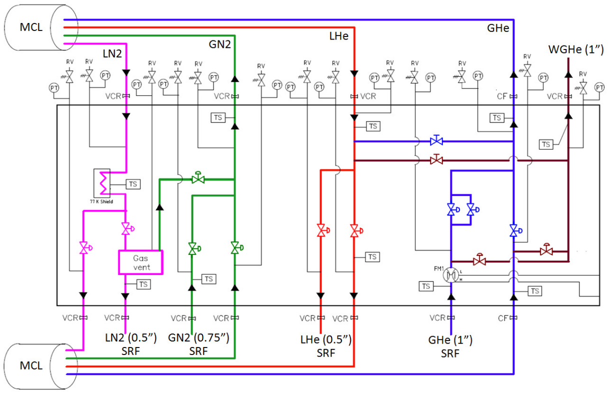

Figure 2: Flow diagram of the SRF valve box for SRF operation at TPS.

SELECTION OF CRYOGENIC VALVES FOR SRF OPERATION

Equal-percentage cryogenic valves modified to zero (WEKA) have been selected for the SRF valve boxes for TPS. The properties of an equal-percentage cryogenic valve are typically characterized with its valve coefficient $K_{v,\max}$ and rangeability R.

For the gas-liquid two-phase flow along the LHe supply line, the calculations of opening of the LHe supply valve cannot be straightforward whenever the amount of gas cannot be neglected. Our simplified approximation is described as follows. Given are the rates of gaseous and liquid helium mass flow through the LHe supply valve. Obtained are the corresponding individual valve openings of single-phase flows with the known pressure drop of the LHe supply valve. Finally, the valve opening of two-phase LHe flow is approximated as a summation of the individual valve openings of single-phase flows. The uncertainty of this approach is within 15 % ranging from the dryness (quality) of two-phase flow from 0.15 to 0.25 experimentally obtained from the LHe valve ($K_{v,\max} = 5.8$, $R = 20$) for the SRF operation at TLS.

The LHe supply valves with equal percentage modified to zero with $K_{v,\max} = 5.8$ and $R = 20$ have been selected for SRF operation at TPS, identical to one used for the

SRF operation at TLS. After the estimates of heat loss, during routine operation of the SRF module, the LHe supply valve manipulates the mass flow rate to cover the upstream (in the gaseous phase at LHe supply valve) and downstream (in the liquid phase at LHe supply valve) heat losses 17.5×1.5 W and 82.5×1.5 W (with a safety factor of 1.5), respectively. The corresponding valve opening is approximately 14 % with a valve pressure drop about 118 mbar (20 mbar among them from the pipe friction). During the CW RF processing, the upstream (in the gaseous phase at LHe supply valve) and downstream (in the liquid phase at LHe supply valve) heat losses become 20×1.5 W and 190×1.5 W (with a safety factor of 1.5), respectively. The corresponding valve opening is approximately 32 % with a valve pressure drop about 73 mbar (65 mbar among them from the pipe friction). The pressures at the main dewar and the SRF module remain invariant, at 1.4 bara and 1.26 bara (18.3 psia), respectively. The openings of the LHe supply valve are 14 % and 32 % at two extreme SRF operational conditions at TPS, implying that our valve sizing with $K_{v,max}$ = 5.8 is somehow excessive but with a sufficient safety margin whenever the heat loss of the LHe supply line becomes unexpectedly huge.

Similarly, the cryogenic valves with equal percentage modified to zero (R = 20) have been selected to regulate the SRF pressure at TPS. The dual-return valves consist of one large and one small cryogenic regulation valves with valve coefficients $K_{v,max}$ = 7.8 and 0.6, respectively. Starting from the requirements on the pressure drop of the single CGHe return valve within 20 mbar under a heat loss of 100×1.5 W (with a safety factor of 1.5) for routine SRF operation, the corresponding pressure fluctuations peak to peak are 1.2 mbar, resulting from the finite accuracy (±0.5%) of the valve opening. The opening of a single large return valve is 50 % for pressure drop 20 mbar. Under a heat loss 210×1.5 W (with a safety factor of 1.5) for CW RF processing, the opening of a single large return valve becomes 74 % for pressure drop 20 mbar. The corresponding pressure fluctuations peak to peak are 1.2 mbar, resulting from the finite accuracy (±0.5%) of the valve opening, identical to those during routine SRF operation, whenever they have an identical pressure drop. Hence the selection of the large CGHe return valve with $K_{v,max}$ = 7.8 is reasonable to maintain a small pressure drop even during CW RF processing but feature an excellent level of pressure fluctuations. As the size of the valve stem is replaceable, the valve coefficient $K_{v,max}$ is variable under some geometrical constraint. Appropriate sizing of the pipe inside the SRF valve box preserves the replaceability of $K_{v,max}$ after installation.

Applying a dual-return valve scheme, the resolution of the pressure regulation can be significantly improved by the small regulation return valve in parallel. For example, considering the ratio of rate of mass flow for a heat loss 100×1.5 W (with a safety factor of 1.5) during routine SRF operation between the large and small CGHe return valves to be 9:1 for the dual-return valve scheme, the small regulation valve ($K_{v,max}$ = 0.6) can significantly decrease the pressure fluctuations peak to peak to 0.12 mabr resulting from its finite accuracy (±0.5%) but with the large valve ($K_{v,max}$ = 7.8) at a fixed opening of 46% for a nominal pressure drop 20 mbar. A significant improvement in the tuning resolution of pressure regulation in a factor of 10 can obviously be obtained.

CONCLUSION

We report our design considerations of the cryogenic regulation valves for the SRF operation at TPS. Heat losses and pressure drops are carefully estimated under two extreme SRF operational conditions: the routine operational mode and the CW RF processing mode. The practical constraints from both sides of the cold box and SRF modules are taken into account in our design consideration. The considerable pressure drop of the CGHe return line inside the cold box, the extremely small maximum allowed operational pressure of the 500-MHz SRF module, and the large dynamic change of heat loss for SRF operation in various modes make difficult the sizing of the CGHe return valve. A dual-return valve scheme has been therefore proposed to regulate the SRF operational pressure to have a fine resolution of pressure regulation during routine SRF operation and a small pressure drop during CW RF processing. On neglecting the intrinsic cross-talk between the LHe level and CGHe pressure in the LHe vessel of SRF module, the achievable pressure stability for a dual-return valve scheme has been estimated to show pressure fluctuations decreased to a tenth of what is obtained from the conventional single return-valve scheme. For a real cryogenic system with the existence of two-phase flows, such as an SRF module working together with its SRF valve box, a strong coupling between the stabilization of the LHe level and the CGHe return pressure exists. A more accurate estimate of the improvement of pressure fluctuations using the dual-return valve scheme requires a detailed thermodynamic modelling of the cryogenic system [3] including the PID loops, which makes the coupling even more complicated, which is now in progress.

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