DESIGN OF THE PHASE REFERENCE DISTRIBUTION SYSTEM AT ESS

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Abstract

PRDS (Phase reference distribution system) at ESS will provide phase reference signals for all LLRF systems and BPM systems with low phase noise and low phase drift. Phase stability requirement is currently 0.1° for short term (during pulse), 1° for long term (days to months). There are 155 LLRF systems, 165 BPM (Beam Position Monitor) systems, and 4 BSM (Bunch Shape Monitor) systems in total at current ESS accelerator design.

INTRODUCTION

PRDS (Phase reference distribution system) will provide phase reference signals for all LLRF systems and beam instrumentation systems such as BPMs (Beam Position Monitors) and BSMs (Bunch Shape Monitors) with low phase noise and low phase drift. Phase stability requirement is currently 0.1° for short term (during pulse), 1° for long term (days to months). There are 155 LLRF systems, 165 BPM systems, 4 BSMs in total at current ESS accelerator design. Figure 1 shows the numbers of LLRF systems and BPM systems in different accelerator sections in current ESS design [1].

PRDS at ESS consists of RF reference signal delivery sub-system, temperature control sub-system, air pressure sub-system, and data acquisition and drift calibration sub-system, by referring mainly the PRDS system implemented at SNS [2].

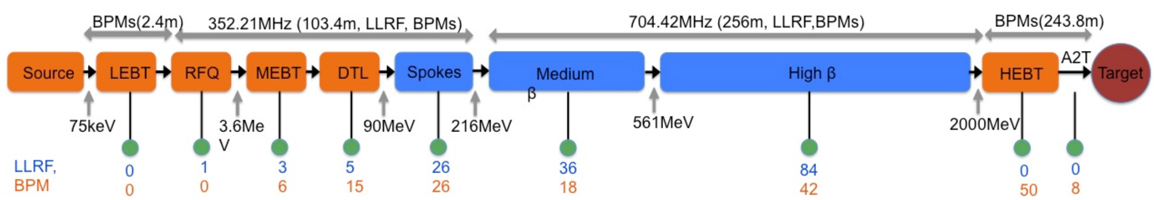

Figure 1: BPM and LLRF system number distribution at ESS.

RF REFERENCE SIGNAL DELIVERY

Topology

RF reference signal delivery topology is chosen as follows at current PRDS design: Master Oscillator (MO) locates in between 352.21MHz section and 704.42MHz section in klystron gallery. Two transition lines will transport RF signals from master oscillator in klystron gallery to main line in tunnel. Two main lines carrying RF frequency 352.21MHz and 704.42MHz goes all the way along the tunnel, with local distribution lines tapping out from each tap (here tap is directional coupler) reach as close as possible to cavity probe cable and BPM/BSM probe cables. Each cavity or BPM/BSM will be assigned a local distribution line, which is bundled together with the cavity probe signal sending to LLRF rack, or bundled together with four probe signals from BPM/BSM sending to BPM/BSM rack. The schematic diagram of phase reference line topology is shown in figure 2 [3].

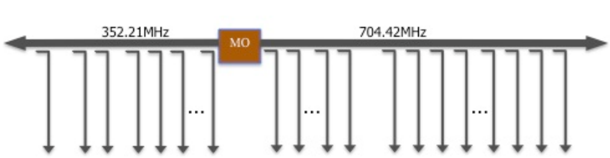

Figure 2: System topology diagram for PRDS.

Main Line

Coaxial rigid transmission lines is chosen as delivery medium due to strong radiation environment in accelerating tunnel, while the main line has to be put in tunnel in order to compensate the phase drift from tunnel to klystron gallery. Optical fibres are first ruled out, due to that they are generally sensitive to radiation, leading not only radiation-induced attenuation, but also radiation-induced refractive index changes [4].

Dielectric filled coaxial cables suffer as well from radiation-induced attenuation and radiation-induced dielectric constant change. It is reported that [5, 6], for PTFE (or Teflon), mechanical properties affected mainly by total absorbed radiation dose, while dielectric properties affected more by dose rate. The experiment made in ORNL half century ago [7] indicated that both polyethylene filled cable and Teflon filled cable experience dielectric constant change, and polyethylene cable showed bigger attenuation than Teflon cable, which is the opposite of radiation effect on their mechanical properties. Dielectric constant change is especially crucial for phase reference distribution, as even small change in dielectric constant will result in significant phase change for 704.42MHz RF signal running on a 300m long cable. Thus, air filled coaxial rigid transmission line with few dielectric

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support in flange is preferred for RF reference signal delivery along the whole linac.

The size selection of the rigid line bases mainly on the consideration of power attenuation and reflection along transmission line. The bigger the size of rigid line, the smaller the attenuation and reflection, and the higher the cost. Therefore, 3-1/8 inch rigid line is chosen based on these considerations and experience at SNS, where 3-1/8 inch rigid line is employed as main line, with vestigial loop directional coupler installed onto the outer conductor of rigid line coupling weakly the electromagnetic field. The attenuation of the whole 3-1/8" rigid line system can be very low as measured at SNS. Another advantage of using 3-1/8" rigid line system is that expansion joint could be used to absorb the thermal expansion, thereby reducing the effort of temperature control for main line.

Local Distribution

Local distribution refers to the route from tap point of the main line to corresponding LLRF/BPM/BSM crate. The reference signals have to be sent to each of LLRF/BPM/BSM crate so as to calibrate long-term phase drift in cable and down-conversion. Instead of having the same point-to-point local distribution at SNS, a point-to-multipoint local distribution scheme is introduced due to the factor that there are 310 taps along the main lines causing increased cost, system complexity and difficulties to install and maintain in point-to-point scheme. A modified point-to-multipoint scheme is shown in figure 3, compared with the previous scheme in reference [3]. Splitter is located in temperature-controlled box together with directional couplers, instead of putting in klystron gallery, which makes system much simpler.

In current design, one tap is taken for each cryomodule

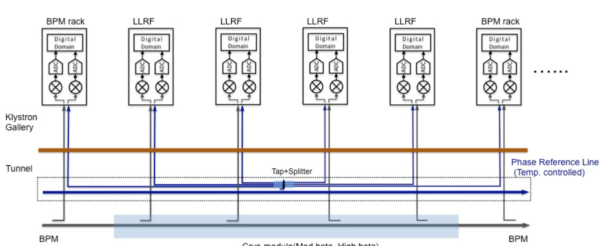

Figure 3: Local distribution for elliptical cavities.

or RFQ/DTL tank (4 elliptical cavities in each medium beta and high beta cryomodule and 2 spoke cavities in each spoke cryomodule).

TEMPERATURE CONTROL SYSTEM

Temperature Stability Requirement

Temperature coefficient of 3-1/8'' copper-made rigid line is 16.5ppm/°C, as shown in SNS data. It agrees well with the pure copper thermal expansion coefficient 17ppm/°C. In order to achieve required long-term phase stability ±1°, ambient temperature stability has to be controlled within ±0.28°C for 704MHz linac section, while ±0.14°C is required if applying one main line all the way along 704MHz linac section, HEBT (high energy beam transport) and A2T (accelerator to target). It is much relaxed in 352MHz linac section, where up to ±1.38°C can be tolerated.

Temperature Control System

Different temperature control strategies are investigated at ESS, by referring the system implemented at JPARC [8] and SNS [2]. Water-cooling temperature control is first considered, as there will be cooling water in tunnel for heat removing and temperature control for RFQ and magnets. Only a couple of temperature control zones are required, if compared with 28 separate temperature control zones at SNS by adjusting heat tape power in each zone. A preliminary design made by O. Persson at ESS is shown in figure 4.

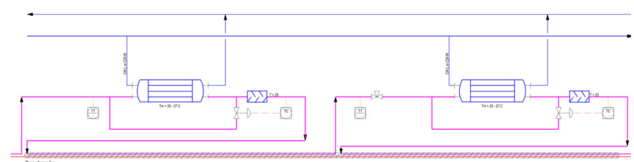

Figure 4: Water cooling temperature control scheme.

The disadvantage of water-cooling temperature control is that there no standard commercial cooling system, and thus it has to be customized at ESS, by using water pump, heat exchange, control valve, static mixer, PID temperature control loop and electric heater. It is expensive, space-consuming and of high complexity if several heat exchangers are taken. Alternative solutions using heater tape in long distance are under investigation at ESS.

AIR PRESSURE SYSTEM

The main line is designed to have dry air inside during operation, to avoid phase drift caused by humidity changes. Dry air expects to be pressurized to a couple of psi above atmospheric pressure. Continuous pressured air with precise regulation is needed to feed into main line.

DATA ACQUISITION, EPICS INTERFACE AND DRIFT CALIBRATION

Data Acquisition and EPICS Interface

Data acquisition expects to be done through control box or other data acquisition devices, and write and read back via EPICS to monitor system performance, indicate the warnings, and configure parameters. The following items have to be integrated into data acquisition and EPICS interface:

- Power monitoring
- Air pressure monitoring and regulation
- Temperature monitoring and control
- Phase drift calibration

Power monitoring at each tap will most likely be accomplished by LLRF system or by commercial power meters for powers not sampled in LLRF system. Commercially available devices like dehydrators will complete air pressure monitoring and regulation. Standard temperature sensors like RTDs will fulfil temperature monitoring, while temperature control will be done by PID loop. These devices will have to be integrated into EPICS so that it can be controlled and monitored remotely. Phase drift calibration will involve down conversion of RF signals from the reference line and from the RF cavity or BPM and processing of those signals in an FPGA, which will be finally implemented in LLRF/BPM/BSM systems.

Phase Drift Calibration

Phase drift mentioned here is the drift along the path from cavity/BPM probe signal in tunnel to the IQ sampling in digital domain, including all drifts from cable, RF components and electronics. The phase reference signal goes in parallel with cavity/BPM probe signal, and sampled into digital domain. These two signal channels will experience identical phase drift resulting from ambient temperature/humidity changes. Thus, the drift could be calibrated in digital domain, if the cables, the connectors, the electronics and other related RF components are identical in these two channels. If non-identical effect is too high, then single channel scheme for both reference signal and cavity signal has to be taken by using combiner or RF switch.

The current calibration scheme has to be examined further for BPM systems, as one of the considerations in current BPM design is, to take harmonics of BPM pick up signals just opposite to cavity RF frequency. It means that 704 MHz harmonic signal is taken for BPM in 352.21MHz (cavity RF frequency) linac while 352 MHz harmonic signal is taken for BPM in 704.21MHz linac. Further discussion is undergoing for alternative harmonic picking up consideration.

Beam Based Feedback

Beam phase errors due to thermal expansion in beam tube and tunnel might be relatively high at ESS, due to relaxed temperature control for klystron gallery and tunnel. Beam based feedback might be required to calibrate this drift if such effect is severe.

SUMMARY

Preliminary design is completed at ESS for phase reference distribution system, but more technical details need to be deeply verified and specified. The work still goes on at ESS.

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