12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB335

SNS WARM LINAC CIRCULATOR BREAKDOWN CONSIDERATIONS FOR THE PPU PROJECT*

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Abstract

The Spallation Neutron Source (SNS) is embarking on the Proton Power Upgrade (PPU) project with the goal to double the proton beam power capability of the existing linear accelerator. The higher beam power will be achieved by increasing the beam energy from 1 to 1.3 GeV and the beam current from 26 to 38 mA. To support the increase in beam energy and current, the PPU will install 28 additional cavities in the superconducting linac (SCL) and increase the peak power of three normal conducting linac (NCL) RF stations. This paper focuses on the NCL RF stations and presents the systematic approach used to assess the ability of the existing waveguide circulators to handle the higher RF power requirements of the PPU project. SNS RF engineers developed a 3-D electromagnetic model of the circulator and analyzed the peak electric field values under three operational cases. The results alleviated critical breakdown and operational concerns.

INTRODUCTION

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) is a megawatt class pulsed neutron source and produces high peak brightness neutron beams for materials research. The existing H- beam accelerator incorporates a normal conducting linac (NCL) and a superconducting linac (SCL). The NCL contains 6 drift tube linac (DTL) and 4 coupled cavity linac (CCL) radio frequency (RF) stations while the SCL has 81 RF stations. To promote unique experiments and new discoveries, the SNS has started the Proton Power Upgrade (PPU) project. The PPU project will eventually double the proton beam power from 1.4 to 2.8 MW [1].

To achieve the additional power, the beam current will be increased from 26 to 38 mA and seven additional cryomodules will be added to the existing linear accelerator to raise the beam energy to 1.3 GeV. Increased beam loading, due to the higher beam current, will demand additional power from the existing RF systems [2]. An analysis of the impact of the higher power demand in the normal conducting linac (NCL) is ongoing. Based on the results of the ongoing study, a few NCL RF stations will need to be upgraded. A principal concern that resulted from proposed upgrade plans was the ability of the existing circulators to handle the increased power without degradation of performance and/or a reduction in lifetime. This paper provides a brief overview of the capability study on select SNS NCL circulators and the results of 3-D electromagnetic simulations that reduced the scope of the PPU project.

* ORNL is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy. This research was supported by the DOE Office of Science, Basic Energy Science, Scientific User Facilities.

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BACKGROUND

A study of the accelerator system parameters needed to accelerate a 38 mA beam for the PPU project provided data that informed the RF design process. Results of the study showed that the RF stations at DTL 2 through 5 failed to produce sufficient power for reliable operation at PPU levels [2]. A 25 percent power margin at each station is required without the operational specification of the klystron cathode current being exceeded. A recommendation was made for DTL stations 3 through 5 to be upgraded from 2.5 to 3 MW capability. While the DTL-2 station did not meet the power requirement, proposed upgrades to the high voltage converter modulator (HVCM) will alleviate those concerns [2].

With plans being made to upgrade select RF stations to 3 MW capability, the RF team needed to upgrade certain waveguide circulators in operation or ensure their ability to handle the higher PPU power specification. The PPU project requires Y-junction geometry circulators that are capable of handling the proposed 3 MW peak power of the RF design. These circulators will also need to adequately operate under high reflected power conditions at a maximum pulse width of 1.5 milliseconds and a maximum repetition rate of 60 Hz [3].

Although designed for a higher peak power, normal PPU operation will utilize a maximum peak power of 2.5 MW. Since the existing circulators at SNS were designed to operate with a maximum peak power of 2.5 MW, the high cost of 3 MW rated circulators drove the RF team's desire to assess the ability of the existing circulators to handle the higher power requirements [3].

The existing circulators were rated for a maximum peak power of 2.5 MW into a short circuit at any phase. The short circuit at any phase rating ensures that the circulators are capable of handling full reflections at any port. Under full reflective conditions, the circulator could see up to twice the voltage magnitude of the standing wave. This means that the circulators have a characteristic peak power of 10 MW when terminated into a matched load. This is because power is proportional to the square of the voltage in passive devices and twice the voltage is four times the power [3]. It is worth mentioning that the reflected power cannot exceed 2.05 MW in a potential 3 MW operation. This is to ensure that the characteristic peak power capability of the device is not exceeded. However, it is highly unlike that the circulators could see such high reflected power levels. The SNS accelerator system includes a high-power protection module (HPM) that stops the RF drive to each RF station within 10 μS if the reflected power exceeds 600 kW. The 600-kW adjustable limit was selected based on operational experience and technical expertise [3].

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MODELLING

A 3-D model of the circulator was built using CST Microwave Studio so that the operational capabilities of the device could be assessed. The physical dimensions of the circulator were obtained from a spare unit, but key ferrite parameters could not be obtained from the manufacturer due to the proprietary nature of the design. A few assumptions were made to certain design parameters that determine the operational attributes of the device. A magnetic flux of 1280 Gauss at the ferrite junction of a spare SNS unit was measured using a gauss meter and incorporated into the model. Ferrite data provided by the National Magnetics Group, Inc was used to develop the model. From the data sets provided, the NG-1200/1201 ferrite material was selected [4]. This is because its 1200 Gauss saturation magnetization and 14.4 dielectric constant value were closest to the design parameters of the existing units [3].

SIMULATION AND RESULTS

Based on the configuration at SNS, port 1 of the circulator was modelled as the input (Klystron Output), port 2 as the output (Cavity) and port 3 as the isolated port (Water/Glycol load). Waveguide ports were used for the termination of each port on the device. Figure 1 shows a model of the circulator.

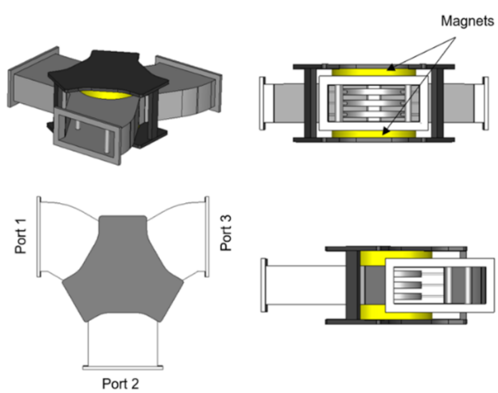

Figure 1: 3-D Model of the SNS DTL Circulator. [3]

The existing circulators contain permanent magnets for biasing the ferrites and electromagnets for fine tuning the device. To reduce the complexity of the simulation, the combined magnetization of the permanent magnets and electromagnets were lumped into the set of magnets shown in Fig. 1.

The next step of the simulation effort was to ensure that the high frequency simulation of the model matched the performance of existing circulators. A bias range from -1.76 to -0.79 Amperes was recorded for the circulators in the RF stations from DTL-2 through 6. Low power measurement results of a spare circulator indicate an S_{11} range from -36.45 to -17.76dB, S_{21} from -0.165 to -0.033dB and S_{31} from 38.22 to -18.25dB over that biasing range. Select parameters of the model were then tuned until the results closely matched or fell within the operational range of S-parameter values. Figure 2 shows the frequency response of the circulator after tuning.

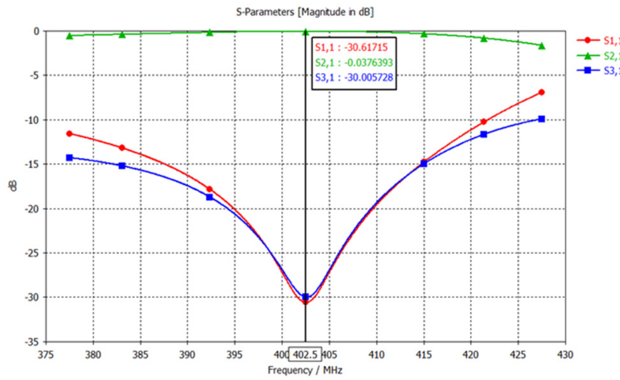

Figure 2: Frequency Domain Response of the DTL Circulator after Tuning.

Post processing of the electric field from the simulation results was used to determine the magnitude of the peak electric field in the structure. The goal was to ensure that the maximum electric field intensity did not meet or exceed the dielectric strength of the air in the circulator. The value of the breakdown voltage of air varies, but a conservative value of 3 MV/m was used as a reference [5]. Insitu measurements made using a Hubbell Hipotronics Dielectric Tester produced an average dielectric strength of 3.39 MV/m.

Three operating cases were then studied for the device. In case 1, the team sought to find the peak electric field value of the circulator at the current SNS operational limit (2.5 MW forward and 600 kW reflected). In the second and third cases, the team compared the maximum electric field value of manufacturer's rating condition (2.5 MW forward and 2.5 MW reflected) and the PPU operating limit (3 MW forward and 2.05 MW reflected). For all three cases, a maximum electric field of 1.1331 MV/m was record for the device. Figure 3 shows a plot of all three cases as a function of the phase of the forward power.

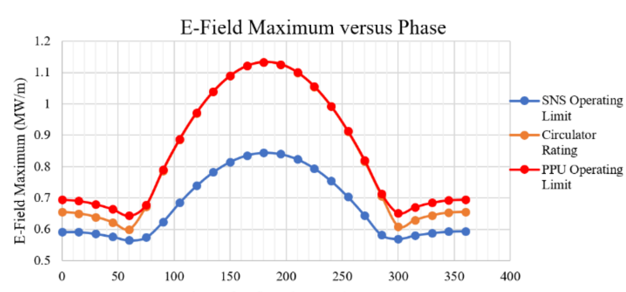

Figure 3: Maximum E-Field Intensity as a Function of the Transmitted Power Phase.

A second study focused on the performance of the device under optimally tuned and the highest achievable simulation directivity conditions. The results of this study showed a maximum electric field intensity of 1.1787 MV/m for the same 3 cases studied earlier. Figure 4

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shows the frequency domain response of the model and Fig. 5 shows a plot of the three operational cases studied. Table 1 shows a list of key ferrite parameters used to produce the results.

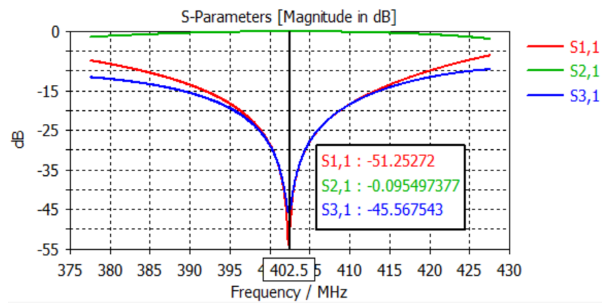

Figure 4: Frequency Domain Response of the DTL Circulator after Tuning (Optimal Tuning Case) [3].

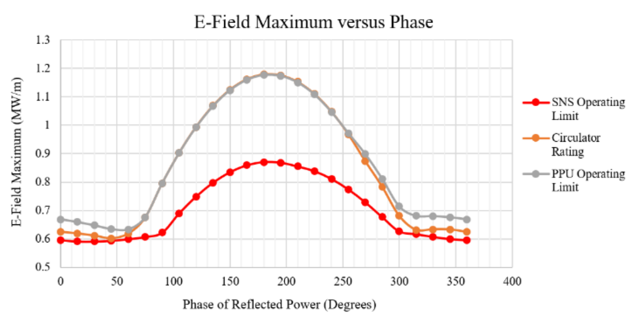

Figure 5: Maximum E-Field Intensity as a Function of the Transmitted Power Phase (Optimal Tuning Case) [3].

Table 1: List of Key Parameter Values [3]

Model Parameter	**Value**
Permittivity (ε_r)	14.4
Landé Factor (g)	2
Simulated Magnetic Flux Density (B, Gauss):	1280
Resonance Line Width (ΔH)	1

CONCLUSION

The impact of the PPU project's higher power requirement on NCL circulators was of concern. However, the rating of existing circulators at SNS, information from the manufacturer and results from simulations of 3 operational cases alleviated those concerns. From the case studies, the potential maximum electric field intensity that the circulator will see is 1.1787 MV/m. The maximum simulated value is less than the referenced, conservative 3 MV/m dielectric strength of air and the measured value of 3.39 MV/m. The study led to a reduction in the scope of the PPU project since the existing SNS circulators were deemed capable.

ACKNOWLEDGEMENTS

The authors of this paper would like to acknowledge Mr. Mark Cardinal and Mr. Timothy Miner for their help on this project.

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