Letter of Interest for Snowmass2021:

R&D on High Power Fundamental Power Couplers for Superconducting Cavities

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Superconducting radio-frequency (SRF) accelerators are essential tools for High Energy Research program, including studies at High Energy Frontier facilities, like next generation of proposed Higgs factories: ILC, FCC-ee, and CepC and studies on Intensity Frontier accelerators like PIP-II and PIP-III developed for dedicated Neutrino Physics experiments.

The fundamental power coupler (FPC) is one of the most critical components of a superconducting RF accelerator, which determine reliability, longevity and operating expenses of machine. The FPC is very often complex structure with cost comparable to the cost of cavities. For many applications the couplers are required to transmit megawatts of pulsed RF power and hundreds of kilowatts of average power. Many successful power couplers have been developed over the years, but the designs continue to evolve, and new designs are proposed and developed to address challenges brought by new SRF projects. As a result, various aspects of the input coupler design, fabrication, preparation, RF conditioning, integration in cryomodules, interactions with beam, etc. are frequently discussed at various conferences and meetings and these discussions are summarized in overview papers, such as [1-4].

New SRF accelerator technologies push the gradient of the cavity and the rf power transmitted to the beam to new limits, much higher than already demonstrated. Upgradability of the future accelerators to a higher energy and luminosity levels requires that many components of the cryomodule, including FPC, should be designed with sufficient margin.

FPC is complicated device includes different materials and operates under ultra-high vacuum, high RF power and big temperature difference. Design and manufacturing of reliable coupler is big challenge. Most critical part of coupler is RF window which typically is ceramic disk brazed into metal environment. Difficulty of production is to provide a reliable bonding between ceramic and metal. It is most critical and expansive operation and only very limited number of vendors can perform it. It is not easy to do a quality control of bonding. Another problem arises during operation at high RF power level. Ceramic can be fractured due to stresses from thermal gradients, internal stresses, rf discharge, breakdown caused by space charge accumulation. Temperatures of coupler parts increase, and mechanicals stresses emerge because of difference between thermal expansion coefficients of ceramic and metal environment. These stresses limit a power level, lifetime and it is main reason of RF window breakdown.

Coupler production requires a critical state-of-the-art technologies, including vacuum e-beam and laser welding, brazing of different materials (ceramic-to-metal), copper plating, coating of ceramics (TiN, TiO,..), vacuum baking, using non-magnetic UHV compatible materials, using ultra-high cleaning technology and equipment. It defines the high cost of the coupler and limit the number of vendors available for the production. The new ideas proposed recently to improve the coupler cost and reliability of the FPC will allow to simplify a design and eliminate some critical technologies.

- We are suggesting to use special alloys/compositions with thermal expansion equal to thermal expansion of ceramics for production of housing of RF window. For example, it can be Molybdenum-Copper or Tungsten-Copper compositions. Playing with ratio of two metals one can achieve the thermal expansion coefficient of the composition close or equal a ceramic's one. It allows minimize residual stresses and make brazing more reliable. Both compositions have good electrical and thermal conductivities. This technology potentially will great impact to RF windows performance, design and production. It will make RF windows more powerful, reliable and simpler for fabrication.
- We are suggesting to develop a technology to fabricate a coupler RF window without brazing ceramic to metal. Instead the ceramic assembled in coupler, using a special metal gaskets similar to aluminum 'diamond' seals commonly used to joint superconducting cavity with elements of accelerator. Preliminary experiments show feasibility of this technology. In case of success it will great impact to coupler design and production: most difficult operation for production and quality control will be eliminated. It will make coupler less expensive, more reliable and more powerful. Number of possible vendors able to produce couplers will be expended significantly.
- We suggest utilization of a newly developed conductive ceramic with low RF losses. Some studies in this direction already ongoing in Euclid Techlab and KEK. It will help to eliminate charging of ceramic during operation with the beam, which improve window reliability. Secondary emission yield of the ceramic expected to be lower to compare with Al2O3 high purity ceramic typically used.
- We are suggesting to introduce special copper electromagnetic shielding of the stainless steel cold outer conductor with small gap between them [5]. In existing designs outer conductor is copper plated (10-15microns copper with high RRR) to minimize rf losses and cryogenic loads at 2K and 5K. Copper plating process is expensive and quality is not always perfect. Also, there is a potential risk that some copper flakes can contaminate niobium cavity over 20 years of operation. In proposed design, there is no RF field between copper shield and SS conductor, all rf losses will be in copper shield, and power will go to 50K cryogenic circuit. Two prototypes of 650MHz coupler were built and tested at high average power as a prove-of-principle.

Summary

There new approaches will allow to develop a new generation of the high power couplers for SRF accelerators to provide high reliability at high pulsed and average power and reduce complexity and cost of the coupler production at the same time. Together with other means for SRF accelerators improvement – cavity processing allowing very high gradient, resonance control, etc. – it will allow to make a next step in development of the accelerators for HEP applications.

References:

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