Nuclear Inst. and Methods in Physics Research, A 870 (2017) 37–42

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Technical notes

Final results of power conditioning of SPIRAL 2 couplers

Y. Gómez Martínez [a,*], M. Baylac [a], P. Boge [a], T. Cabanel [a], P. De Lamberterie [a], J. Giraud [a], F. Vezzu [a], F. Chatelet [b], C. Joly [b], J. Lesrel [b], D. Longuevergne [b], R. Martret [b], G. Olry [b], L. Renard [b], P. Bosland [c], C. Marchand [c], L. Maurice [c], O. Piquet [c], P.-E. Bernaudin [d], R. Ferdinand [d]

[a] LPSC, IN2P3 (CNRS), Université Grenoble Alpes, 38026 Grenoble, France
[b] Institut de Physique Nucléaire, CNRS-IN2P3, Université Paris-Sud, 91400, Orsay, France
[c] CEA, 91400, Saclay, France
[d] GANIL, 14000, Caen, France

ARTICLE INFO

Keywords:
Coupler
Power conditioning
Preparation
Multipacting
SPIRAL 2
Linac accelerator
Superconducting accelerator

ABSTRACT

Cryomodules of the superconducting accelerator SPIRAL 2 have been successfully qualified and are now under commissioning on the linac at GANIL (France).

This paper presents the successful results of the power conditioning of the couplers both on a test bench in Grenoble and during the cryomodules qualification. It also shows the influence of some factors, such as surface state and experiencing a cavity quench around the antenna, on the power conditioning process (duration, quality).

1. Introduction

SPIRAL 2 [1] is based on a superconducting accelerator producing 40 MeV, 5 mA deuterons and 14.5 MeV/u, 1 mA heavy ion beams. Its linac operates at 88.05 MHz. It is composed of twelve cryomodules housing one low beta ($\beta = 0.07$) cavity, developed at CEA Saclay (France), and seven cryomodules housing two high beta ($\beta = 0.12$) cavities, developed at IPN Orsay (France). The cavities are quarter-wave resonators and have been designed to operate at a nominal accelerating gradient of 6.5 MV/m for 5 mA deuterons with a duty cycle (DC) of 100%.

In 2010 and 2011, while testing six high beta cavities inside cryomodules, unusually high radiation dose rates were measured (>100 mSv/h) and cavities quenched below the nominal field of 6.5 MV/m. After disassembly of these cryomodules, no visible alteration of four couplers was observed. On the contrary, two couplers exhibited spots, suggesting marks of a breakdown, at the tip of the antenna [2].

These incidents led to several improvements in the preparation protocol of cryomodules, including couplers, as listed in Table 1: more stringent cleanliness control of cryomodules with systematic particle counts, electropolishing and de-oxidation of the coupler's antenna and finally radio-frequency (RF) mode for the coupler power conditioning on the cryomodules (pulse mode instead of continuous wave, used previously). This improved protocol, detailed in Section 3, was applied for the present paper.

Table 1 summarizes the differences between the old and the updated coupler preparation protocol.

Since this new protocol was imposed, all cryomodules were tested successfully (radio-frequency, vacuum, cryogenics). Thirty-five couplers (prototypes, series and spares) have been manufactured. There are twenty-six couplers in the linac: nineteen of them were prepared with this improved protocol, six couplers were prepared with this improved protocol but experienced a cavity quench and one coupler was prepared with the old protocol.

In this paper, we present our feedback on the power conditioning of these couplers, both on a test bench and on the cryomodules.

2. Coupler design

The coupler aims to transfer energy from the RF source to the accelerating cavities of the linac. It provides a vacuum and a thermal

* Correspondence to: LPSC, IN2P3 (CNRS), Université Grenoble Alpes, 53, avenue des Martyrs, 38026 Grenoble, France
E-mail addresses: gomez@lpsc.in2p3.fr (Y. Gómez Martínez), baylac@lpsc.in2p3.fr (M. Baylac), boge@lpsc.in2p3.fr (P. Boge), cabanel@lpsc.in2p3.fr (T. Cabanel), pierre.de-lamberterie@lpsc.in2p3.fr (P. De Lamberterie), giraud@lpsc.in2p3.fr (J. Giraud), vezzu@lpsc.in2p3.fr (F. Vezzu), chatelet@ipno.in2p3.fr (F. Chatelet), joly@ipno.in2p3.fr (C. Joly), lesrel@ipno.in2p3.fr (J. Lesrel), longuevergn@ipno.in2p3.fr (D. Longuevergne), martrer@ipno.in2p3.fr (R. Martret), olry@ipno.in2p3.fr (G. Olry), renard@ipno.in2p3.fr (L. Renard), bosland@cea.fr (P. Bosland), marchand@cea.fr (C. Marchand), maurice@cea.fr (L. Maurice), piquet@cea.fr (O. Piquet), bernaudin@ganil.fr (P.-E. Bernaudin), ferdinand@ganil.fr (R. Ferdinand).

http://dx.doi.org/10.1016/j.nima.2017.07.004
Received 6 March 2017; Received in revised form 30 June 2017; Accepted 4 July 2017
Available online 16 July 2017

Table 1
Differences in the steps of the coupler preparation for the old (before 2012) and updated protocol.

Preparation steps	Old protocol (before 2012)	Updated protocol
Antenna electro-polished	No	Yes
Metallic surfaces deoxidized	No	Yes
Baking under vacuum (60 h, 200 °C)	Yes	No
Cleanliness control criterion on each coupler piece	Simple blowing of filtered N_2 on each piece	After blowing filtered N_2 at 5 bars on each piece, acceptance if: • no particle ≥5 μm measured • less than 100 particles <0.5 μm
Assembly on the conditioning bench	In ISO 6 clean room	In ISO 4 hood placed in ISO 6 clean room
Transportation	Coupler upward (tip of the antenna on top)	Coupler downward (tip of the antenna down)
RF cryomodules conditioning	CW	Pulse

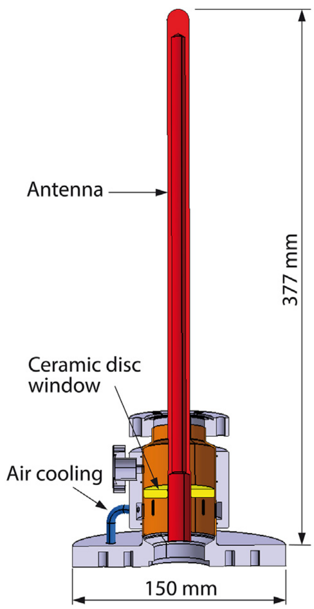

Fig. 1. 3D drawing of the RF coupler.

barrier to the superconducting cavity while preserving its cleanliness. Eventually, the coupler allows some mechanical flexibility to compensate differential thermal expansions and mechanical misalignments.

For SPIRAL2, the coupler is designed to provide, in nominal operation, up to 13 kW continuous wave (CW) power to each cavity. This power is among the highest reached in linacs operating with a DC of 100 % at low frequency (88.05 MHz) [3–5].

Both types of cavities, with high and low beta cavities, are equipped with the same coupler. Couplers were designed, prepared and power conditioned on a test bench at LPSC (France).

The coupler is composed of a 6 mm thick ceramic disc window and a hollow copper antenna 377 mm long (Fig. 1). A permanent cooling of clean air is used to keep the ceramic window at ambient temperature and to prevent condensation.

The coupling factor is given by the penetration of the antenna in the cavity. As there are no bellows in the coupler, the length of the outer conductor is chosen, once and for all, to obtain the penetration of the antenna corresponding to the required coupling factor.

The outer conductors, made of stainless steel, have been coated with copper (20 ± 5 μm thick) with a measured Residual Resistivity Ratio of 30.

Cavity specifications require the reflection coefficient (S_{11}) to be better than −25 dB and the thermal load (static and dynamic) to the cavities to be less than 1 W at nominal power. RF and thermal simulations demonstrated that these conditions can be satisfied, with a reflection coefficient of −50 dB as calculated with the HFSS code and a thermal load <0.2 W for low beta cavities and <1 W for high beta cavities, as calculated with the code SAMCEF [6]. Mechanical simulations have also been done with SAMCEF. The first modal frequency of the coupler is 73.5 Hz far away from the typical motor frequency (50 Hz). It was also validated that, in the frequency range 0–700 Hz, the endurance stress limit of the material (>60 MPa) due a fixed displacement of 0.01 mm at the window is never reached. Results obtained with HFSS show that the electric surface field on the tip of the antenna reaches 12 MV/m in nominal operation.

Multipacting is an undesired phenomenon of resonant electron build up encountered in electromagnetic field regions under vacuum. It is created as an electron is accelerated by the electric field and hits the enclosure's wall. Depending on the secondary electron yield of the wall, more than one electron can be emitted and accelerated by the electric field, creating a self-sustained electron avalanche [7,8].

Simulations using the MUSICC3D code (from IN2P3/IPNO) [9] were performed to evaluate multipacting on the power couplers. Two multipacting barriers were calculated, one around 10–20 W and another one between 30 and 130 W, but both were found to have no resonant electron trajectories on the window of the coupler [10]. In addition, these multipacting barriers were detected experimentally with a very low level of multipacting current (<0.6 mA) [11]. Therefore, no coating was applied on the ceramic window, although an anti-multipactor coating is generally agreed upon by the community [12,13].

Table 2 summarizes the main coupler specification and simulation results.

3. Power conditioning on the test bench

Power conditioning (or processing) is the procedure to expose the couplers gradually to the power. The goal is to reproduce conditions potentially harmful for the coupler (such as multipacting) under safe conditions where vacuum and electron (or multipacting) current are monitored and kept within acceptable limits.

For the SPIRAL2 couplers, conditioning in travelling wave mode would require a very large cavity because of the low operating frequency (88.05 MHz). Therefore, the power conditioning was performed in a stand-alone configuration with an open termination, in a full stationary wave regime and at room temperature.

Before the power conditioning, the couplers' antennas are electropolished for 90 min to remove a thickness up to 400 μm of diameter. The electropolishing solution is a mixture of phosphoric acid, alcohol and metallic ionized salts.

Then couplers are prepared in a clean room (ISO 6 with an ISO 4 hood for the assembly) as follows: after an ultrasonic bath during 15 min at 50 °C with TicopurR33®, it is rinsed with ultra-pure water and deoxidized. Then, filtered N_2 is blown at 5 bars on every element of the couplers to verify the number of particles released at each stage of the coupler preparation (Fig. 2). The cleanliness specifications impose, as mentioned in chapter introduction:

- For particle size <0.5 μm: less than 100 particles per 28 litres of sucked air measured
- For particle size ≥ 5 μm: no particle measured.

Finally, an in-situ baking is performed as the couplers are mounted on the power conditioning bench.