PROCESSING AND TEST RESULT OF 650 MHZ 50KW CW PROTOTYPE COUPLERS FOR PIP-II PROJECT

TUPTEV017

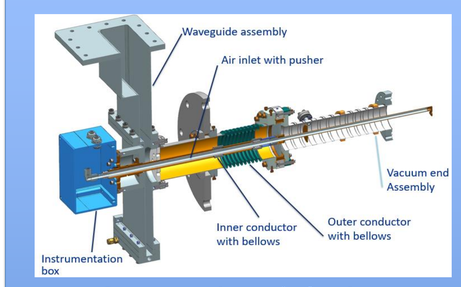
Nikolay Solyak, Bruce M. Hanna, Sergey Kazakov, FNAL, Batavia, IL 60510, USA

INTRODUCTION

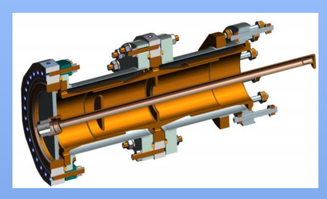
The PIP-II/LBNF/DUNE project will be the first internationally conceived, constructed and operated mega-science project hosted by the Department of Energy of the United States [1]. The PIP-II project represents the upgrade plan of Fermilab accelerator complex. It will lead to the construction of world's highest energy and the highest power CW proton Linac reaching 800 MeV. Five types of cryomodules will be built to achieve this performance. For the highest energy part of this Linac, the LB650 and HB650 cryomodules equipped with 650 MHz Superconducting (SC) cavities are used. The same 650MHz Power Coupler (PC) design will be used for both low-beta (LB650) and high-beta (HB650) cavities. PIP-II requires that coupler should work in 50kW CW regime with 20% power reflection. Before installation to the cavity each coupler should be tested and conditioned at the room temperature test stand. Power requirements for the test stand more stringent: 50kW with full reflection at any reflection phase to have more margin during long time coupler operation in cryomodules.

COUPLER PROTOTYPING

During project R&D phase two design modifications of the coupler were developed, built and tested [2,3].



Conventional design



Vacuum part of EM-shielded design

Features:

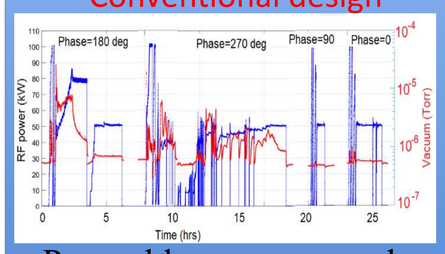
- Flat ceramic window, separate vacuum and air parts of the coupler
- Antenna, ceramic and air part of coupler are cooled by dry air
- SS tubes and bellows in warm part copper plated.
- In vacuum part outer conductor is copper plated only in conventional design. In EM-shielded design copper screens hide outer conductor from the field
- Kapton foil between inner and outer conductors allows use HV bias up to 5kV

TEST RESULTS

Processing protocol for DC bias applied

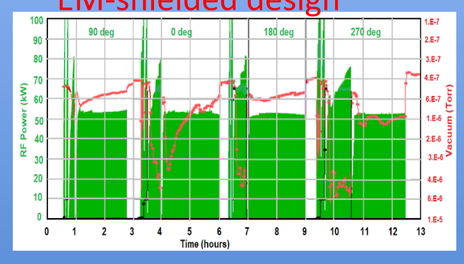
- Pulse 10ms, power ramped up to 100kW, average power ≤1 kW, ~15min
- Pulse 100ms, power ramped up to 100kW, average power ≤10 kW, ~15min
- Pulse 650ms, power ramped up to 80kW, average power ≤50 kW, limited by vacuum.
- CW mode, ramping up to 50kW, stay ~2 hrs or longer if vacuum exceeds 1.E-6 Torr.

Conventional design

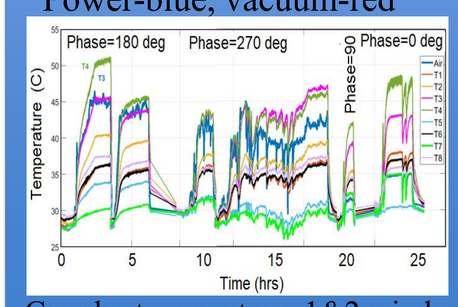


Power-blue, vacuum-red

EM-shielded design



Power-green, vacuum-red

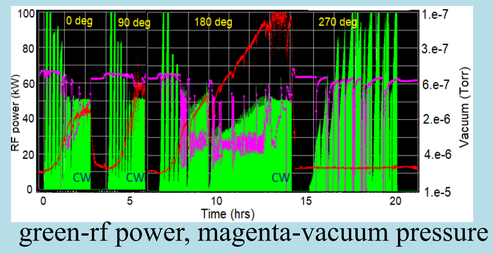


Coupler temperature: 1&2 window; 3&4 air outlet

Coupler tested at full reflection for 4 reflection phases: 0; 90; 180; 270 degrees. More processing required for 180 and 270 deg reflection phase

Power processing without DC bias

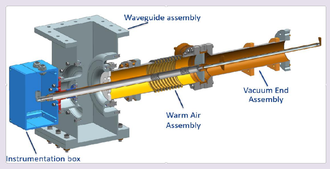
- Short pulses: 10;20;50;100,200,500 μs, Power ramp 0 => 100 kW, (average power < 50 W)
- Long pulses: 1;2;5;10;20;50;100;200; 500 ms. Power ramp 0=>50 kW, (avrg power < 25 kW)
- CW, Power ramp 0 => 50 kW, after that stay 2 hours at 50kW

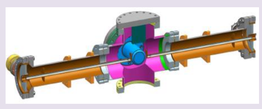


green-rf power, magenta-vacuum pressure

Processing w/o bias much longer, especially for 180 and 270 degrees

DESIGN MODIFICATION OF PRE-PRODUCTION COUPLERS





- *Narrow waveguide replaced with standard WR1150 waveguide to improve pass-band and reduce heating*
- *Thicker ceramic window, copper sleeve modified for better brazing*
- *Use standard CF flanges for window connection. It provides compactness, smaller weight, easier handling.*

8 couplers and 3 antennas in production on CANON

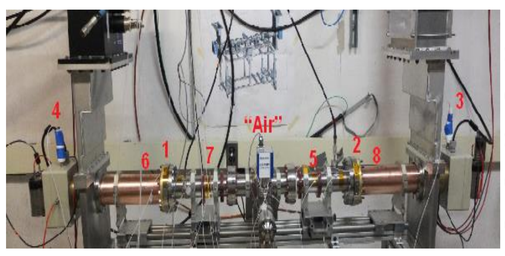
Coupling chamber is designed for capacitive coupling of two antennas, to simplify assembly of test stand and reduce risk of ceramic damage

Testing of prototype

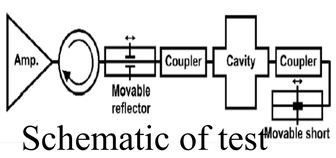
Two couplers of each design is built, vacuum part in CPI,

Cleaned by US bath
Leak-checked, assembly in the clean room,

Assembly two couplers with coupling cavity for test. Flexible copper bridge for antennas. Leak-check and baking 48 hrs at 120C



Full assembly on test stand support. Pumping, diagnostics, air cooling system. 8 T-sensors to control temperature of coupler and cooling air

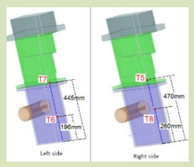


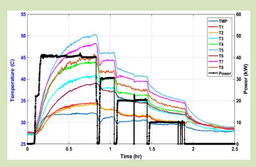
Schematic of test stand RF power

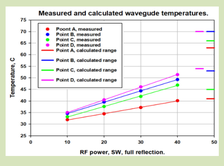
30kW IOT rf source. Available RF power for qualification test is 100kW, using resonance scheme to multiply power. For each reflection phase move short by adding WG piece and adjust reflector

WG heating test

WG was hot during CW tests, to cross-check simulations we install T-sensors on narrow WG and WG transition







measured data and calculated temperature at 50 kW power

temperature of waveguide was measured for different levels of power in CW regime 10kW, 20kW, 30kW and 40kW (middle). Reflection phase was 0 degrees in this test. Temperature traced are shown in colours.

Calculations done for all reflection phases, two lines in plot corresponds minimum and maximum values. Measurements are in a good agreement with simulations.

Simulations predict that maximum power dissipation in waveguide ~427W and Tmax > 68° C with water cooling (short) and 137° C w/o water cooling. In pre-production design instead of narrow waveguide we will use standard WR1150 which allow significantly reduce dissipated power and temperature even without water cooling.

Effect of HV bias polarity

- *To understand effect of bias polarity on coupler performance we changed polarity from positive to negative and repeat processing using same protocol for the last configuration point with reflection phase 270 degrees.*
- *Positive and negative bias was applied for short pulses (10ms) to compare MP threshold at 3 kV bias. For negative polarity the MP activity starts at about 18 kW, while for the positive bias the threshold was moved to 50 kW power level.* Without bias MP starts at ~6kW. For negative polarity -3kV couplers were conditioned for ~ 4 hrs
- With -5kV bias coupler was processed again. It takes ~2,5 hrs, vacuum plot still show hairy noise, means MP not suppress completely.

From bias polarity test we can conclude that positive bias is much more effective for the current configuration than negative polarity bias.

Conclusions

Two prototypes of 650MHz couplers for PIP-II project were designed, built and tested. One is conventional design, second is EM-shielded design, where copper screens shield SS outer conductor from EM-field. Both designs passed successfully through qualification test and demonstrated excellent performance with DC bias applied. Some of them already tested with cavity in horizontal cryostat. One pair of couplers were successfully processed without bias. Processing w/o bias is more time consuming, but better clean coupler vacuum surfaces by multipacting.
Based on assembly, testing experience and lessons learnt, we chose conventional design as a baseline for PIP-II. Design was modified for pre-production series to improve handling and performance.

REFERENCES

[1] L. Merminga, "PIP-II project status", presented during the PIP -II Machine Advisory Committee Meeting, 1-3 June 2021.
[2] S. Kazakov, "Design studies on LB650 & HB650 power couplers - simulation challenges and issues", presented in the PIP-II Technical Workshop, December 1th, 2020.
[3] O. Pronitchev#, S. Kazakov, "DESIGN OF MAIN COUPLER FOR 650 MHz SC CAVITIES OF PIP-II PROJECT", MOPOB24, Proceedings of NAPAC2016, Chicago, IL, USA, ISBN 978-3-95450-180-9
[4] N. Solyak, S.Kazakov, PIP-II power couplers cleaning and Room Temperature RF power tests, presented in the PIP-II Technical Workshop, December 2th, 2020.