Mock-up Waveguide Loop Development toward a half-meter scale Traveling-Wave (TW) SRF cavity

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Abstract

Traveling-Wave (TW) technology can push the accelerator field gradient of niobium SRF cavity to 70MV/m or higher beyond the fundamental limit of 50~60MV/m in Standing-Wave regime. The success of TW resonance excitation in a proof-of-principle 3-cell SRF cavity in 2K liquid helium encouraged to advance TW technologies necessary more for future accelerator-scale one. Fermilab has proposed a preliminary RF design of a half-meter scale TW cavity by considering the physical dimensions of existing SRF facilities and the lessons learned from the 3-cell. It consists of a 7-cell structure and a power feedback waveguide (WG) loop with new TW excitation and control schemes such as, double directional coupler and two WG tuners. Mock-up waveguide loop development was launched under Fermilab LDRD program to demonstrate those new RF schemes at a room temperature. Fabrication drawings of a mock-up loop were completed. Here details and plans of the development are reported.

INTRODUCTION

The 1st demonstration of TW resonance excitation at a cryogenic temperature was successfully achieved with a niobium 1.3GHz 3-cell proof-of-principle SRF cavity in a collaboration between Fermilab and Euclid Techlabs [1]. In parallel with that 3-cell developments, Fermilab begun the RF design process of 0.5~1 meter scale TW cavity for advancing TW technologies necessary more for future accelerator scale one. Considering the physical dimensions of available SRF facilities (for fabrication, processing, and cryogenic testing with low/high-power RF) and high-power RF and beam applications, a preliminary RF design of a half-meter scale TW SRF cavity was proposed (Fig.1) [2]. It consists of a 7-cell structure, the inner cell shape is identical to that of the 3-cell TW cavity, and a power feedback waveguide (WG) loop with novel techniques to establish and control TW resonance in a structure such as a double directional coupler and a two-tuner system. Multiple critical developments are needed to realize a half-meter scale (7-cell) TW cavity. One of them is a demonstration of those new RF techniques on a WG loop. To focus and proceed that, a seed project of a low-cost mock-up WG loop development was awarded and launched under the LDRD program at Fermilab. In a mock-up loop, 7-cell structure will be replaced with an equivalent simple straight waveguide structure (Fig.2). Fabrication of a mock-up loop using alternatives to niobium materials such as copper or aluminum can effectively model the most important RF properties of these novel techniques and motivate later investment in a full-scale niobium version once the operative principles have been demonstrated.

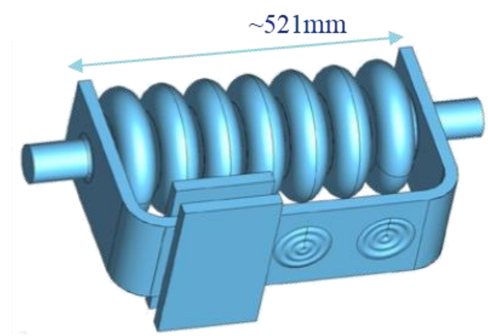

Figure 1: A preliminary RF design of a half-meter scale (7-cell) TW cavity [2].

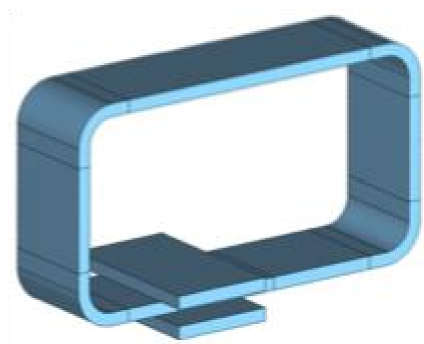

Figure 2: A preliminary RF design of a mock-up WG loop.

NEW TECHNIQUES ON A WG LOOP OF A 7-CELL TW CAVITY

Double Directional Coupler

Figure 3 shows the models of the 3-cell TW cavity and RF ports on WG highlighted with the circles. Two unity couplers on the 3-cell WG for RF feeds (red circle in Fig.3) are replaced with a powerful directional coupler for a TW 7-cell shown in Fig. 4 as an input directional coupler. Advantages are 1) only one high power RF coupler is needed to feed a cavity, 2) TW resonance excitation and control are simplified compared to the 3-cell procedures which require to adjust phases and amplitudes of two RF input sources [4]. Three RF monitoring couplers on the 3-cell WG (purple circle in Fig.3) are also replaced with a directional coupler shown in Fig.4 as a monitoring directional coupler. It reduces the efforts on calibrations and monitoring signal processing to evaluate a TW mode in a structure. Figure 4 shows a proposed RF design of a

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double directional coupler structure with x-shape coupling holes.

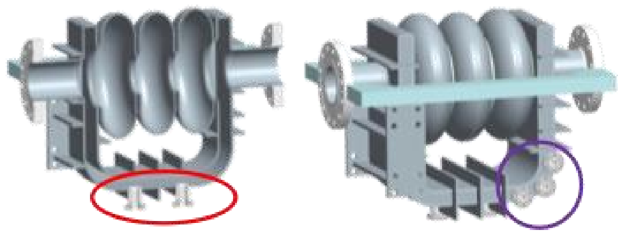

Figure 3: Two unity couplers and three monitoring couplers on the TW 3-cell's WG loop.

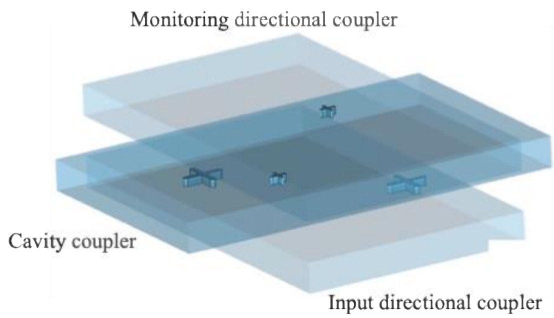

Figure 4: RF design of a double directional coupler for a TW 7-cell.

Two Waveguide Tuner System

A special waveguide tuner device, called *matcher*, was designed and fabricated for the 3-cell. This proof-of-principle matcher of the 3-cell can adjust an RF volume of the WG loop by pushing its wall to eliminate a mode splitting and deliver a pure traveling wave [5] (Fig.5). This matcher also has a position adjustability along with a waveguide. To fit and optimize a matcher system into an accelerator-scale TW cavity, two-tuner system is proposed for a TW 7-cell. Two tuners will be attached on a WG loop at optimized locations and deform its wall by pulling and pushing to tune a TW mode in a structure. To simulate that system, two wave-formed circle walls shown on a 7-cell's WG loop in Fig. 5 are used. A development of compact tuner for an accelerator scale TW cavity will also be one of the critical items to realize a 7-cell TW cavity.

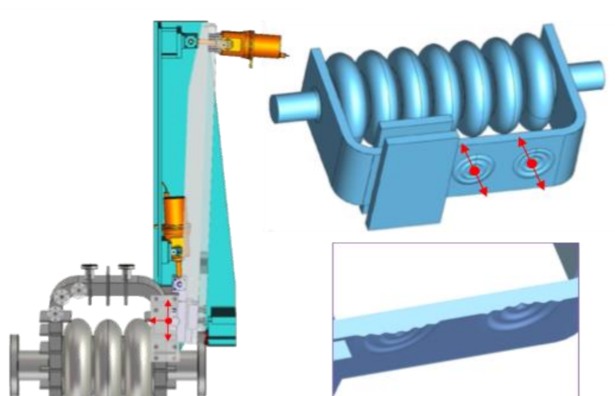

Figure 5: the 3-cell with a matcher (left) and a RF model used to simulate a two-tuner system for a 7-cell (right).

A MOCK-UP WG LOOP DEVELOPMENT

RF simulation

Fig. 6 shows an example of RF simulation for TW signals excited in a mock-up loop RF volume. The direction of TW signal will be determined by which port of input directional coupler is used. The other ports of input directional coupler will be connected to a matched load.

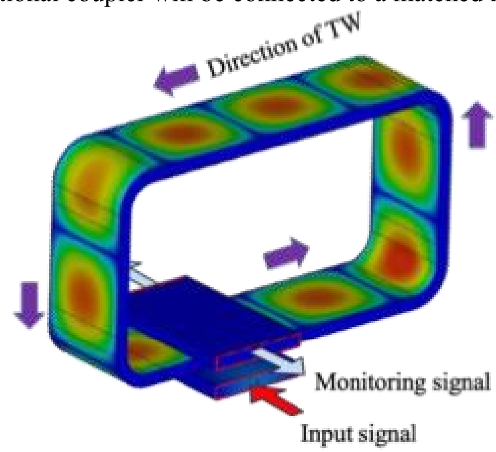

Figure 6: An example of RF simulation results of excited TW signal.

Fabrication models

Fig. 7 shows a 3D fabrication model of a mock-up loop and its cross sections. The loop is divided into sub-assemblies for a fabrication as summarized in table 1 and will be made of aluminum. dividing the loop into sub-assemblies allow us to modify and upgrade the loop easily by replacing sub-assembly per the development progresses. As an example, stub style tuner sub-assembly is employed to imitate and evaluate a two-tuner system for the very first version of a mock-up loop, but in a future, that portion can be replaced with more realistic design of waveguide compact two tuners to evaluate. So, the loop can provide a broad capability as a study bench of RF signals and WG loop to advance and evaluate future RF schemes. A double attenuator and a double launcher are also designed to feed an RF signal into and monitor RF signals from a double directional coupler. Double launcher has two N-type RF feedthrough with antenna to transfer an RF power between coaxial RF cable and waveguide structure. A double attenuator will be used to optimize RF signals into/from the loop. Those sub-assemblies and single attenuator sub-assemblies (straight WG sections to imitate a 7-cell portion) also have a tunability with three stubs to optimize and match a loop to deliver a pure traveling wave. The procedures of calibration, tuning, and measurement for each sub-assemblies before putting things together as a mock-up loop were also established and hardware necessary for those also designed [6], e.g. single short and single quarter waveguide will be fabricated to tune each launcher component. Vector network analyser and low power amplifier will be used to evaluate sub-assemblies and a mock-up WG loop and demonstrate new RF schemes on the loop at a room temperature. Fabrication drawings were completed, one sub-assembly and tuning hardware are under procurement process as of now, which will be used to evaluate the drawings and fabrication procedures, feedback will be made to the other drawings, if any.

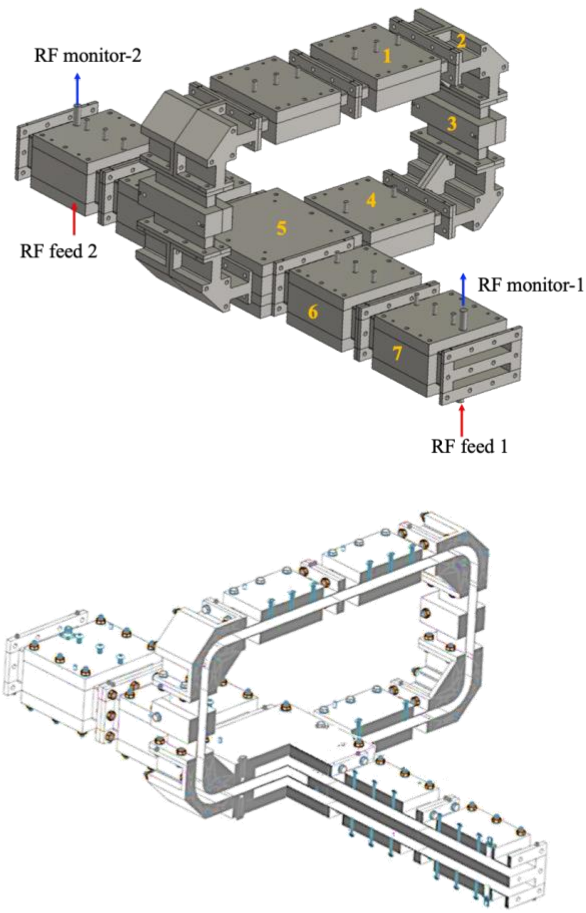

Figure 7: Solid model of mock-up waveguide loop assembly (top) and cross sections (bottom).

Table 1: A list of sub-assemblies

#	Sub-assembly name	QTY
1	Single attenuator	2
2	90-bend	4
3	Spacer waveguide	2
4	Stub style tuner	1
5	Double directional coupler	1
6	Double attenuator	2
7	Double launcher	2

SUMMARY

Development of a mock-up waveguide loop toward a half-meter scale (7-cell) TW SRF cavity was launched under the LDRD program at Fermilab. the purpose is to advance and demonstrate novel TW technologies necessary for future accelerator-scale TW cavity such as a double directional coupler and a two-tuner system. Models, fabrication drawings and calibration/tuning/measurements procedures of a mock up loop were completed. One preliminary procurement is under way to evaluate the drawings and fabrication procedures.

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