DESIGN OF A 3-CELL TRAVELLING WAVE CAVITY FOR HIGH GRADIENT TEST*

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Abstract

Utilization of a superconducting traveling wave accelerating (STWA) structure with small phase advance per cell for future high energy linear colliders may provide an accelerating gradient 1.2-1.4 times larger [1] than a standing wave structure. However, STWA structure requires a feedback waveguide [1]. Recent tests of a 1.3 GHz model of a single-cell cavity with waveguide feedback demonstrated an accelerating gradient comparable to the gradient in a single-cell ILC-type cavity from the same manufacturer [2]. In the present paper, a design for a STWA resonator with a 3-cell accelerating cavity for high gradient tests is considered. Methods to create and support the traveling wave in this structure are discussed. The results of detailed studies of the mechanical and tuning properties of the superconducting resonator with 3-cell traveling wave accelerating structure are also presented.

INTRODUCTION

The main goal of this project is the development and experimental demonstration of a STWA structure. These structures have huge advantages compared to the standing wave (SW) structures such as the 9-cell TESLA cavity [3] and the Re-Entrant [4], which can increase an accelerating gradient by a factor of 1.2-1.4. First of all, TW allows the employment of a smaller phase advance per cell compared to SW. We improved the effective accelerating gradients by a factor of 1.2, for a phase advance equal to 105° for TW in our calculations, because of the increasing transit time factor in the cavity. In the second place, improvement of the accelerating gradient comes from the field flatness. Present SW accelerating cavities have an average 1 m length, because it would be more difficult to obtain the required field flatness for longer cavities. STWA does not have such sensitivity to cavity inhomogeneity. Our calculations [5] show that STWA could be up to 16 m long and it would have better field flatness than the 9 cell TESLA cavity. This means that STWA is limited only by cryomodule length, and this fact could increase the effective accelerating gradient by an additional 20%, excluding the gaps between the short 9 cell cavities.

The first approach to STWA cavities was, as usual, a single cell cavity, which was recently manufactured at Advanced Energy System, Inc (AES) and processed at Argonne and Fermi National Labs (IL, USA). This cavity provided understanding of the manufacturing problems and surface processing issues. There were problems with the waveguide (WG) processing such as high pressure rinsing. These problems did not lead to quenching in the WG because the surface electric and magnetic field amplitudes in the WG were 2 and 3 times less than in the cavity respectively. 16 temperature sensors were attached around the equator of the cavity and 8 sensors were attached to the high magnetic field regions on the WG. High gradient test results showed the maximum temperature rise of those sensors on equator was no more than 0.1 °K and no significant temperature rise was recorded on the WG in accelerating mode. This suggested the quench was not near equator in the cavity cell, nor in the WG. Another high magnetic field region is the iris between the WG and the cell. Unfortunately, the area is not accessible by thermometers.

In spite of the reduced processing (without electropolishing), we were able to obtain rather good results for this cavity, taking into account that it was tested only in the standing wave regime [6]. This cavity is depicted in Figure 1.

Figure 1: The single-cell travelling wave cavity assembled for evacuation.

The surface electric field reached the same levels as in the TESLA-shaped cavity with a 31 MV/m accelerating gradient.

These results open the way to take the next step of STWA cavity development: to build and test a travelling wave three-cell cavity with a feedback WG.

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3-CELL TRAVELLING WAVE DESIGN

A STWA 3-cell cavity was designed containing only one regular cell in the middle of the cavity. In spite of the fact that the 3-cell has only one regular 105° cell, there is the same field distribution in this regular cell as in a 1 meter 15-cell pattern.

The superconducting TW structure involves utilizing the RF power passing through the cavity, redirecting it back to the input of the accelerating structure. This scheme of RF wave circulation in the traveling wave cavity requires a feedback loop. The energy from the RF source goes into the ring TW resonator (or feedback loop) through the directional coupler to set, by the phase and amplitude relations, the correct direction of the RF propagation in the accelerating structure. The TW in the ring is exited by two couplers spaced by a quarter waveguide wavelength. One can see the 3-cell STWA cavity assembly in Figure 2.

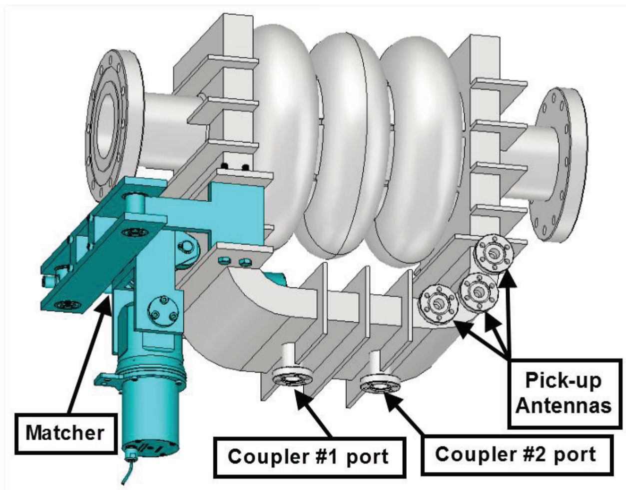
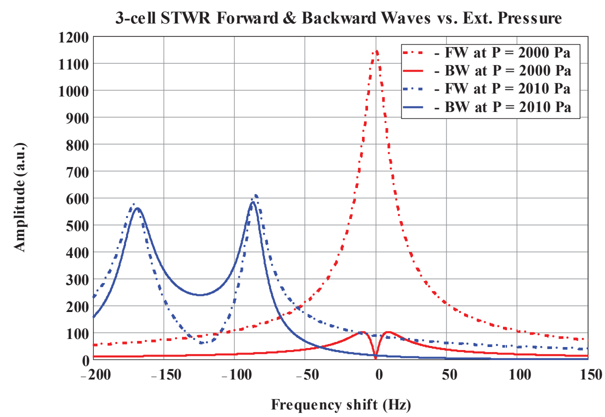


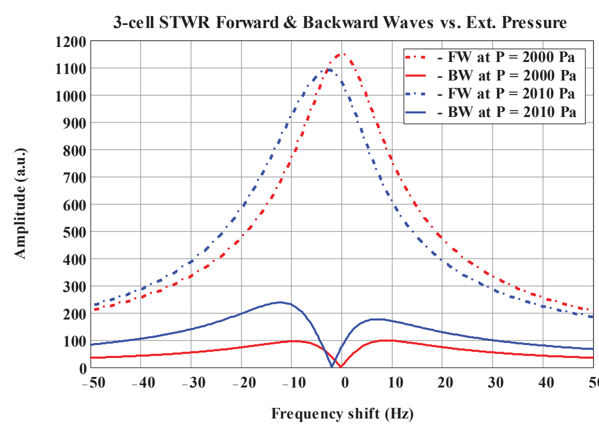
Figure 2: The 3-cell STWA cavity assembly.

This assembly consists of a 3-cell TW cavity with a WG, 2 feeding couplers (which will be mounted to the bottom flanges), 3 pick-up antennas (which will be mounted to the side flanges) and a fine tuning element "matcher" (the blue part in the Figure 2). The couplers are not shown in this Figure in order to leave a clear view.

The finished cavity will be tested at the Fermilab Vertical Test Stand (VTS), where the amplitude variation and the mean value of liquid helium pressure are about 10 Pa and 2 kPa, respectively. The available power is 300 W for cavity feeding at the VTS. This means that Q_{Load} will be around 10^8. This fact makes the cavity bandwidth very narrow and sensitive to microphonics. It is important to emphasize the fact that the narrow cavity bandwidth will be only at the VTS. For usual cavity application, STWA cavity typical Q_{Load} value is around 10^6, which relaxes all tolerances, described below. The non-reinforced cavity was extremely sensitive to microphonics and Lorentz Force Detuning (LFD). The pressure variation could completely break down the TW regime. One can see our simulations of the TW regime vs. a 10 Pa pressure variation in Figure 3. The first graph (Figure 3-a) represents a strong microphonics detuning for the non-reinforced cavity – there is no TW regime and the average resonant frequency shift is about -128 Hz. The second graph (Figure 3-b) represents the detuning of the most reinforced model with stiffening ribs on the waveguide and cavity parts. Apparently, this is rather acceptable design for the VTS application. The cavity was adjusted after applying the pressure variation by changing the phase difference between the input RF signals from 90° to 96.3° and the input amplitude ratio from 1/1 to 1.23/0.69. As a result (see the blue curves in Fig. 3-b), the backward wave amplitude was completely suppressed, but the forward wave amplitude was kept almost the same (~94%). A 12% power overhead is required to obtain the initial value of the forward wave amplitude.



a)



b)

Figure 3: Microphonics detuning at a 10 Pa external pressure variation: a) in the non-reinforced TW resonator; b) in the TW resonator with stiffening ribs on the waveguide and cavity parts.

STWA cavity shown in Figure 2 is reinforced by stiffening ribs on the WG and stiffening rings between the cavity cells to withstand microphonics and LFD. There are four stiffening rings between the cells and in the space between the cells and the WG. Their position was

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optimized according to the minimum of S_{11} amplitude and phase changes.

This cavity is fed by two couplers spaced by a quarter waveguide wavelength which will be mounted to the bottom conflat flanges. This feeding scheme allows us to change the amplitude and phase of the input power in each port to obtain and adjust the travelling wave regime. We will have 300 W of CW RF power which will be split between two feeding couplers. As was mentioned above, it might be necessary to redirect power up to 70/30 from one coupler to another for adjusting the TW regime. That means that the coupler should withstand up to 200 W of CW power. We are going to test a standard N-type feedthrough from Kyocera for this power level at 2 °K.

There are three pick-up antennas on the WG bend narrow wall that will be used to obtain information about the wave regime in the cavity. They have 1/8 of the WG wavelength (λ_{WG}) between each other. It is enough to have only two couplers for directivity measurements, but the third one will be needed to calibrate the others. Pick-up antennas will have a loop type end which is easy to calibrate by changing the coupling.

The last part of the assembly is the so called "matcher." It has a one lever construction with a mechanical advantage close to 2, two stepper motors, and a movable pushing element. The first stepper motor is for pulling the lever, which in its turn will push the pushing element. The second stepper motor is for moving the pushing element, which can be moved along the WG in a specially designed cage. This cage is mounted to the lever. The first stepper motor is reinforced and can withstand up to 1.3 kN of pulling force. These stepper motors can provide up to a 10 nm displacement because of their gear ratios of up to 10^5 and the 1 mm shaft thread. We simulated cavity adjustments and obtained the matcher requirements. One can see them in Table 1.

Table 1: The Matcher Requirements

Cavity reflection, dB	-60	-30
WG deformation range, mkm	2	90
WG deformation step, nm	20	20
Longitudinal position range, mm	±2	±4
Longitudinal position step, mkm	20	0.5

The main goal of this device is to push the WG wall with great accuracy in a defined point to adjust the TW regime. It is like a tuner for a SW cavity which adjusts a cavity's resonant frequency. In our case, we do not care much about the resonant frequency of the cavity. It is more important to match the S parameters of all the ring components [7]. All parts of the TW resonator were optimized for minimum reflection at operation frequency. We succeeded in obtaining about -60 dB of each part, but with realistic manufacturer errors, the maximum expected reflection will not be worse than -30 dB.

For obtaining the TW regime in the ring, the reflections of each part in it should be compensated. According to calculations, they can be compensated in several particular places. These places are indicated in Figure 4. They are separated by $\lambda_{WG}/4$. The places separated by $\lambda_{WG}/4$ need opposite sign reflection. In one of these places we mounted the matcher. But the matcher is a precise but not very strong device, so we plan to perform a pretuning at RT in another adjusting place. Pretuning is a plastic deformation of the WG at RT while matching is an elastic deformation at a cryogenic temperature to obtain the required amplitude and phase reflection at the certain position.

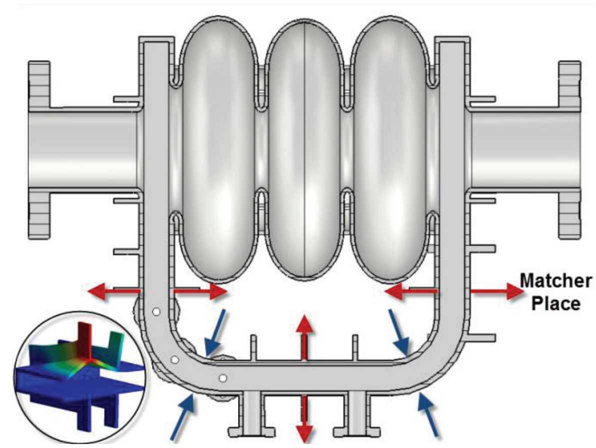

Figure 4: The 3-cell travelling wave cavity with indicated places for matching.

For pretuning, we plan to have a pulling/pushing device which will deform the WG. Plastic deformations of the WG and the reflection from it were calculated. One can see the corresponding plot in Figure 5.

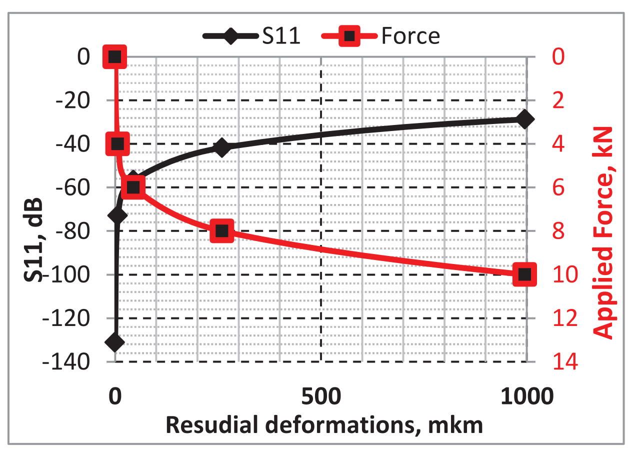

Figure 5: Residual deformations and reflection amplitude of the waveguide.

1 mm of residual deformation is enough to cause a -30 dB reflection which is enough for the worst case scenario. The required force for these deformations is 10 kN. We

used the experimental stress & strain curve of niobium RRR 300 at RT [8] which is depicted in Figure 6.

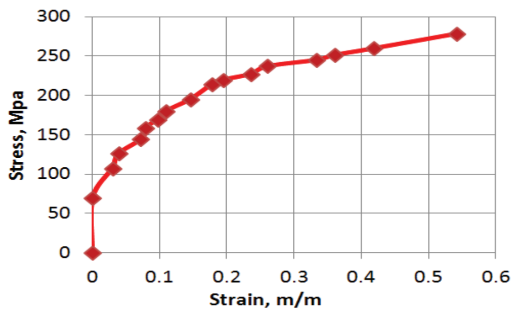

Figure 6: The experimental stress & strain curve of Niobium RRR 300 at room temperature.

The cavity will be loaded into the VTS with liquid helium after adjusting it at RT. We will have an opportunity to control the matcher because it includes two Phytron [9] stepper motors which will be employed in liquid helium.

CONCLUSION

The successful test of the single-cell model of STWA structure opens the way to take the next step in travelling wave SC cavity development: to build and test the travelling wave three cell cavity with the feedback waveguide. Methods to create and support the traveling wave in this structure were discussed. The results of detailed studies of the mechanical and tuning properties of the superconducting resonator with 3-cell traveling wave accelerating structure were also presented.

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