Traveling wave SRF cavity status and R&D plan

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Session
Accelerator: Superconducting RF
On behalf of SRF TW collaboration:

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Outline

• Introduction
• Advantages of TW
• Challenges for TW structure
• One-cell cavity with feedback waveguide
• 3-cell TW cavity status
• R&D plans
• Summary
Introduction

Present Limits of SRF:

- The Standing Wave (SW) TESLA Niobium-based structure is limited to a gradient of about 50 MV/m by the critical RF magnetic field (200 – 210 mT).

- Advanced shape cavities will be limited by the critical RF magnetic field to about 60 MV/m
  - Re-entrant, Low-Loss, Ichiro, Low Surface Field
  - For advanced shape, we lower $H_{pk}/E_{acc}$ (by 10-20%)
    - but we raise $E_{pk}/E_{acc}$ (15-20%)

- How to break through the gradient barrier with Niobium?

- Explore the option of Niobium Traveling Wave (TW) structures
Advantages of TW Structures

- Travelling wave improves transit time factor and therefore allows lower BOTH $B_{pk}/E_{acc}$ and $E_{pk}/E_{acc}$
  - RF power returns not through the accelerating structure (to form a standing wave with harmful peaks), but through a separate feedback Nb waveguide

- Travelling wave cavities operate at maximal group velocity in contrast to SW operating at zero group velocity, and therefore allow
  - Longer cavities → smaller gaps between cavities → higher average gradient;
  - Smaller aperture → additional increase in gradient because smaller $B_{pk}/E_{acc}$ and $E_{pk}/E_{acc}$
  - Field profile tuning easier,

- Travelling wave $\pi/2$ structures offer higher $G^*R/Q$ → lowers Cryo power.

- By choosing the Low-Loss cell shape + reduced aperture it is possible to lower $B_{pk}/E_{acc}$ by 48% over the TESLA structure!

- Opening the door to $E_{acc} > 70$ MV/m !!
Advantages of TW Structures (cont)

- Smaller aperture (see above) is allowed because bunch charge for 3 TeV ILC upgrade will about 3 X less to get acceptable IP background...

- Putting SRF on the Road to ILC – 3 TeV with Niobium

- No need to struggle with exotic new superconductors or overlayers
Challenges for TW Structures

- Requires twice the number of cells per meter to provide the proper phase advance (about 105 degrees).

- Cavity fabrication and surface processing procedures and fixtures must deal with (roughly) double the number of cells per structure.

- A feedback waveguide for redirecting high power from the end of the structure back to the front end of accelerating structure.
  - The feedback requires careful tuning to compensate reflections along the TW ring to obtain a pure traveling wave (a special “matcher“ in addition to a main tuner to reach partial standing wave degeneracy).
Path for TW cavity for ILC

General studies:

- New approach of multi-parametric optimization developed, which takes into account both maximally possible fields, $E$ and $H$.

- Optimization shows that TW structure can have the accelerating gradient above 70 MV/m with the same critical magnetic and electric fields that in the SW structure.

- No multipactor in the cavity and in a feedback waveguide.

- No cavity length limitation by a coupling between cells.

- Tuning and “matching” (achieving of travelling wave) procedures are developed.

- High-power coupler concept is developed.

- TW RF diagnostics is developed.
Path for TW cavity for ILC

Strategy of technology development for TW: step-by-step approach

HG tests of a single cell cavity with feedback WG*:
- Designed, manufactured (AES), processed;
- Reached 26 MV/m with inferior (easier) treatment of BCP

HG tests of a 3-cell TW cavity with feedback WG*:
- Designed, manufactured (AES), processed (BCP);
- Tuning is in a process
- HG tests are scheduled for summer 2023

HG tests of a 0.5 m-long TW cavity with feedback WG, HP couplers, tuners and diagnostics (in collaboration with Cornell):
- The cavity cell RF optimization is OK
- Cavity-WG transition RF design is OK
- TTF-III HP coupler are supposed to be used.
- He vessel design – not started yet
- Tuners design – not started yet

*Euclid Techlabs DOE SBIR DE-FG02-06ER84462 and DE-SC0006300.
Status of the 1.3 GHz, 3-cell TW cavity HG tests:

- The cavity – OK
- The “matcher” -OK
- Diagnostics – OK
- The input couplers - OK
- Processing fixtures – OK
- The cavity processing* - OK

*120um rotational BCP, 800c bake, external BCP to remove oxides
3-cell TW cavity tests. RF measurements

Setup 1

3 modes
### 3-cell TW cavity tests. RF measurements

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3-cell TW cavity tests. RF measurements

New setup

- New short cables
- Actuated phase shifters by EUCLID control box and stepper motors
- Yellow – clear signal from middle
- Blue and Magenta – FW and BW
- Mathcad model predicts similar behavior:
  - FW changes both directions following phase
  - BW only on and repeats SW signal.
3-cell TW cavity tests. RF measurements
Tuning SW to get symmetrical distribution of TW03AES1

- First attempt
  - Push cell 3 by 20kHz
  - Negative frequency shift expected but behaved opposite
  - Frequency increased and field in cell 3 increased

- Second attempt
  - Push cell 2
  - Same opposite behavior

- Problem with tuning split ring discovered (next slide)
3-cell TW cavity tests. RF measurements

Tuning fixture problem

• Split rings should contact the cavity close to the stiffening ring to deform the length
• In our case the point of contact is at the equator and cavity shape is deformed. The cavity is more rigid there.
• New split rings have been designed and fabricated.
• Tuning is continuing.
Further R&D plans

❑ **Nearest plan:**
  - Complete the 3-cell cavity tuning – field flatness and TW (May-June 2023)
  - Demonstration of a HG TW in the 3-cell cavity at VTS (summer, 2023)
  - Achieving maximal acceleration gradient in this cavity (fall and winter 2023)

❑ **Further development:**
  - Design of the 0.5 m long TW SRF structure and its components including
    - The cavity;
    - Tuners (the main tuner and the “matcher”);
    - He vessel
    - Diagnostics probes
  - Manufacturing, processing and HG tests of the bare TW cavity (3 years).
  - Manufacture and tests of the dressed cavity with the main tuner and TTF-III couplers.
Summary

❑ TW Nb cavity with feedback waveguide potentially may allow acceleration gradient up to 70 MV/m

❑ R&D plan includes step-by-step experiments from a one-cell cavity with the feedback WG to a full-scale cavity.

❑ One-cell SRF cavity with the feedback WG is successfully designed, manufactured and tested, that showed the possibility of the feedback WG processing.

❑ Basing on this experiment the next step is planned: a 3-cell TW SRF cavity, which should demonstrate a HG TW wave in a SRF cavity.

❑ The 3-cell cavity and its components are designed and manufactured.

❑ The cavity is processed and under the tuning.

❑ The HG tests are scheduled for summer 2023.

❑ The next step – 0.5 m long TW SRF structure is under design.
TW SRF cavity has a long story

and, we are sure, a bright future!

MANY THANKS!