Quarter Wave Resonators Pushing the Limits

Jeremiah Holzbauer – NSCL

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Outline

- Historical Accelerator Technology
- Quarter Wave Resonators (QWR)
- Present Limitations
- Advantages of High Frequencies
- Disadvantages of High Frequencies
- State of the Art/Problems to be Solved

In the Beginning….

- RF accelerators were first conceived of in 1927 (R. Wideroe). The purpose was to allow for much higher beam energies than was possible for DC accelerators.

ANTARES Tandem Accelerator – 10MV

Evolution of a Field

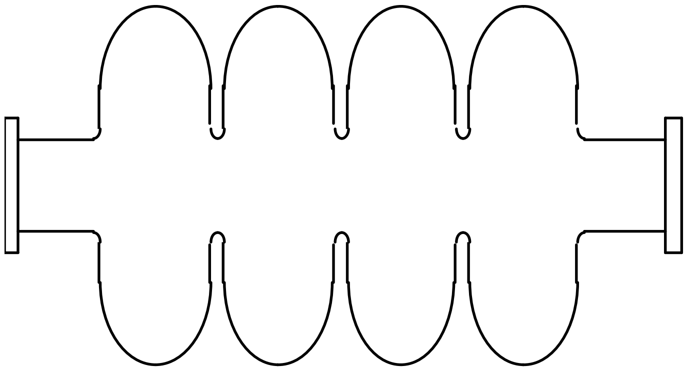
- Since this time, the technology has been advanced greatly, along two general paths: High beta (v/c) and Low/Medium beta.
- High Beta
  - Due to their light mass, electrons (positrons) can be accelerated to (almost) the speed of light very quickly.
  - This means that most (all) of the accelerating structures they need are designed for beta = 1.

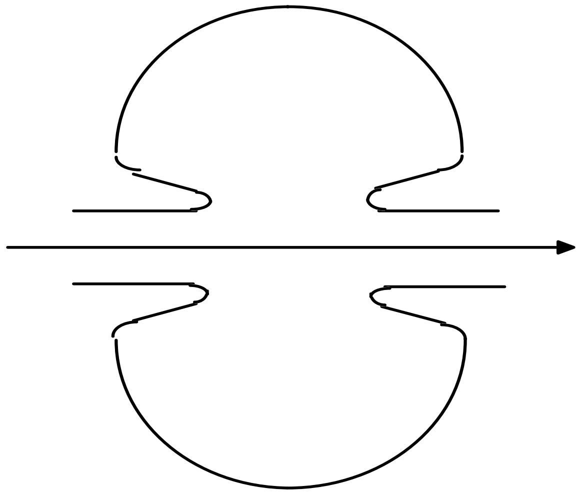
The Other End of the Spectrum

- Low/Medium Beta
  - For heavy ions, the relatively large mass means that until recently, the energies achievable were still low beta. (Beta<.5)
  - Energy gain depends on q/A.
- “State of the Art”
  - Most of the accelerating structures for these were either Cyclotron, DTL, or QWR structures for linear accelerators.
  - Cyclotrons become far more complicated for heavily relativistic particles.

High Beta Cavities

- Elliptical Cavities and Reentrant Cavities are a mainstay of high beta accelerators.
- For lower velocity acceleration, their size becomes prohibitive, requiring different cavity designs.

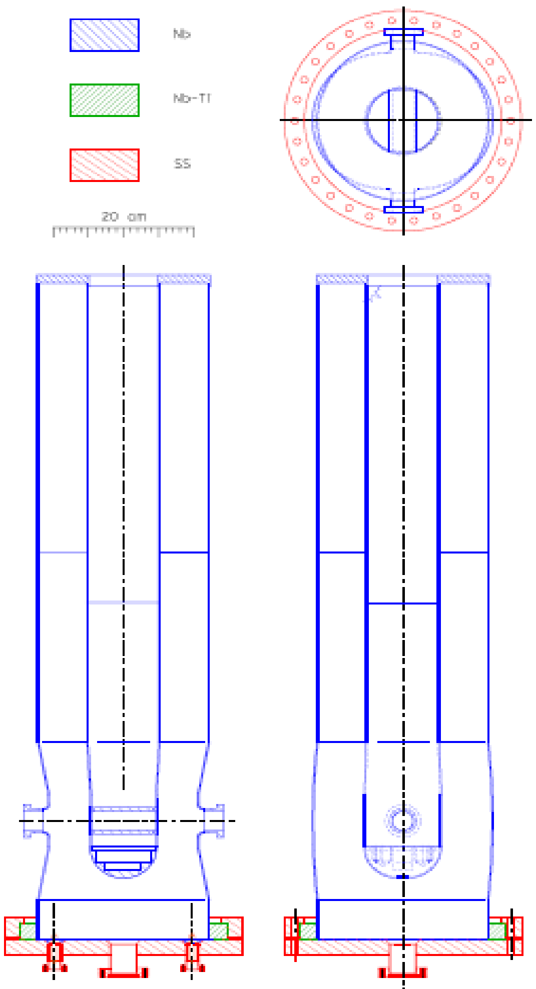


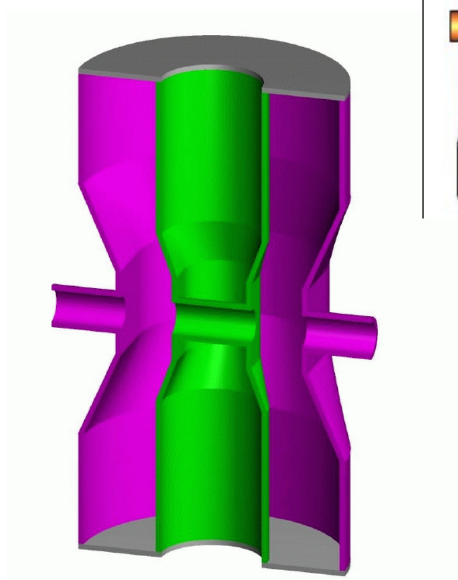


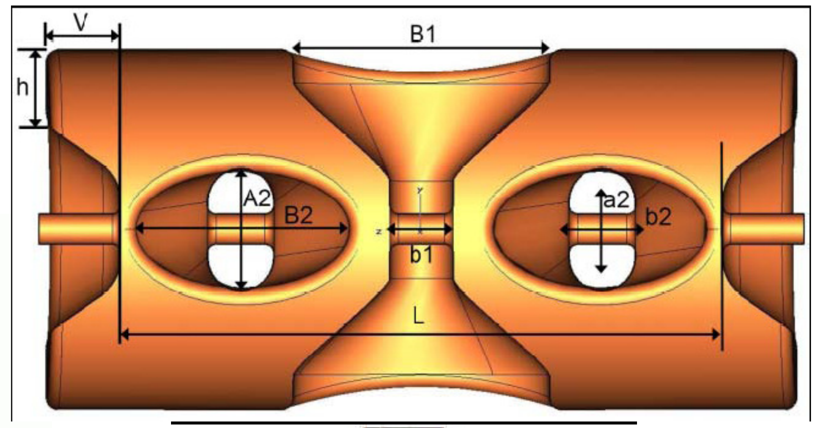
Synchro-Cyclotrons

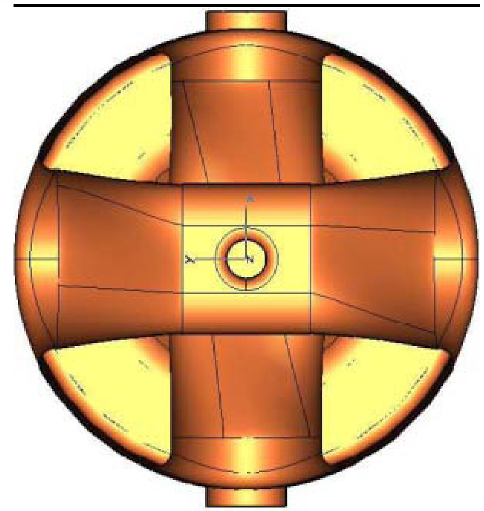
- Correcting for relativistic effects has extended the reach of cyclotrons to around 200 MeV.
- Because of Synchrotron losses, Cyclotron technology has reached its limit, even for heavy ion accelerators.

Low/Medium Beta Cavities









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In the middle

- For particles light enough to be accelerated to Beta ~ 1, all the design work has been focused on pushing the gradients of the elliptical cavities and improving efficiency.
- In recent years, the trend for heavy ions has been to push the energies, leading the field into energy ranges that have been, until now, unexplored.

Demands of High Beta

- If you want to accelerate heavy ions to higher energies, different demands are placed on the accelerating structures than they were previously designed for.
- Because the gap length depends directly on beta, higher energies demand a larger and larger cavity.
- Eventually, this leads to unmanageable cavity size, and another solution is required: going to a higher frequency.

Pushing the Frequency

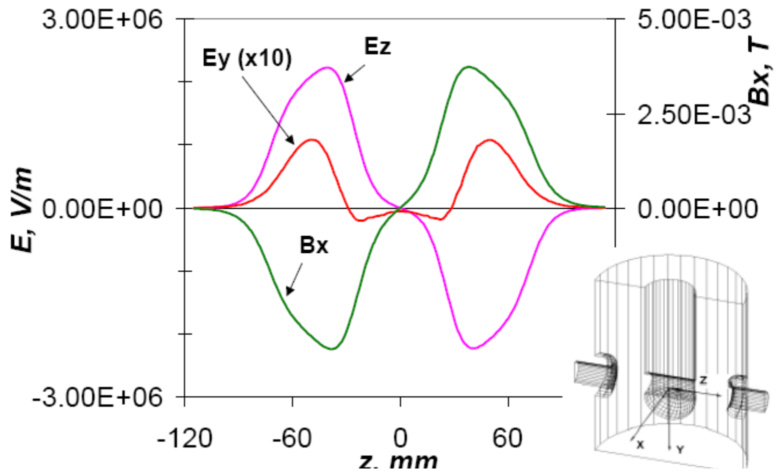
- Implications (Positive)
  - Smaller size
    - Less Niobium, lower cost.
    - More compact, less cryomodule space.
  - More rigid structure
    - Reducing the length of the inner conductor increases the fundamental mode frequency significantly.
  - Still has demountable flange

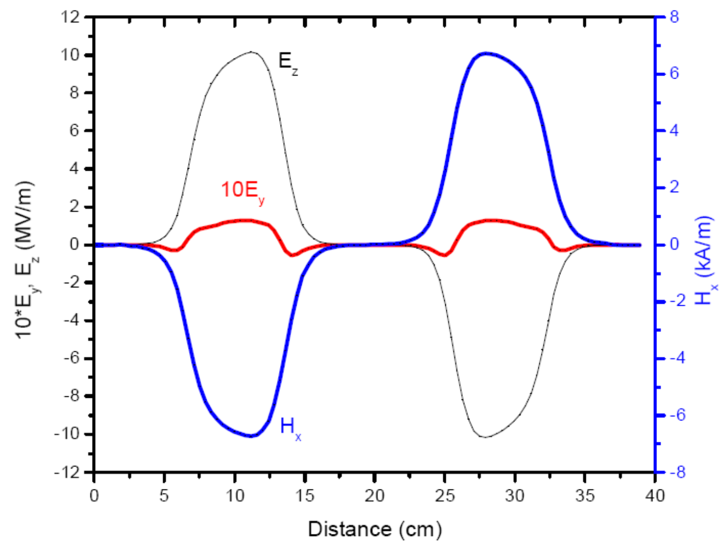
Pushing the Frequency

- Implications (Negative)
  - Increased surface losses ($R_s \alpha f^2$)
  - Smaller Velocity / Beam Acceptance
  - Non-insignificant tangential electric and magnetic field components
- While Half Wave and Spoke geometries share the first two problems, the tangential fields are a unique problem of QWR.

Undesired Fields

- Modeling of typical QWR at high frequencies (352 MHz/115 MHz).
- From this, we can see that the dominant steering will be from the magnetic field.
- Remember, the magnetic field here is shown 90 degrees later in phase for clarity.





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Correction Methods

- Offset cavities a few mm
  - Largely compensates for q/A<1/3, beta <.15
  - Doesn't require major design changes of the cavities
- Modify shape of beam ports and cavity walls
  - Essentially completely corrects field shape
  - Adds to losses, changes to cavity performance not fully examined

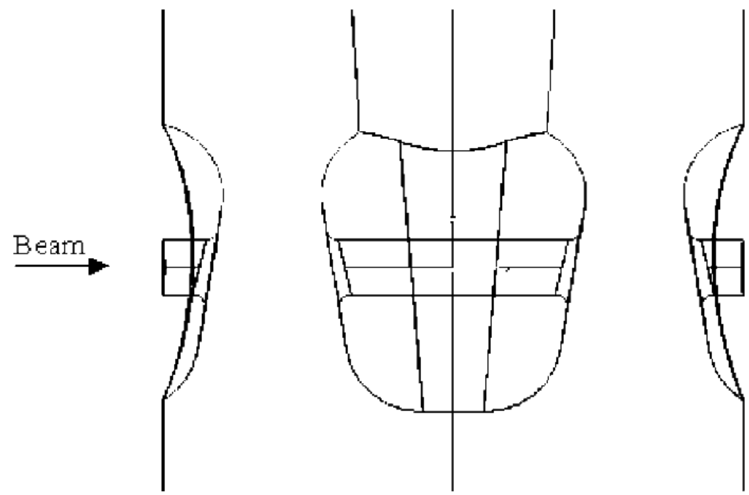
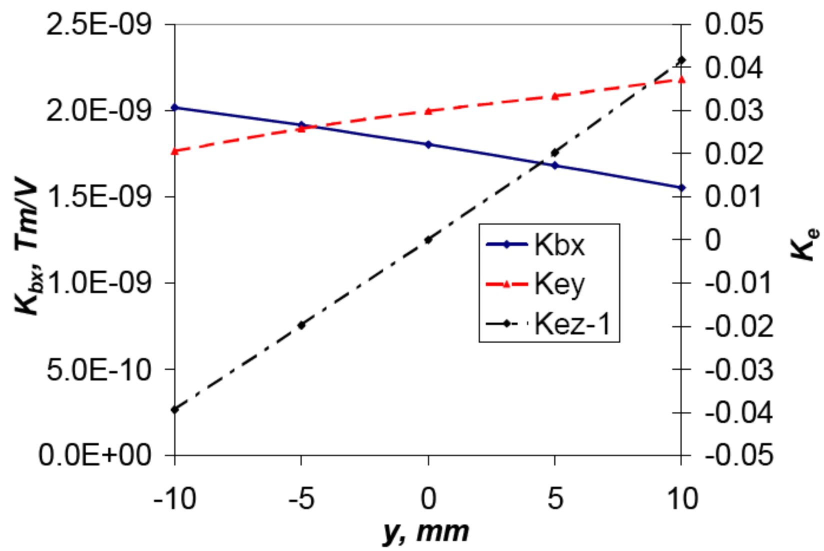


FIG. 8. 115 MHz QWR with modified shapes of drift tubes.

Alternating Quarter Wave Acceleration (AQWA)

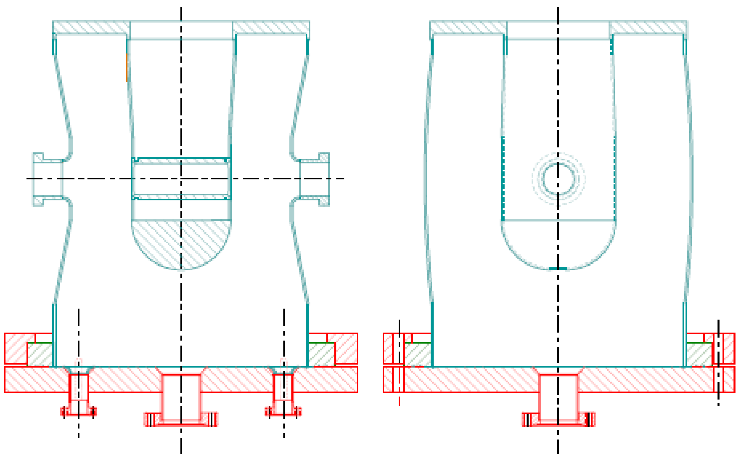
- Modeling of Dipole
  - Using elementary methods, the deflection can be modeled.
  - The deflection is clearly dominated by the magnetic field, and is linear.
  - This means that a second cavity, positioned in the opposite alignment would almost perfectly cancel the kick.

$$\Delta y' = -\frac{\Delta U}{\gamma m c^2 \beta} tg\varphi \left(\frac{\cos\left(\frac{\pi d_y}{\beta\lambda}\right)}{\beta \sin\left(\frac{\pi d}{\beta\lambda}\right)} K_{EY}(y) + c K_{BX}(y) \right)$$



AQWA

AQWA



Conceptual Drawing of 322 MHz $\beta \sim 0.4$ QWR

Conceptual Drawing of alternating 322 MHz QWRs

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Technical Challenges

- Size
  - Alternating cavities would take up more room in the cryomodule.
  - However, increased frequency reduces the length of the cavities, making this less of an issue.
- Cooling
  - The inner conductor of the flipped cavities would trap helium gas.
  - Mount the cavities sideways? Teflon tube?

References

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