Review of MA Cavity

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• Summary
Magnetic Alloy (MA)

- Thin Tape, 18 µm
  - Large core(<4m)
  - Rectangular Shape is possible to make, Thickness -35mm (50mm in future)
- High Field Gradient
  - Voltage limit: Brf < Bsat. (1T), Voltage per layer < 5 V
- High Curie Temperature
- Stable characteristics: Good for Beam Loading Compensation
- Large permeability (about 2000 at 5MHz)
- Original Q value is small(0.6).
- High Q is possible by cut core configuration
High Gradient

Magnetic Alloys

Ferrites
JKJ RF Cavities

Field Gradient of Cavities for Proton Synchrotrons

**Proton Synchrotron RF System**

- SATUNE
- MIMAS
- CERN PSB
- CERN PS
- AGS
- ISIS
- KEK BSTR
- KEK PS
- JKJ 50GeV MR
- JKJ 3GeV RCS
- 50GeV MR Upgrade
- KEK-HGC

![Graph showing field gradient versus frequency for various proton synchrotron RF systems.](image)
Why High Field Acceleration

3 GeV RCS
Fast cycling: 25 Hz
Needs high voltage: 450 kV
Number of Bunches: 2 by N-users
Low Frequency: 0.9-1.7 MHz
Circumference is limited.
Needs spaces for extraction of 3 GeV beam with large beam size, injection and collimation.

50 GeV MR
Needs high voltage: 280-600 kV
Needs space for 2\textsuperscript{nd} Harmonic system
Like 3 GeV RCS
Large Permeability and Low Q

• Advantage
  – Shunt Impedance is high.
  – Wide Band System
    • Acceleration w/o Tuning System (Cost & Stability)
    • Bunch Manipulation (Barrier, Dual H and SawTooth)
    • Easy to compensate beam loading (Feed Forward)

• Disadvantage
  – Number of harmonics to be compensate.
Cut Core and High Q

• Loss (Shunt Impedance) is not reduced.
• Inductance is reduced.
• Advantages
  – Reduce Harmonic to be compensated.
  – Minimize Bandwidth to cover the RF frequency.
  – Still easy to compensate Beam Loading
• Disadvantages
  – Need Another System for manipulation.
• JKJ-RCS System (Q=2-3)
  – Still Dual Harmonic by single system is possible
• JKJ-50 GeV MR : Q~10
Other MAs
History of MA Cavity

First Generation:
Wide Band and Air Cooling
Barrier Bucket Cavity installed in AGS (US-Japan Collaboration)
2.6m, 40kV, 6% duty, driven by 30kW tubes
PoP FFAG Cavity

Proton beam was successfully accelerated. And two medical Synchrotrons are using same type...
The Second Generation: 
Wide Band and Water Cooling 
HIMAC Cavity: 50cm, 20kV, water cooling driven by 150kW tubes
5kV, CW, driven by 30kW tubes.
The Second Generation: Wide Band and Water Cooling
COSY Cavity:

From A. Schnase
The Third Generation:
Narrow Band and Direct Water (or Coolant) Cooling
KEK-PS MA Cavity: 90cm, 30kV, Cut Core, Fluorinate Cooling
The Third Generation:
JKJ RF Cavity (Direct Cooling Type): 1.7m, 60kV, Cut Core
Water cooling, driven by 600kW tubes
The Fourth Generation
Narrow Band and Indirect Cooling
JKJ RF Cavity (Indirect Cooling Type): 1.7m, 60kV, Cut Core
Water cooling, driven by 600kW tubes
The Fourth Generation
Narrow Band and Indirect Cooling
FNAL MA Cavity (US-Japan Collaboration)

From Wildman, FNAL
The 0th Generation
Wide Band and Indirect Cooling (?)

From A. Schnase
Barrier Bucket Experiments

- Two Barrier Cavities for Experiment
  - Ferrite and MA cavities
- Each cavity generates single sine wave of 40 kV at rep. rate of 351 kHz.
- Five bunches from Booster were accumulated and $3 \times 10^{13}$ was stored w/o loss. Barrier bunch was generated.
- Longitudinal Emittance Growth by factor of 3 was observed. It was caused by Mismatch, mainly.
- Beam Loading on MA cavity was compensated.
- Beam Loading on Ferrite Cavity and overshooting Voltage of MA Cavity disturbed smooth debunching. After BB experiment at AGS, the overshooting problem was solved by adding H=1 and 2 voltage.
Barrier Bucket Experiment

- Use two cavities:
  - KEK MA-loaded cavity (2.6m, 2X30kW tubes) KEK made for this experiment
  - AGS ferrite cavity (2.6m, driven by 600kW tube).

\[
V(t) = \begin{cases} 
V_0 \sin \omega \tau, & \text{if } 0 < \omega \tau < 2\pi \\
0, & \text{otherwise} 
\end{cases}
\]

\[
I(t) = \frac{V(t)}{R} + \frac{1}{L} \int_0^t V(t') dt' + C \frac{dV(t)}{dt}
\]

\[
= \begin{cases} 
\frac{V_0}{\omega L} + \frac{V_0}{R_P} \sin \omega \tau + V_0 \cos \omega \tau \left( \frac{1}{\omega L} - \frac{1}{\omega C} \right), & \text{if } 0 < \omega \tau < 2\pi \\
0, & \text{otherwise}, 
\end{cases}
\]

\[
= \begin{cases} 
\frac{V_0}{R_P} (Q + \sin \omega \tau) + V_0 \cos \omega \tau \left( \frac{1}{\omega L} - \frac{1}{\omega C} \right), & \text{if } 0 < \omega \tau < 2\pi \\
0, & \text{otherwise}, 
\end{cases}
\]
Barrier Bucket Experiment

W/o FF

(a) Gap induced voltage by $8 \times 10^{12}$ proton per bunch

With FF

(b) FFT results
Barrier Bucket Experiment

MA cavity was used for Moving Barrier because of adiabatic turn-on/off
Barrier Bucket Experiment

Mountain range plot of WCM
Interval of trace is 5.8 ms
Barrier Bucket Experiment

Overshooting Problem

Beam Loading on Ferrite Cavity
Making of MA Cavity

Wideband Cavity: Capacitance Effect.

Cavity Impedance

Frequency (Hz)

Impedance (Ohm)

Re(Z) w/o AMP
Im(Z) w/o AMP
Re(Z) with AMP
Im(Z) with Amp
Making of MA Cavity

Narrow Band and Direct Water Cooling Cavity

Cavity Impedance: 3 X 80cmO.D X 3.5 cm core
For 12 MHz Cavity in KEK-PS, Fluorinate Coolant is used.
Making of MA Cavity

Narrow Band and Indirect Water Cooling Cavity with Insulators (5mm thickness and 2-4 W/mK)

Cavity Impedance: $3 \times 67\text{cmOD} \times 2.5 \text{ cm Core}$

High Impedance at Low and High Frequency.
Making of MA Cavity

• Cavity Impedance
  – No Cut, Direct Water Cooling: OK, tube capacitance
  – Cut, Direct Water Cooling: OK up to several MHz
  – Cut, Indirect Water Cooling: OK
  – Cut Direct Cooling with Coolant: OK

• Cooling Efficiency
  – Direct Water Cooling: Very Good > 12 kW/core
  – Indirect Water Cooling: Good > 5 kW/core
Making of MA Cavity

• **Power Loss**
  Distribution in Core

  – **Low Q**: Loss at Gap, Few % of cores have very localized loss.

  – **High Q**: Loss at Outer side because of inhomogeneity of core. Outer has better characteristics.
Unsolved Problems

• Impedance reduction mechanism in Direct Water Cooling Cavity. Measurements are difficult because cores are in Water.
• Distribution of Loss in case of High Q cut core.
Localized Heat Loss

“Onion Cut” cuts a core into two pieces.
Before cut: 80cm OD, 24.5cm ID
Inner: 60cm OD, 24.5cm ID
Outer: 80cm OD, 62cm ID

Preliminary measurements suggest difference of characteristics for inner and outer parts. This may be another cause of localized loss.
Summary

• We developed 4 different types of MA cavity
• For J-PARC (used be called JKJ or JHF), Direct (or Indirect) Water Cooling Cavity with Cut Cores
• Barrier Cavity: No Cut Core Cavity @ few MHz (or Small Gap Cut Core @ several MHz)
• For Bunch Rotation: Small Gap Cut Core or No Cut Core Cavity because of Saw Tooth RF
• For High Frequency (>several MHz) Cavity: Indirect Cooling Cut Core Cavity
• For Medical accelerator and Low Energy FFAG: No Cut Core Cavity
• Papers: http://hadron.kek.jp/member/chihiro/papers.html