Cavity Fabrication for ILC

What we know

and what we'd like to know

Fabrication – What we know

- ~1000 Nb cavities have been built.
- The experience has matured to the point that one may now adequately specify the fabrication process that transforms spec'd Nb material into finished, tuned cavities ready for processing.
- For solid Nb (fine grained and likely large also) only two issues remain:
  - **Quality Assurance – controlled consistency**
  - **Cost**

Fabrication – What we know

- The accelerating structures for ILC will need to be fabricated from well-controlled materials according to established and well-controlled methods.
- It is critical that the applied methods yield a consistent "defect-free" interior rf surface.
- The options available vary somewhat with the principal starting material. The materials appear to be some combination of bulk Nb, bulk Nb/Cu, or, perhaps longer term, even thin film Nb on Cu.
- Only with bulk Nb is there sufficient experience to define a confident solution today to ILC needs.
- Endgroup fabrication is more expensive than cells.

Fabrication – What we know

- Principal opportunities for cost savings:
  - Reduce material costs
    - Using cheaper Nb – higher Ta and/or direct from ingot
    - Reducing the amount of required Nb, substituting cheaper material where possible.
  - Reduce the number of components and steps.
  - Reduce the “hands-on” time for each cavity.
- Method with most effortless QA will eventually win out.

Fabrication – Options - I

- Bulk fine-grained niobium from sheet, bar, and plate stock
  1. Machining, deep draw forming, mechanical polishing, EBW, inelastic deformation tuning – with appropriate intermediate cleaning steps
  2. Substitute <u>**spinning**</u> for the deep draw forming and the EBW of cells.
  3. Substitute <u>**hydroforming**</u> for the deep draw forming and the EBW of cells.
  4. Treat the fabrication of the **endgroups** differently – use <u>**Nb film**</u> on copper for these low-field parts.

Fabrication – Options - II

- Bulk large or single-grain niobium direct from ingot
  - Similar to standard but using wire EDM to form sheets for cell blanks
  - Evidence to date suggests that the balance of fabrication is not significantly changed with respect to “standard” fine-grained Nb material.
  - Inherent “QA” of single crystals may be the “silver bullet” for consistent high performance
- Bulk **Nb/Cu clad** material for cells (and beamtubes?)
  - **Hydroforming**

Fabrication - BCD

- By the specified criteria, the fabrication Baseline choice must be the “standard.”
- Note:
  - “Touch” labor is relatively high, with piece part handling, cleaning, and inspection required for EBW steps.
  - The endgroups require as much fabrication attention as the cells. This seems less justified for the cost.
  - Mass production analysis for TESLA showed 77% of residual fabrication cost in “machining” operations.
  - Mass production fabrication costs should be less than half of the prototype fabrication cost, and mass production EBW costs are expected to be 20% of the prototype welding costs. (Per DESY industrialization study)

Fabrication - Alternates

- Motivations for alternate fabrication choices are almost exclusively related to <u>cost</u>.
  - No presently considered alternative methods claim to directly improve ultimate performance.
- Cost reductions may result from methods which either reduce the cost of required material or aid the automation of fabrication.
  - Thus the consideration of hydroforming, spinning, and film coating.
- **Hydroforming** and **spinning** offer the prospect of seamlessly forming the cavity cells, eliminating several machining, chemical cleaning, and EBW steps.

Fabrication – ACD 1- Hydroforming

Pros

- Technique quite suitable for factory production with automation and reduced total fabrication costs.
- Recent progress has demonstrated that the technique can produce equally-performing Nb cavities. (42 MV/m and Q -value ~ 10^{10} test cavity without EP) (KEK & DESY) 3-cell structures have been built.
- If applied to Nb/Cu clad tubing, the quantity of required high-purity Nb for cells could be reduced by 75%.
- Highly consistent interior cell geometry expected, thus less required tuning.

Cons

- With Nb/Cu, must manage the end transitions, e.g. Cu removal to avoid Nb weld contamination.
- Must assure tubing QA for consistent forming properties.
- Less experience translates into less awareness of subtle difficulties ahead.

Fabrication – ACD 1- Hydroforming

Technical advantages, increased tech potential

- Avoidance of machining and welding in the high field regions of the cavity eliminates some potential sources of defects which could degrade ultimate cavity performance.

Potential cost impacts

- Elimination of multiple machining steps and expensive EBW time – trade for hydroforming tooling
- Expected time required to form 9-cell structure from tube: **~6-8 hours**
- If applied to Nb/Cu clad tubing, would reduce quantity of required Nb.
- Estimated net potential fabrication cost reduction compared to BCD mass production: **??? (~30-40% less than current std method or industrialized method?)**

Fabrication – ACD 1- Hydroforming

R&D necessary

- **Fabrication of seamless bulk Nb tubes of the length sufficient for 9 cell cavity from one piece (ca. 1.8 m long)**
- **Development of "industrial" production routine and qualification of cavities.**
- **Avoid or suppress the trapping of magnetic flux caused by thermo - coupling effect in Nb/Cu cavities?**
- **New methods of bimetallic tube fabrication**
- **More appropriate material for Nb clad cavities instead of Cu (Cu alloys etc.)?**
- **End group cost reduction for Nb/Cu clad cavities**
- **Seamless cavity of new shapes (low losses, re-entrant etc.)?**

Fabrication – ACD 1- Hydroforming

- **How far away is routine hydroforming of 9-cell structures from Nb or Nb/Cu clad material - with yield and rf performance no different from (or better than) "standard" methods?**

Fabrication – ACD 2 - Spinning

Pros

- **Technique quite suitable for factory production with automation and reduced total fabrication costs.**
- **Recent progress has demonstrated that the technique can produce equally-performing Nb cavities. (40 MV/m test cavity) (INFN Legnaro)**
- **9-cell structures have been built.**

Cons

- **Must assure tubing QA for consistent forming properties.**
- **Less experience translates into less awareness of subtle difficulties.**

Fabrication – ACD 2 - Spinning

Technical advantages

- Avoiding machining and welding in the high field regions of the cavity eliminates some potential sources of defects which could degrade ultimate cavity performance.
- Limited experience makes evaluation difficult.

Potential cost impacts

- Elimination of multiple machining steps and expensive EBW time.
- Expected time required to form 9-cell structure from Nb sheet (or tube?): **4 hours** (INFN)
- Estimated potential fabrication cost reduction: ??? (**Industrial study said none?)**

Fabrication – ACD 2 - Spinning

- How far away is routine spinning of 9-cell structures from Nb or Nb/Cu clad material - with yield and rf performance no different from (or better than) "standard" methods?

Fabrication – ACD 3 – Nb films

Pros

- **Potential for reduced cost by eliminating bulk Nb from low-field endgroup.**
- **Improved thermal conduction in portions of accelerating structure outside of the helium vessel.**
- **If successfully made demountable, (as proposed by KEK) could maximize QA of high field region of cells by providing opportunities for restructuring inspection, cleaning, and assembly sequence.**
- **Successful SC flanging would create a new type of modularity that could be exploited.**

Cons

- **Complexity of endgroup shape makes confident coating difficult.**
- **Lack of experience base leaves potential problems unrecognized.**

Fabrication – ACD 3 – Nb films

Technical advantages, increased tech potential

- **None**

Potential cost impacts

- **Reduced cost of material for endgroups (~??%)**
- **Greatly reduced need for EBW if Cu endgroups can be formed as a brazed? assembly, followed by Nb film coating and endgroups are flanged to seamless cell structure.**
- **(Is the undeveloped Nb coating actually cheaper in production ?)**

Fabrication – ACD 3 – Nb films

R&D necessary

- **Develop Nb coating of HOM coupler and end group assembly. (complex shape)**
- **Develop low-profile reliable superconducting flange joint for use just outside of helium vessel.**
- **Develop less complex HOM damping scheme for easier fabrication and coating.**
- **Industrial cost study: Is the undeveloped Nb coating cheaper in production than endgroups of BCD?**

Time scales for R&D

- **?? -- today just an idea**