3. Fabrication

General Requirements_ Overview

The accelerating structures for ILC will need to be fabricated from well-controlled materials according to established and well-controlled methods. The scope of fabrication spans between receipt of starting materials and completion of tuned structures meeting specified mechanical configuration criteria. It is critical that the applied methods yield a consistent "defect-free" interior rf surface. The fabrication steps must not add defects to the 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.

Since structure design is treated separately, one may note that fabrication R&D bears only weakly on couplings to other design elements. Therefore, competitive pressure to develop lower cost methods of providing the chosen structure may proceed until construction start.

> A serious **industrialization** study has only been made for the current "standard" fabrication method (1.a.).
>
> Principal opportunities for cost savings:
> 1. Reduce material costs by reducing the amount of required Nb, substituting cheaper material where possible.
> 2. Reduce the number of components and steps.
> 3. Reduce the "hands-on" time for each cavity.
>
> Method with most effortless QA will eventually win out.

Options under consideration

1. Bulk fine-grained niobium from sheet, bar, and plate stock
    a. Machining, deep draw forming, mechanical polishing, EBW, inelastic deformation tuning – with appropriate intermediate cleaning steps
    b. Similar to 1.a., but substituting **spinning** for the deep draw forming and the EBW of cells.
    c. Similar to 1.a., but substituting **hydroforming** for the deep draw forming and the EBW of cells.
    d. Similar to 1.a. for the cavity cells, but treating the fabricating the **endgroups** differently – using **Nb film** on copper for these low-field parts.

2. Bulk large or single-grain niobium direct from ingot
    a. Similar to 1.a., 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.

3. Bulk **Nb/Cu clad** material for cells (and beamtubes?)
    a. Similar to 1.c. - **hydroforming**

BCD choice

1.a. Present “standard” fabrication methods, applied with serious attention to QA. (2.a. is not significantly different in fabrication methods after)

Pros & Cons of BCD (technical, cost, reliability/risk)

Pros

1. There exists a clearly adequate experience basis for describing and implementing appropriate fabrication methods for bulk sheet Nb cavities. ~1000 such cavities exist.
2. Costs are well understood from low-volume production runs.
3. Serious production analyses exist for high-volume scale-up of the “standard” fabrication methods.

Cons

1. “Touch” labor is relatively high, with piece part handling, cleaning, and inspection required for EBW steps.
2. The endgroups require as much fabrication attention as the cells. This seems less justified for the cost.
3. Mass production analysis for TESLA-type cavities showed 77% of residual fabrication cost in “machining” operations.

Potential cost impact

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)

Potential Mods to BCD with impact (tech, cost, difficulty/time scale).

The opportunities lie in engineering production efficiency rather than in technical performance, so are more thoroughly addressed under the topic of *Industrialization* and lie outside the expertise of L

Technical advantages, increased tech potential ??
Potential cost impacts ??
Risk and Reliability impacts ??

R&D necessary (at different levels)

See *Industrialization*

ACDs choices prioritized

Overview-

Motivations for considering alternate fabrication choices are almost exclusively related to cost. 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.

ACDs

Pros & Cons of specific ACD

Hydroforming of cell structure - priority 2 ACD

Pros

1. Technique quite suitable for factory production with automation and reduced total fabrication costs.
2. 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.
3. If applied to Nb/Cu clad tubing, the quantity of required high-purity Nb for cells could be reduced by 75%.
4. Highly consistent interior cell geometry expected, thus less required tuning.

Cons

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

Technical advantages, increased tech potential

1. 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.
2.

Potential cost impacts

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

Risk and Reliability impacts

1. Impact on production yield is unknown.
2. No impact on accelerator reliability is expected.

3.

R&D necessary (at different levels)

1. Fabrication of seamless bulk Nb tubes of the length sufficient for 9 cell cavity from one piece (ca. 1.8 m long)
2. Development of "industrial" production routine and qualification of cavities.
3. Avoid or suppress the trapping of magnetic flax caused by thermo - coupling effect in Nb/Cu cavities?
4. New methods of bimetallic tube fabrication
5. More appropriate material for Nb clad cavities instead Cu (Cu alloys etc.)?
6. End group cost reduction for Nb/Cu clad cavities
7. Seamless cavity of new shapes (low losses, re-entrant etc.)
8.

Time scales for R&D

1. Bulk Nb seamless 9 cell TESLA shape cavity (option 3x3) suitable for installation in the cryomodule (2006).
2. Multi cell NbCu clad cavities from special copper without Cu layer inside (2006)

??

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

Spinning of cell structure - Priority 2 ADC

Pros

1. Technique quite suitable for factory production with automation and reduced total fabrication costs.
2. Recent progress has demonstrated that the technique can produce equally-performing Nb cavities. (40 MV/m test cavity) (INFN Legnaro)
3. 9-cell structures have been built.
4.

Cons

1. Less experience translates into less awareness of subtle difficulties.
2. Must assure tubing QA for consistent forming properties.
3.

Technical advantages, increased tech potential

1. 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.
2. Limited experience makes evaluation difficult.
3.

Potential cost impacts

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

Risk and Reliability impacts

1. Impact on production yield is unknown.
2. No impact on accelerator reliability is expected.
3.

R&D necessary (at different levels)

1. Development of “industrial” production routine with multiple cavities and RF qualification of those cavities.
2.

Time scales for R&D

??

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

Nb films on Cu for endgroups - Priority 2 ADC

Pros

1. Potential for reduced cost by using Nb film coating in low-field regions.
2. Improved thermal conduction in portions of accelerating structure outside of the helium vessel.
3. 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.
4. Successful SC flanging would create a new type of modularity that could be exploited.

Cons

1. Complexity of endgroup shape makes confident coating difficult.
2. Undevel
3. Lack of experience base leaves potential problems unrecognized.
4.

Technical advantages, increased tech potential

1. None

Potential cost impacts

1. Reduced cost of material for endgroups (~**??**%)
2. 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.
3. (Is the undeveloped Nb coating cheaper in production ?)

Risk and Reliability impacts

1. Impact on production yield is unknown.
2.

R&D necessary (at different levels)

1. Develop Nb coating of HOM coupler and end group assembly. (complex shape)
2. Develop low-profile reliable superconducting flange joint for use just outside of helium vessel.
3. Develop less complex HOM damping scheme for easier fabrication and coating.
4. Industrial cost study: Is the undeveloped Nb coating cheaper in production than endgroups of BCD?
5.

Time scales for R&D

??