

## FABRICATION OF SUPERCONDUCTING CAVITIES FOR SNS

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### Abstract

During the last three years ACCEL fabricated almost all 109 superconducting cavities for the Spallation Neutron Source (SNS) in Oak Ridge, Tennessee. Two series of 35 medium beta ( $\beta=0.61$ ) and 74 high beta ( $\beta=0.81$ ) cavities will be delivered until October 2004. Besides cavity manufacturing ACCEL also performed RF tuning and chemical surface preparation. We give an outline on the current manufacturing experience and comment on future developments for industrial cavity production.

### INTRODUCTION

In August 2001 the contract for the production of in total 109 elliptical 6-cell 805 MHz superconducting niobium cavities was awarded to ACCEL by JLAB. Two families of cavities had to be produced, 35 cavities of the medium beta type optimised for  $\beta=0.61$  particle velocity and 74 cavities of the high beta type optimised for  $\beta=0.81$  particle velocity needed to be produced within a 3 years period.

In addition to the manufacturing, the contract also included the surface removal of 30  $\mu\text{m}$  from the outside and 100  $\mu\text{m}$  from the inside by buffered chemical polishing.

The last step before delivery is field flatness tuning of the  $\pi$ -mode to accuracy better than 5% in amplitude and adjustment of the external Q of the fundamental mode of the HOM couplers to values above  $10^{12}$ .

### CAVITY MANUFACTURING

At the time of the contract award prototype cavities of both families were already produced at Jefferson Laboratory. After contract award major milestones for the successful run of the project were:

- Engineering review of manufacturing procedures of the prototype cavities.
- Develop production drawings to reflect different manufacturing methods used at ACCEL compared to the JLAB used procedures for the prototype cavities.
- Establish QA plan for the cavity production and detailed workshop travellers.
- Design and manufacturing of all tooling for metal forming, turning, milling, electron beam welding, leak check, tuning, inner and outer BCP needed for the series production.
- Determine optimum electron beam welding parameters for all weld geometries.

The engineering review of the cavity manufacturing methods lead to the decision to change production details compared to the prototype cavities. The main changes were:

- Deepdrawing of half cells using a stamp and a cushion instead of inner and outer die. This technique requires fewer production steps and results in better accuracy of cell geometry.
- Production of raw end groups (see figure 1) out of one sheet of reactor grade niobium by deep drawing and nipple pulling.
- Production of the HOM coupler bodies out of reactor grade niobium cans (ordered from Heraeus GmbH).

The finished cavities can be seen in Figure 2 (medium beta cavity) and Figure 3 (high beta cavity) ready for shipment to JLAB.



Figure 1: Raw end groups produced for SNS cavities by deep drawing and nipple pulling from one reactor grade niobium sheet.



Figure 2: Medium beta 6 cell 805 MHz cavity produced for the Spallation Neutron Source Linac. The production of the medium beta cavities is finished.

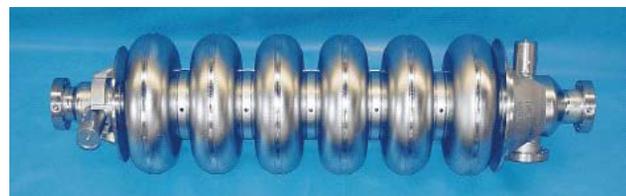


Figure 3: High beta 6 cell 805 MHz cavity for SNS. The series production of the 74 high beta cavities is scheduled to be completed in October 2004.

The surface removal after final welding of 30 µm from the outside and 100 µm from the inside is done in our closed loop chemistry cabinet using buffered chemical polishing (BCP 1:1:2). The acid temperature control during the etching process to values below 15 °C ensures that no hydrogen contamination of the niobium can take place. Thus no Q-disease has been observed in any of the cavities treated at ACCEL so far.

Before shipment an integral leak check to demonstrate leak tightness with a leak-rate below  $2 \cdot 10^{-10}$  mbar·l/s followed by a careful dimensional control of the cavity is performed. It should be noted, that all cavities delivered to JLAB meet the required dimensions especially the length of all cavities is in the tolerance of +/- 3mm after tuning to the correct frequency. To achieve the correct length safely, the frequencies of all produced dumbbells were measured during the production and depending on the individual frequency measurement result the length of the dumbbells before final welding was adjusted. Beside achieving the right frequency this also helps to achieve a field flatness of already < +/- 25 % (deviation from mean value in amplitude) in the cavities directly after final welding and thus the tuning effort is greatly reduced. Normally a field flatness of +/- 1 % in amplitude is easily achieved after final tuning.

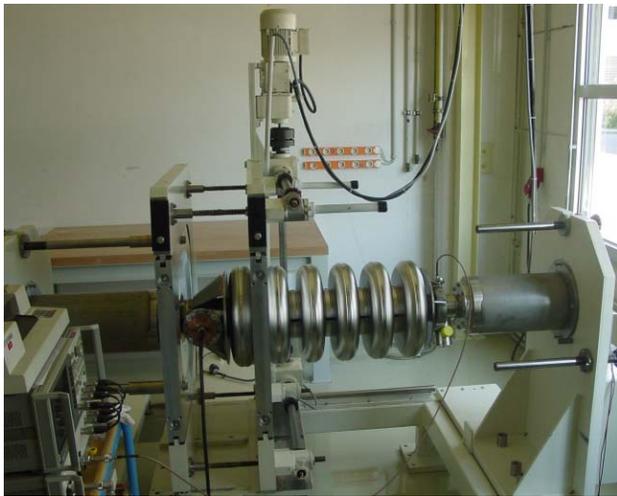


Figure 4: Tuning apparatus for SNS medium beta and high beta cavities. A field flatness of +/- 1% in amplitude is easily achieved.

### TIME SCHEDULE

The time schedule for the project included a first article cavity production of medium and high beta cavity each. The first article medium beta cavity production included the tooling development and took one year, thus in August 2002 the first cavity was shipped to JLAB for vertical test and to demonstrate, that the specified cavity performance of 11.2 MV/m accelerating gradient with  $Q_0$  values above  $5 \cdot 10^9$  could be achieved. This result was needed to launch the electron beam welding of the medium beta series production. Some single parts for the medium beta cavity series were already produced in parallel to the first article.

The remaining manufacturing work, chemical treatment and tuning of the additional 34 medium beta cavities was then finished within another 8 months. (Last medium beta cavity delivered in beginning of April 2003).

Some time during the production of the medium beta and later also of the high beta cavities was lost due to the finding from JLAB, that for all end groups originally requested to be produced out of reactor grade (RRR 40) material, a RRR value in the order of RRR 100 was needed for safe and stable operation in the SNS linac at the design fields and design currents. For this purpose all endgroups were shipped after deepdrawing and nipple pulling to JLAB for additional post purification in a vacuum furnace. At 1000 °C, the endgroups were annealed wrapped in titanium foil to increase the RRR. Some samples were taken from annealed endgroups to demonstrate the required increase in RRR and also to show that the mechanical properties of the niobium were not reduced due to that heat treatment.

In parallel to the work on the medium beta series cavity production, the first article high beta cavity was produced and delivered to JLAB for qualification vertical RF test 17 months after contract award (February 2003). The series production of single parts for the high beta cavities was started in June 2002. The first series high beta cavity was finished in June 2003. Since then, we are shipping cavities to JLAB with a rate of approximately 6 cavities every 6 weeks. The last lot of cavities is scheduled to be delivered to JLAB in October 2004. A comparison of planned and achieved time schedule for the main tasks of the project is shown in Figure 5. Only for the first article cavities, some delay was observed, caused by the additional work for annealing the raw endgroups and by the prototype character of this work.

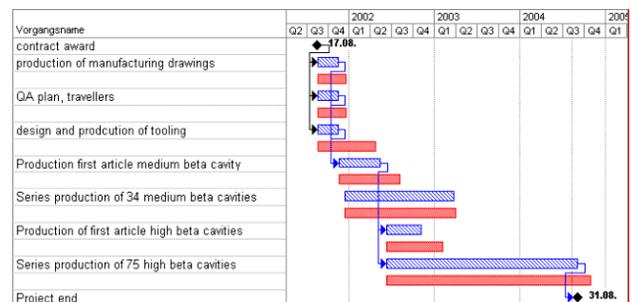


Figure 5: Comparison of planned (blue) and achieved (red) time and delivery schedule of SNS cavities. In summary the originally time schedule could be fulfilled.

### CAVITY TEST RESULTS

No delivered SNS cavity has been reported to not exceed the specified and guaranteed design parameters of

$$Q_0 = 5 \cdot 10^9 \text{ at } E_{\text{acc}} = 11.2 \text{ MV/m}$$

for the medium beta cavities and of

$$Q_0 = 5 \cdot 10^9 \text{ at } E_{\text{acc}} = 15.1 \text{ MV/m}$$

for the high beta cavities during the vertical cold RF test at a bath temperature of 2.1 K. Sometimes a cavity needed to be tested more than once in order to reach the

desired performance, the limiting effect being field emission loading by most probably insufficient high pressure water rinsing [1].

In figure 6 typical cold RF test results of a medium and high beta cavity are shown in comparison to the design specifications.

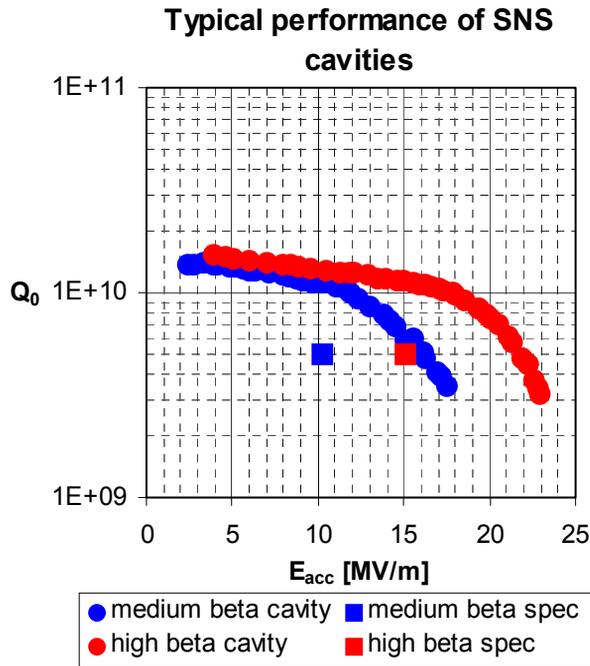


Figure 6: Typical cold test result of medium and high beta cavities for SNS. Accelerating gradients of up to 23 MV/m were achieved in the high beta cavities.

### REQUIRED PERSONNEL

In average the contract was finished with approximately 10-15 people working on the project.

Figure 7 shows the relative distribution of engineers and skilled technicians involved in the project.

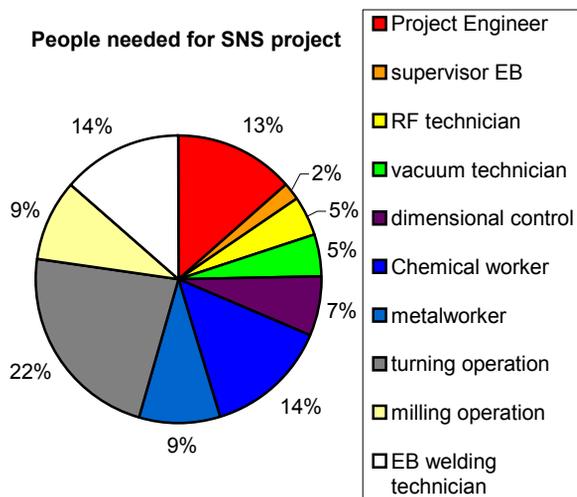


Figure 7: Relative distribution of engineers and skilled technicians involved in the SNS project.

Besides specific tasks like dimensional control and leak checks performed by vacuum technicians, QA work is included in the engineering, supervision of EB and RF technician work.

As can be seen, the heaviest work load is for turning operation followed by chemical workers (chemical treatment before welding and final chemistry), project engineering and EB welding. For the SNS project our two electron beam welding machines were loaded in a one shift operation to approximately 75 %.

With a view to future possible industrial cavity manufacturing projects with an even higher number of cavities produced per time, we would like to comment this additionally as follows:

- The two required cavity types for SNS reduced the number of similar cavities to maximum 73 during series production. This number is still too low to implement highly efficient mass production tools. Less engineering per cavity will be required for higher cavity numbers.
- The two first article cavities and design of all tooling also required a relative high percentage of engineers involved in the production.
- The tools for electron beam welding and the electron beam welding machines itself have still potential for further optimization when producing higher cavity numbers. There is still some room to reduce the needed electron welding machine time for one cavity and increasing the number of completed cavities per time.
- All involved machines and services were not exclusively dedicated to this project during the whole contract period. Storage of parts and internal transport can be reduced when machines and locations are dedicated to only one big mass production project.
- Milling and turning capacity can be easily enlarged for high cavity numbers by establishing a two or three shift operation. For the SNS project, turning and milling machines were operated in a one shift operation only.

### ACKNOWLEDGEMENT

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### REFERENCES

- [1] Peter Kneisel, private communication