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FABRICATION AND TUNING TECHNIQUES FOR SIDE-COUPLED ELECTRON ACCELERATOR STRUCTURES

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Summary

Beginning in 1979, Los Alamos entered into a collaboration with the National Bureau of Standards (NBS) to develop an advanced cw microtron accelerator. The accelerating structures (one 0.9-m-long, one 2.7-m-long, and two 4.0-m-long) containing a total of 184 accelerating cavities have been fabricated and tuned to the 2380-MHz operating frequency. New methods simplified the fabrication of these structures and eliminated several furnace-brazing steps. These fabrication methods, lathe-mounted tuning fixtures, and streamlined tuning techniques were developed to allow efficient production of side-coupled structures. These techniques are now being applied to the 2450-MHz racetrack microtron accelerator structures being fabricated at Los Alamos for the Nuclear Physics Department of the University of Illinois. Refinements of the described techniques will allow future accelerators of this type to be fabricated by private industry.

Introduction

Refinement of previously-developed techniques, and development of new approaches to fabrication and tuning techniques for side-coupled electron accelerator structures began with the joint project of the National Bureau of Standards (NBS) and Los Alamos to build a racetrack microtron (RTM) accelerator system for NBS.[1] Constructed at Los Alamos, the NBS RTM accelerators are all room- temperature, 2380-MHz, side-coupled, standing-wave, cw structures. The 0.9-m-long capture accelerator has 15 accelerating cavities, and the similar 2.7-m-long preaccelerator has 43 accelerating cavities. The main microtron accelerator (Fig. 1) consists of two accelerator tanks (each 4.0 m long with 63 accelerating cavities) with an rf iris in the center of each. All of the accelerating structures have been installed at NBS.

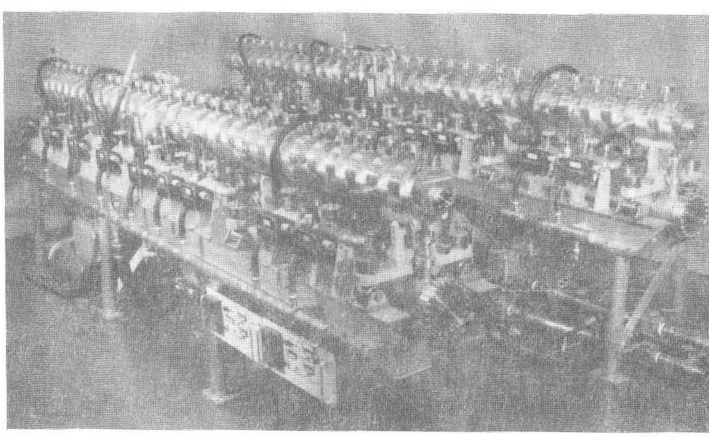

Fig. 1. NBS RTM main microtron sections.

Success with the NBS RTM led to Los Alamos efforts on two other side-coupled electron-linac structures. One is an RTM accelerator system for the Nuclear Physics Department of the University of Illinois. It is very similar to the NBS RTM with a slightly higher operating frequency (2450 MHz), and fabrication is essentially the same as the NBS RTM accelerators. The Stage I microtron and the capture accelerators (each with 17 cavities) have been fabricated; the preaccelerator (45 cavities) is being fabricated in 1986, with a large Stage II microtron accelerator to follow later.

Another side-coupled electron linac built at Los Alamos is a 20-MeV 1300-MHz accelerator for the Los Alamos free-electron laser (FEL) project. The FEL accelerator consists of two brazed copper assemblies, a 13-cavity tank and a 15-cavity tank. Because of the relatively large size, the FEL accelerator is constructed like the 805-MHz LAMPF accelerator with separate, brazed-on side-coupling cells. Instead of alternating the coupling cells from side to side, the FEL coupling cavities are successively rotated so that the coupling slots appear at spirally ad-vancing positions around the beamline. This rotation minimizes the effects of spurious beam-steering modes that may appear when extremely intense electron micro-pulses traverse the accelerating cells slightly off center. The tuning techniques used on the RTM structures were applied to the larger FEL cavities. The FEL accelerator is in operation at Los Alamos and has, at four times the design beam current, produced a beam of excellent quality.

Design, Fabrication, and Tuning Requirements

Because of the RTM's higher frequency, the small structure size allows great simplification of fabrication methods used on the LAMPF-style structures. The major design innovation is in the RTM cell structure (Fig. 2), which has half an accelerating cell, half a coupling cell and the cooling channels all machined into the same blank, minimizing the number of brazing operations. A high-flow-rate (19.4 kg/s) water system removes the large heat deposition (25 MW/m of accelerator structure), and it controls the average cavity temperature to within one-half degree Celcius despite relatively low thermal mass of the accelerator structure (139 kg/m). The largest pressure drop occurs in the cooling channels within the accelerator (Fig. 3). Careful design of these parallel-path channels minimizes the pressure drop, consistent with maintaining vacuum integrity and cavity shape.

Tuning and fabrication are intimately related. A precisely shaped and tuned accelerator structure is required to produce the field for a high-quality beam. Side-coupled accelerators are machined from annealed OFHC copper, which is very abrasive, requiring a hard-surfaced cutting tool. Fixturing parts for machining is difficult because the extremely soft copper easily deforms when clamped. Because of the relatively large ohmic losses in room-temperature cw accelerator cavity walls, tests were done to determine the effect of surface finish on the operational efficiency (as measured by the cavity Q). Cutting tools of natural diamond, synthetic diamond, tungsten carbide, and high-speed steel were tested; although the surface finish did vary with the type of cutting tool, there was very little effect of surface finish on the cavity Q, as seen in Table I. The best overall performance was by tungsten carbide, the material used for all cavity machining.

Table I
EFFECTS OF MACHINING TECHNIQUE ON CAVITY PERFORMANCE

Cutting Material	Speed (rpm)	Q	% of SUPERFISH Q
Carbide	625	17630	99.1
Carbide	2000	17550	98.7
Synthetic diamond	625	17550	98.7
Synthetic diamond	2000	17600	99.0
Natural diamond	625	17510	98.5
Natural diamond	1120	17600	99.0
Natural diamond	2000	17600	99.0
Average (standard deviation)		17577 (38)	98.9 (0.2)

*Work performed under the auspices of the U. S. Dept. of Energy and supported by the U. S. Army Strategic Defense Command

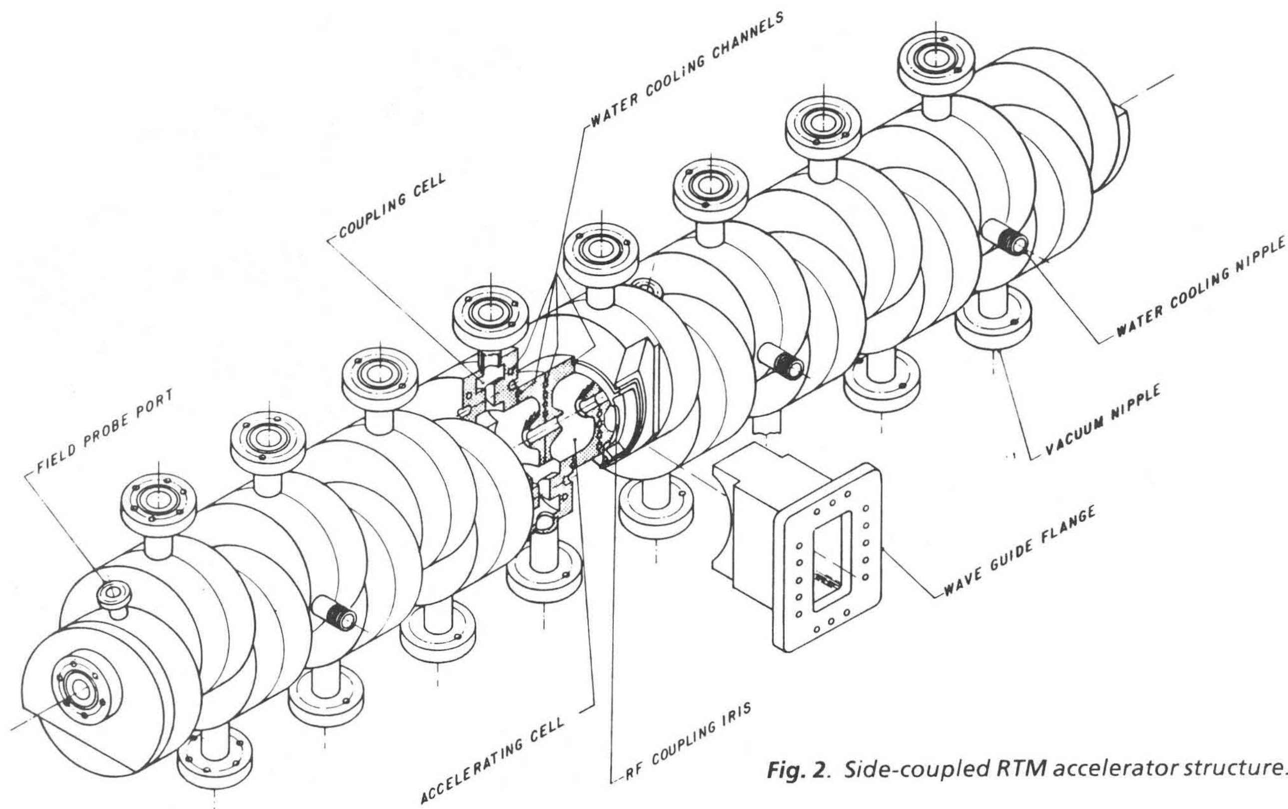

Fig. 2. Side-coupled RTM accelerator structure.

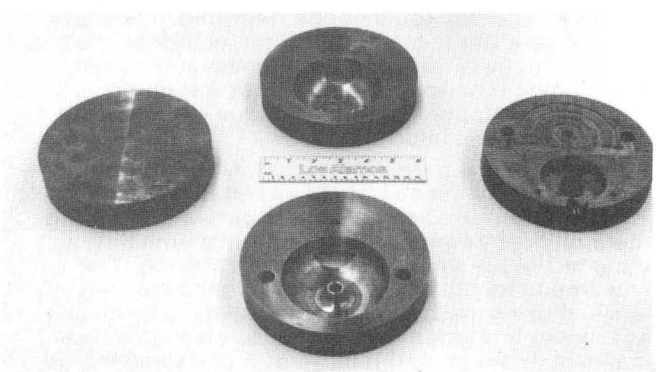

Fig. 3. RTM accelerator half-cell showing the OFHC copper billet, the rough machined cavity, and both sides of the final machined cavity.

Fabrication and Tuning

The accelerator structure is an arrangement of furnace-brazed copper assemblies. Brazing accelerator structures is a complex procedure requiring special hydrogen-atmosphere furnaces, and the tuning and vacuum integrity of the accelerators highly depend on the skills of the brazing personnel. Fabrication begins with an anneal of the OFHC copper billets in a hydrogen brazing furnace to the highest temperature anticipated for brazing; this ensures that the billets will resist damage in succeeding furnace heats. The billets are rough machined; one-half an accelerating cell is machined into one side of each billet, and one-half a coupling cell and the cooling water passages are machined into the other side. The rough-machined half-cell bodies are annealed to remove residual stresses before finish machining.

The annealed, rough-machined, half-cell bodies are finish machined except for the accelerating-cells' nose tips and the post tops in the coupling cells. Next, preliminary tuning of the accelerating cells is performed using a tracer lathe. The tuning method used for the accelerating cells is to progressively machine down the nose contours of each half-cell (material removed with an accuracy of 0.0003 in.) raising the frequency to the desired value. Depth of each succeeding tuning cut is determined by measuring the rf frequency of the half-cell; based on previous data, an estimate is made of how much more nose material must be removed to raise the frequency to the required value. Several tuning cuts are required on each nose. Similarly, the coupling half-cells are tuned by slowly removing material from the cell center post. This preliminary tuning also provides the finish-machined nose contour in both the accelerating cells and coupling cells.

Following preliminary tuning, the complete coupling-cell assemblies are formed by brazing together sets of the tuned half-cells (the first, or half-cell braze). These full-cell assemblies consist of one complete coupling cell and two half-accelerating cells. Holes are then machined into these assemblies for various connectors, which are brazed into the full-cell assemblies (the second, or nipple braze). The full-cell assemblies are then stacked to form a multi-cell assembly on which several rf checks are performed. A bead pull is performed to check field uniformity, and the accelerating cell frequencies are measured. Cell frequency out of tolerance is corrected by retuning the full-cell assembly in the tracer lathe. Nonuniform fields are corrected by adjusting the length of the coupling slots between the accelerating cells and coupling cells.

A stack of full-cell assemblies making up a segment of the accelerator can then be brazed together in the manner shown in Fig. 4 (the third, or half-stack braze). If the accelerator is long, an accelerator segment may have flanges on one or both ends. If a segment contains the rf waveguide adapter, the cell with the waveguide adapter is assembled (not brazed) and the iris is machined. The iris size determines the waveguide coupling coefficient to the

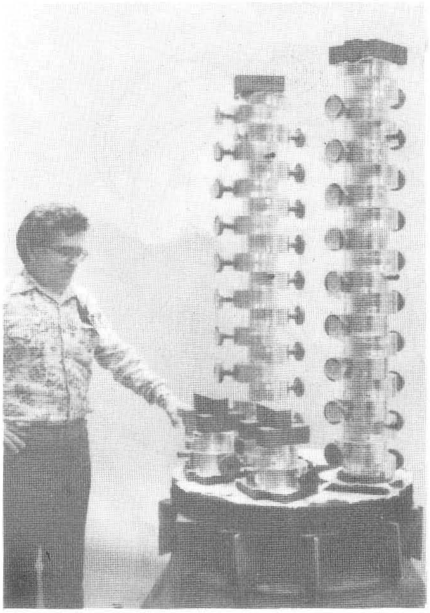

Fig. 4. RTM stack and iris section arranged for the braze.

Fig. 5. Tuning an RTM half-cell on a lathe using electronic measurement methods.

accelerator. The coupling coefficient is measured, and the iris size is adjusted. This segment is then brazed together, usually in combination with another braze. If the iris segment is to be an integral part of the accelerator (the case in Fig. 4), it will brazed in between the two half-stack assemblies (the fourth, or stack braze). Finally the rf waveguide flange with a tapered copper transition is brazed to the iris segment (the last braze).

Final accelerator tuning is done by first measuring the frequency of each cell. The accelerating cells can then tuned by raising the frequency of each cell an appropriate amount by deforming the outer cavity wall. In an RTM-style cavity, this deformation is accomplished by denting the copper at the bottom of a hole to a depth near the interior surface of the cavity. The coupling-cavity frequency is tuned by squeezing the center posts closer together to lower the frequency, or by pushing the center posts apart with a special tool inserted through the vacuum port to raise the frequency. The accelerator assembly tune is checked and readjusted as required. Mumetal magnetic shields are installed to enclose the entire beamline because the electron beam will be deflected by the earth's magnetic field. A final accelerator test is to measure the center-line magnetic field with the magnet shield installed.

The tuning procedure used on the NBS RTM accelerators evolved through several iterations. The original method generally used the procedure described above; after each tuning cut, the half-cell was removed from the lathe fixture. The completed half-cells were then stacked together and the stack frequency was measured. Based on these measurements, each half-cell was replaced in the lathe machining fixture, and additional nose material was removed as indicated by the stack measurements. Because of inherent inaccuracies in replacing the half-cells in the lathe machining fixture, this procedure was very slow and not always repeatable.

To make the tuning procedure less time-consuming, several tuning innovations were made. The most significant was development of appropriate tuning fixtures and procedures that allowed the half-cells to be electrically measured while still in the machining fixture. Using the lathe-mounted tuning fixture (Fig. 5) and prior data, an accurate calculation was made to estimate how much more nose material to remove to achieve the required frequency. The design frequency normally could be reached in three tuning cuts. When complete, each half-cell was removed from the lathe fixture. This innovation allowed accurate and repeatable tuning, with four-to-tenfold reduction in tuning time.

Alternative Tuning Technique

After the FEL accelerator had been fully assembled and tuned, circumstances required that the accelerator frequency be lowered. No technique to do this existed, although a method had been developed during the construction of the large 805-MHz LAMPF side-coupled accelerator. A special tool inserted down the accelerator bore scraped off part of the outside of the cavity nose when the tool was rotated. While the tool was in place, the cavity frequency could not be measured. Therefore, the procedure was to make a small cut, withdraw the tool, measure the cavity frequency, and repeat as required–difficult, time-consuming, with inconsistant results. Furthermore, adaption of this technique to the smaller FEL cavity bore was impossible.

A special tool was developed that, when inserted down the bore of the assembled accelerator, mechanically deforms the accelerating cavity nose outward, lowering the frequency by flaring the nose. Results from this tuning technique were exceptionally gratifying. The cavity frequency can be measured while the tool is in place and being used, allowing each cavity to be quickly and accurately retuned. The entire FEL accelerator was retuned in 2 days using this technique, and some individual cells were also adjusted on the NBS RTM accelerator.

Conclusions

Major strides have been made to make the fabrication of side-coupled structures a commercial process. The University of Illinois preaccelerator will be fabricated in a commercial machine shop, with only liaison, final tuning, and brazing provided by Los Alamos. Refinement of tuning techniques have significantly reduced the fabrication difficulty, and the new tuning technique for assembled acceler-ators (the nose-flaring method) has significant impli-cations. For the first time, a technique now exists to quickly correct the frequency of side-coupled accelerators after fabrication. These developments have signifi-cant implications for the commercialization of high-frequency, side-coupled, electron accelerators.

Reference

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