CHARACTERIZATION TECHNIQUES FOR X-BAND MEDICAL ACCELERATOR STRUCTURES

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Abstract

The majority of medical accelerators for radiation therapy use frequencies in the S-band range. Having a compact accelerator allows for a wide range of treatments. The size and weight of the accelerator are substantially reduced if a higher frequency is used. X-band frequencies are suitable for such applications. X-band accelerator technology has been used in high-energy, as well as, industrial applications. In the medical field, it has already been implemented in some machines [1, 2]. To develop and manufacture reliable X-band radiation therapy machines, accurate and efficient techniques that characterize accelerator structures are needed. In this paper, we review some of the low-power testing techniques developed to characterize X-band accelerators.

1 X-BAND MEDICAL APPLICATIONS

X-band accelerator development has gained great momentum in the last ten years, motivated by the need for high-gradient accelerators for future linear colliders in high-energy physics research [3]. Design of accelerator cells [4], manufacturing [5], and characterization techniques [6] have been developed. In the industrial [7] and medical [1, 2] fields, there are obvious advantages for using frequencies higher than the S-band range that has prevailed in these applications. The dominant factor is the compactness of the accelerator with the attending reduction in weight. Consequently, the linac motion can be more precisely controlled. By implementing the X-band technology, shorter accelerator structures can be used for a given RF power to achieve a certain electron beam energy. The reasons for this are twofold. Firstly, the shunt impedance per unit length is higher than S-band. Secondly, the maximum permissible electric field strength is also higher.

Currently, there are two different radiation therapy applications that use the X-band technology.

1.1 Intra-Operative Radiation Therapy

The Intra-Operative Radiation Therapy (IORT) technique basically refers to the delivery of radiation during an operation using an electron beam. This technique of radiation therapy has proven to increase the survival rates in certain cancer cases. Conventional radiation therapy machines must be housed in shielded rooms to which patients must be moved from the operating room. A mobile radiation therapy machine, the Mobetron [1], engineered and developed by Intraop, has met the need for a self-shielded machine. Since the unit is mobile, it can be easily positioned in an operating room to treat cancerous growths with good precision during surgery, increasing the effectiveness of radiation doses to tumors while reducing the dose to surrounding healthy tissue. Siemens Medical Systems, Oncology Care Systems Group (OCS), is manufacturing the Mobetron, as well as, marketing it in collaboration with Intraop Medical.

Figure 1: The Mobetron IORT system.

1.2 Stereotactic Radiosurgery

Another important application for X-band technology is stereotactic radiosurgery. Accuray Oncology has developed the CyberKnife [2]. This machine uses an image-guided robotic system to precisely deliver an X-ray beam to focal lesions. It integrates treatment planning, imaging, and delivery components, all of which are controlled by a workstation. The CyberKnife uses a compact X-band 6MeV linac operating at 9.3GHz. The

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relatively lightweight linac makes it possible for the robotic arm carrying it to be accurately positioned.

2 ROLE OF LOW-POWER TESTING

To develop reliable radiation therapy machines, accurate and efficient techniques that characterize accelerator structures have been developed. These techniques are implemented at different phases of accelerator development and manufacturing. At Siemens, we have been developing different microwave techniques to verify predictions from computer simulations in the design phase, to insure that the machined cells are within design tolerances, to perform accurate tuning, and finally, to confirm overall RF performance of the completed structure. For this final test, a semi-automated system has been developed to implement the bead-pulling technique. This technique maps the amplitude of the axial electric field along the structure. Fig. 2 shows the series of tests used through the phases of the design, manufacturing, and assembly of an accelerator.

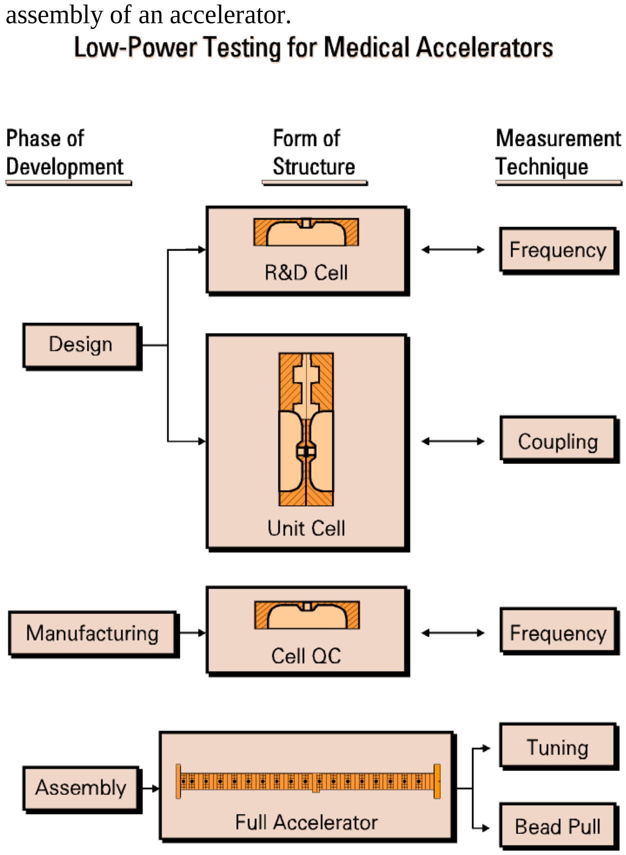

Fig. 2 Low-Power Testing Techniques for Medical Accelerators.

2.1 Tests Supporting Design Phase

During the design phase of an X-band accelerator, the accuracy of the simulation is tested by fabricating short stacks representing different types of cells in the accelerator structure. On-axis probes measure the accelerating mode frequency. To verify the coupling between cells, a "unit cell" is tested. This consists of two halves of the accelerating cavities and one full side cell, as shown in Fig. 3. Results of these measurements are used to refine the dimensions of the cells of the structure predicted by computer simulation.

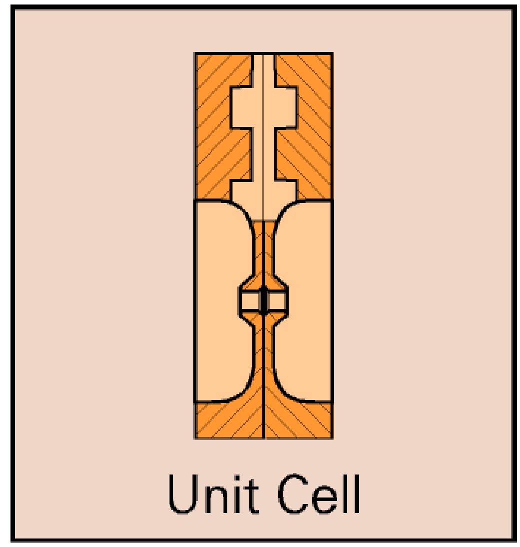

Fig. 3 A "unit cell" composed of two halves of accelerating cavities and a side cavity.

2.2 Cell Machining QA

To verify the frequency of the machined cells, a set-up has been developed. A computer-controlled network analyzer measures the resonant frequencies of individual cells. The measured frequency and the serial number (SN) for each cavity measured are both recorded and archived. A Statistical Process Control (SPC) system imports the data. Control charts are observed and analyzed for quality assurance (QA) and reduction of variance in the machining process.

2.3 Tuning and Bead Pull Tests

The use of brazing in the assembly of an accelerator section can result in deviations in the volume of the constituent cavities (cells). Thus, tuning individual accelerator cells is usually required. This is done with the help of a computer program which uses explicit instructions and diagrams to lead the operator through a tuning sequence, while appropriate S-parameters are remotely configured and measured by an HP 8719 network analyzer. Measured data (waveguide VSWR, transmission, and history of cell tuning) are saved in a folder unique to the SN of the accelerator structure type. Measurement settings (e.g. target tuning values, sweep parameters, etc.) can be edited by privileged operators at startup. A master tuning window acts as a template that dynamically adjusts to each accelerator type. Fig. 4 shows a typical tuning window.

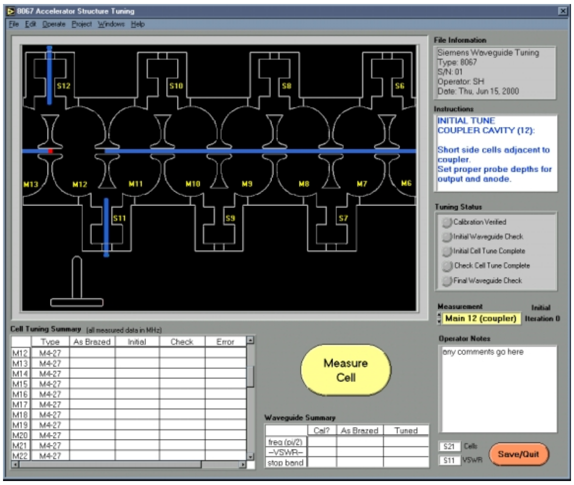

Fig. 4: A typical tuning window to guide the operator.

The operator is guided through a step-by-step assisted calibration sequence. This window is depicted in Fig 5. In addition, the tuning program incorporates various error checking capabilities. Other features include automatic in-progress saving that can recover data from partially tuned structures.

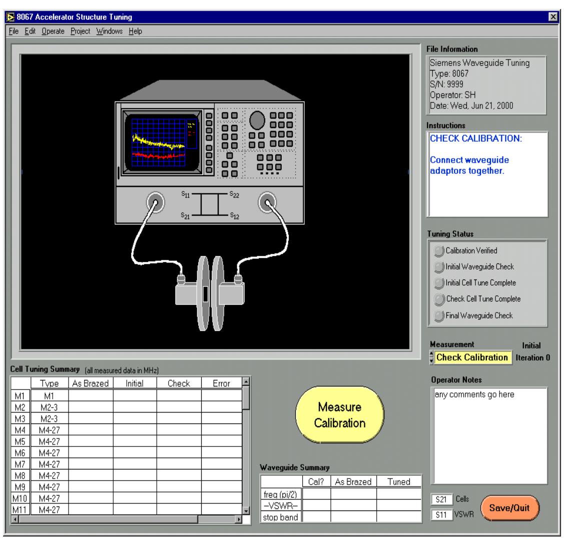

Fig. 5 A panel diagram guiding the calibration process.

3 DISCUSSION

The recent X-band research and development for the linear collider project have been providing an impetus for the development of X-band accelerators. For medical accelerators, this technology provides opportunities for new applications in radiation therapy. Nevertheless, the tighter dimension tolerances for X-band accelerators require low-power RF testing techniques that ensure the precise and reliable performance of these new medical accelerators.

ACKNOWLEDGEMENT

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