A HIGH-POWER RF EFFICIENT L-BAND LINAC STRUCTURE

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Abstract

A standing-wave, on-axis coupled, 10 MeV electron linac structure has been assembled at Chalk River Nuclear Laboratories as a prototype for a family of high-power industrial irradiators. The 3.25-m-long accelerator structure has an rf power dissipation capability of 150 kW/m for electron beam powers up to 250 kW. The 1300 MHz structure has a measured shunt impedance of 57 MΩ/m. General features of the computer modeling, cavity fabrication with numerically controlled machines and assembly are discussed. Results of rf tests are described.

Introduction

IMPELA (Industrial Materials Pulsed Electron Linear Accelerators) is a family of industrial irradiators being developed by Atomic Energy of Canada Ltd. to cover beam energies ranging from 5 to 18 MeV at beam powers of 20 to 250 kW. These irradiators are built from similar basic components. The IMPELA accelerator structures are modular, made from similar cavity segments grouped together into basic sections.

Three types of accelerator sections are required to form an IMPELA standing-wave accelerator structure: a beam capture section, where an injected beam pulse is accelerated, bunched and synchronized to the rf fields; a coupler section, used to transmit the rf power into the resonant structure and acceleration sections, used to bring the beam bunches to the desired output energy.

The accelerator sections are made from the basic on-axis coupled, 1300 MHz, cavity segment shown in Fig. 1 and can be arranged to meet various output beam energy requirements. The cavity profile is optimized for high rf efficiency with the computed code SUPERFISH[1].

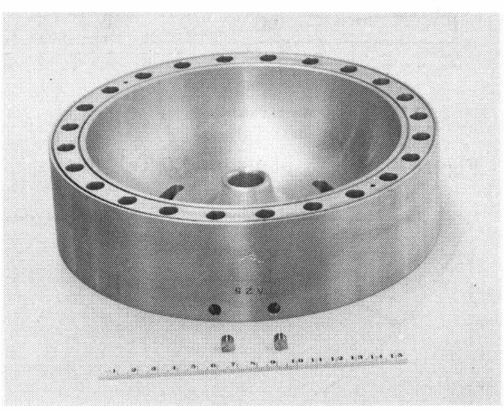

Fig. 1 IMPELA basic cavity segment.

Cavity web and circumferential cooling are provided to minimize the structure frequency shift during startup. Rapid recovery from a system failure and minimum down time are best achieved with both web and circumferential cooling. Structure detuning from a change in the stopband frequency gap at high power is significantly reduced by minimizing the thermal stresses in the cavity webs. The cooling arrangement was optimized by three-dimensional finite-element heat transfer and thermal stress analysis[2].

A prototype 10 MeV accelerator structure is shown in Fig. 2. It is 3.25 m long and designed to operate at an energy gradient of 3 MeV/m. It is made from four sections: a beam capture section, an acceleration section, a coupler section and a final acceleration section. These sections are assembled with double knife-edge, stainless steel, conflat flanges located in half-accelerating cavities. The inner knife is for rf contact and the outer knife provides the vacuum seal[3].

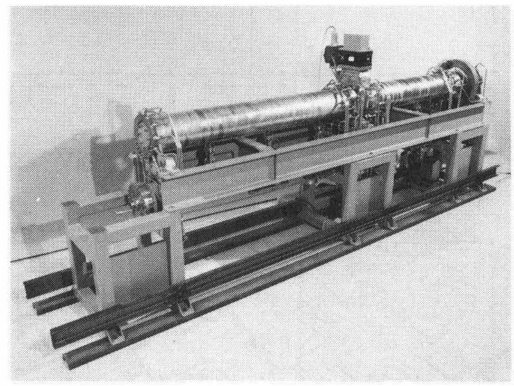

Fig. 2 The IMPELA prototype structure.

This paper reviews the optimization and fabrication procedures of the IMPELA prototype structure.

Accelerator Structure Design

Power handling capability and rf efficiency are the important parameters to optimize in choosing a cavity profile for high-throughput industrial irradiators. The power-handling capability increases with the cavity web thickness while the rf efficiency decreases with web thickness. The cavity geometry is optimized by a computer analysis of the rf efficiency and by a finite-element heat transfer and thermal stress analysis[2].

The cooling arrangement of the IMPELA structures is shown in Fig. 3. Circumferential and web cooling channels are arranged to minimize thermal stresses[4]. An example of the results of a stress contour calculation is shown in Fig. 4.

The IMPELA cavities are designed for a power-handling capability of 150 kW/m. This does not compromise their rf efficiency since with a cavity beam aperture diameter of 20 mm, for good beam transmission, the measured shunt impedance is 57 MΩ/m (85% the value calculated with SUPERFISH). This is a large value of shunt impedance for an L-band structure since the measured shunt impedance of an S-band structure with similar power-handling capability is 71 MΩ/m[4].

Cavity Machining

The IMPELA irradiators utilize a single accelerator structure driven with a klystron amplifier with a bandwidth of 7 MHz. The rf system is designed to track the structure resonant frequency by comparing the phase of the rf signal at the input and in the structure with a double balanced mixer. This allows for considerable relaxation in the fabrication tolerances of the cavity segments. The tuning requirement is that the resonant frequency of the structure over the design-system operating temperature range of 25 to 45°C be well within the klystron bandwidth.

The frequency sensitivity of resonant cavities to geometrical changes depends on the magnetic- and electric-field amplitude at the location of a perturbation and on the magnitude of the geometrical change. For a linac with a single accelerator structure operated with AFC (automatic frequency control), reproducibility of the individual cavity-segment frequency is more important than a target-operating frequency. Having all the cavity segments machined to the same individual frequency is more important than the operating frequency as long as it is within the bandwidth of the klystron. Excellent reproducibility in cavity dimensions is achieved with numerically controlled lathes.

The cavity-segment coupling slots, shown in Fig. 1, provide a first-neighbor coupling of 0.075. With this value of first-neighbor coupling, the field droop resulting from individual cavity-segment frequency errors of ± 500 kHz in a 3.25 m long, 1300 MHz, structure is less than 1 %. Machining of the cavity segments with a numerically controlled lathe gave results well within these tolerances.

The prototype structure requires 58 cavity segments. A total of 70 cavity segments, identical to Fig. 1, were fabricated. Cavity segments were machined from grade 10100 OFHC (oxygen free high conductivity) copper. Individual cavity-segment frequencies are shown in Fig. 5 in the form of a histogram with a 250 kHz window. A majority of segments are within a ± 250 kHz frequency range. Some segments have a larger frequency deviation related to initial setup procedures.

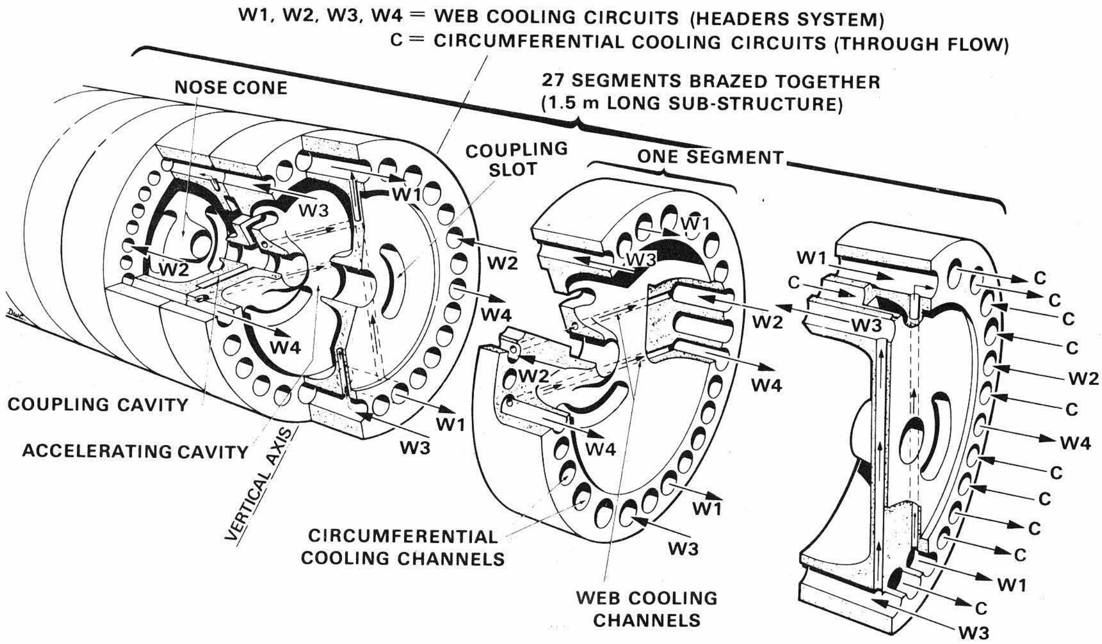

Fig. 3 Cooling circuits of the 1300 MHz on-axis coupled structure.

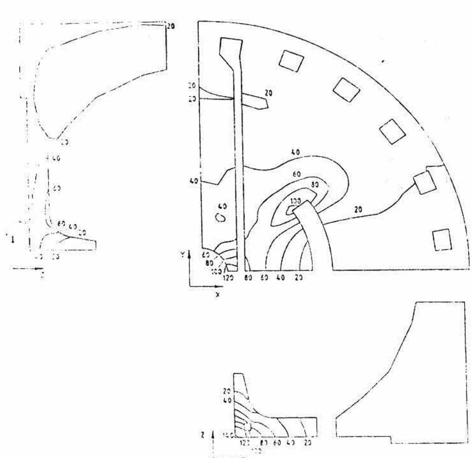

Fig. 4 Von Mises stress contours in the cavity walls at a power level of 150 kW/m (stresses in MPa).

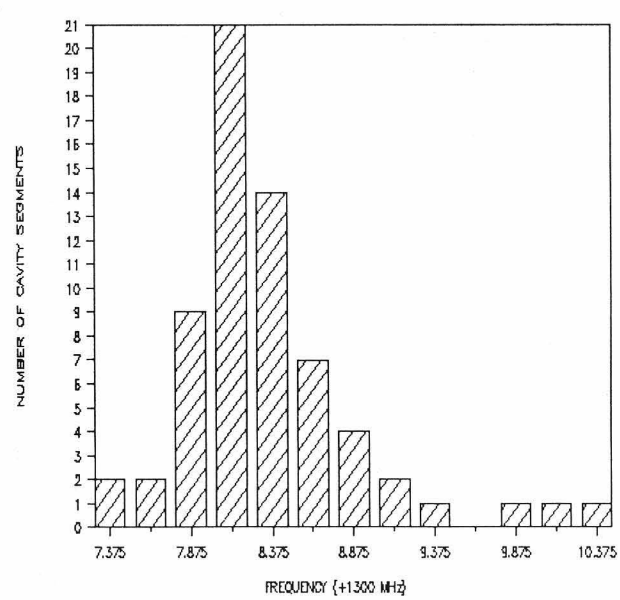

Fig. 5 Histogram of the accelerating half-cavity frequency after machining with a numerically controlled lathe.

Assembly

Fine tuning of the cavity segments machined with a numerically controlled lathe is greatly reduced. The tuning of the IMPELA structures must allow their operation over a wide power range. The 1300 MHz structure frequency will decrease with temperature at a rate of -21.5 kHz/°C. Frequency shifts of -7 kHz/kW/m are expected over the operating range of the structure and the changes in the stopband frequency gap should not exceed 2 kHz/kW/m.

Cavity segments are brazed into sections in a hydrogen furnace. The inner braze joint located below the cooling channels shown in Fig. 1 isolated the cooling channels from the structure vacuum. The outer braze joint prevents leaks from the cooling channels to the outside.

The accelerator structure is evacuated through a vacuum manifold located below the structure, see Fig. 2, and through a port in the tapered waveguide at the coupler section. Vacuum is maintained in the structure at 10^{-8} torr with a 60 L/s ion pump at the vacuum manifold and an 8 L/s pump at the tapered waveguide port.

Pumping is done through slots in accelerating cavities. This arrangement allows for the passage of rf currents and minimizes rf power losses through the pumping ports. Short bellows are mounted between the structure pumping ports and the vacuum manifold below. The weight of the prototype structure assembly shown in Fig. 2 is 1000 kg.

RF Characteristics

The IMPELA prototype structure is designed to be critically coupled with a beam loading coefficient of 0.65. The unloaded VSWR is 2.8 overcoupled.

The structure is composed of 29 accelerating cavities and 28 coupling cavities. The average on-axis accelerating field determined from bead pull measurements is shown in Fig. 6. Variations in the average field amplitude do not exceed 6%. The structure has 57 TM_{010}-like modes and the fundamental mode spectrum is shown in Fig. 7. The first and second neighbor-coupling constants calculated from the measured mode frequencies are 0.075 and 0.0019 respectively.

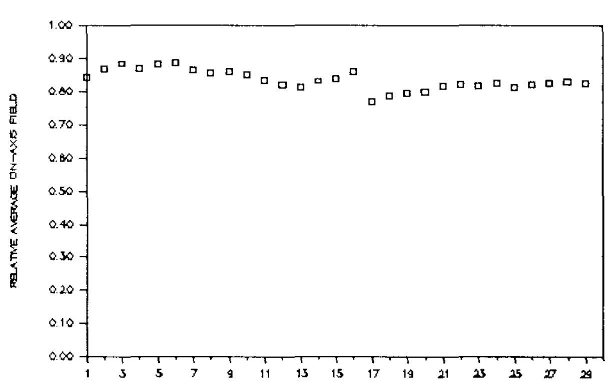

Fig. 6 Average on-axis electric field distribution in the IMPELA prototype cavities.

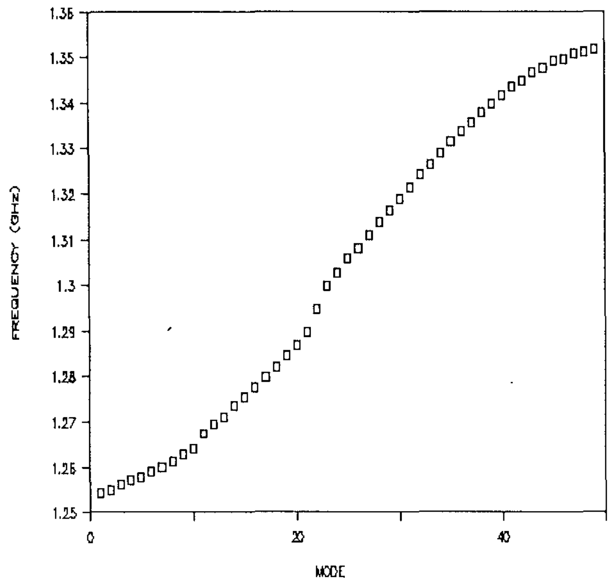

Fig. 7 TM_{010}-like mode dispersion curve for the IMPELA prototype structure.

Acknowledgments

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