HIGH POWER ELECTRON LINAC STRUCTURE

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Abstract

An on-axis coupled continuous wave (cw) electron linac has been designed for operation under 63% beam loading conditions. A prototype 2450 MHz linac structure has been constructed to determine operational stability at power levels up to 200 kW/m, corresponding to an average energy gradient of 3.5 MeV/m. Heat transfer from the structure to the cooling water has been optimized by computer modeling. Mechanical behaviour and predicted changes in the rf parameters during high power operation are described.

Introduction

High power electron linacs are being developed as radiation sources for applications such as medical supply sterilization, food preservation and waste treatment[1]. The energy efficiency of linacs used for radiation processing is maximized by heavily beam loading the accelerator structures. Experiments at Chalk River Nuclear Laboratories (CRNL) have demonstrated stable operation of a standing wave cw electron linac at beam loadings up to 85%[2].

The relationship between average energy gradient, E, beam current, I, and a structure's beam loading coefficient, β, is given by

$$E = ZT^2 \, I \left(\frac{1-\beta}{\beta}\right) \qquad (1)$$

where ZT^2 is the shunt impedance per unit length. There will be a limiting beam loading coefficient, and high beam current applications will thus require large average energy gradients or low shunt impedance for stable operation.

Average energy gradients of 2 MeV/m have been obtained in room temperature cw linac structures[3,4]. This paper describes a high power on-axis coupled structure constructed at CRNL to determine the mechanical behaviour and changes in the structure rf parameters at average energy gradients up to 3.5 MeV/m, and power levels up to 200 kW/m. Temperature distributions and thermal stresses are calculated with the computer code MARC[5] and results of a study of the heat transfer from the structure to the cooling water are discussed.

Description of the Accelerator Structure

Figure 1 shows a photograph of the 2450 MHz on-axis coupled structure, a prototype for a linac designed to accelerate electron beams up to 50 mA intensity to an energy of 10 MeV[6]. Beam loading of the linac is 63% and 60 kW/m of rf power will be dissipated in the structures.

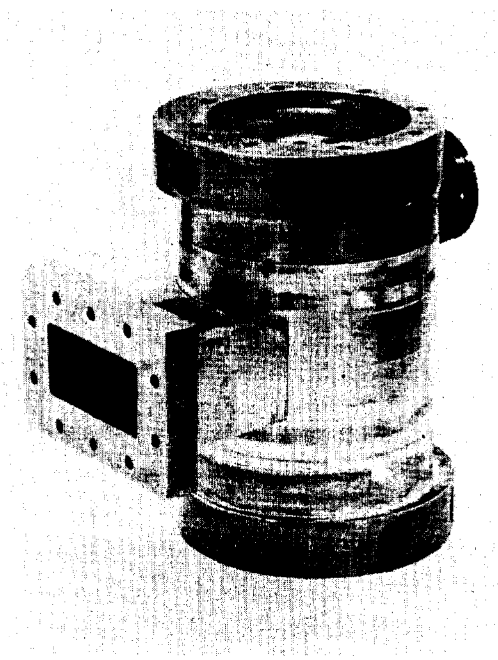

Fig. 1 High power on-axis coupled structure.

The OFHC copper prototype structure is composed of three accelerating and two coupling cavities. The overall length, including stainless steel end flanges for cooling water inlet and outlet, is 0.25 m and the outer diameter is 0.15 m. Rf power is fed into the center cavity through an iris sized for critical coupling. A mechanical tuner with a range of 4.5 MHz is located in an end cavity.

Figure 2 shows a sketch of the cavity profile and the water cooling circuits arrangement. The cavity profile is the same as used for the linacs in the microtrons at the University of Mainz[7], which have a shunt impedance of 67 MΩ/m. A first neighbour coupling constant of 0.08 was obtained with coupling slots 6 mm wide, having an azimuthal span of 78°. Field tilts associated with the tuner operation are less than 7%. The orientation between adjacent pairs of coupling slots is 90°. Second neighbour coupling between accelerating cavities is 0.002 for the fundamental TM_{010} mode and 0.0005 for the beam blowup TM_{110} mode.

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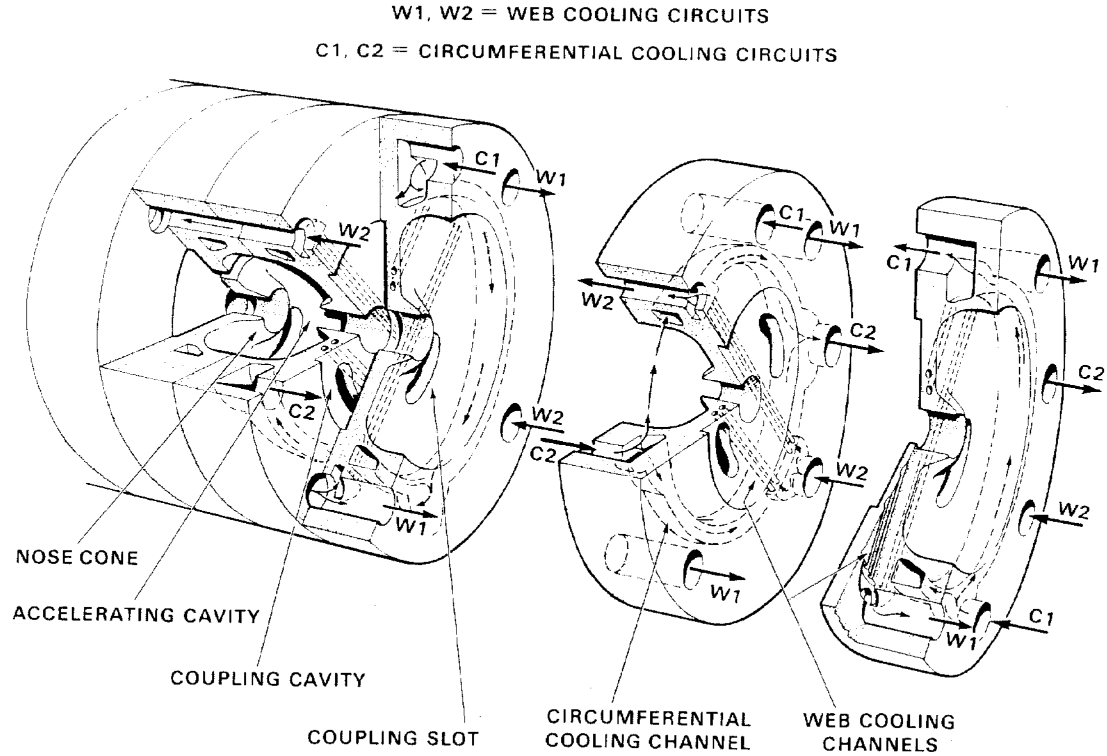

Fig. 2 Cooling channels for the on-axis coupled cavities.

Four independent cooling circuits, two for the webs and two for the circumference of the cavities, minimize temperature gradients in the structure. Each circuit cools alternate cavity segments. Circuits are in counterflow, reducing temperature differences between the inlets and outlets. The web thickness is 6.19 mm and coolant channels in each web consist of four 3 mm diameter holes drilled across the web between the coupling slots and the nose cones.

Coolant velocity is restricted to 3 m/s to prevent erosion. The circumferential coolant flow per circuit is limited to 0.45 L/s with a pressure drop of 25 kPa. Webs are cooled in parallel and limiting coolant velocity is reached with a pressure drop across one cavity segment of 28 kPa and a coolant flow of 0.08 L/s per web. The total coolant flow rate through the structure is 1.38 L/s.

Thermal Stress Analysis

The behaviour of linac structures under power has been modeled with the finite element computer code MARC[8]. Approximately 40% of the rf power is deposited at the web surface in on-axis coupled accelerating cavities. Thermal stresses are largest in the nose cones and are directly proportional to the temperature gradient between the nose cone and the outer wall of the cavity. Temperature gradients increase linearly with power and permanent deformation of cavities can occur if thermal stresses exceed the material yield strength, resulting in a change of the low power resonant frequency. After initial deformation, thermal stresses can be increased by approximately a factor of two above the yield strength without causing further deformation of cavities[9].

On-axis coupled structures are characterized by a stopband frequency gap approximately given by the difference between the average accelerating and coupling cavity frequencies. Non-uniform temperature distributions result in different expansions of the accelerating and coupling cavities, and changes in the stopband frequency gap can be observed[8].

Figure 3 shows results of calculations with MARC to optimize the heat transfer from the high power structure to the cooling water. Circumferential and web coolant flow rates were varied in the simulations, to study changes in the stopband frequency gap and overall frequency shifts. Increases in the circumferential flow rate reduce the frequency shift but are ineffective at reducing the temperature gradient between the nose cone and the cavity outer wall and the resulting change in stopband frequency gap.

For circumferential and web coolant flows of 0.43 and 0.08 L/s respectively, minimum changes in the stopband frequency gap are obtained, the coolant velocity is within the limit of 3 m/s and frequency shifts from cold to 200 kW/m are in the range of the tuner. The calculated temperature gradient between the nose cone and outer wall is 0.3°C/kW/m, resulting in a maximum thermal stress of 0.6 MPa/kW/m in the

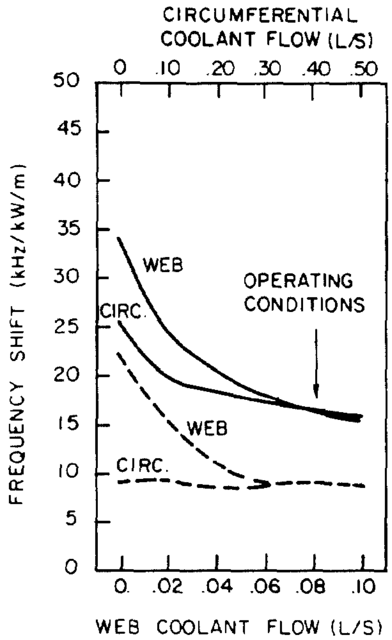

Fig. 3 Calculated frequency shifts (continuous curves) and change in stopband frequency gap (dashed curves) as function of circumferential and web coolant flow rates. Results are shown for fixed web coolant flow of 0.08 L/s (identified by CIRC.) and for fixed circumferential flow rate of 0.43 L/s (identified by WEB).

Table 1

Results from Thermal Stress Analysis

Circumferential Coolant Flow:	0.43 L/s per circuit
Web Coolant Flow:	0.24 L/s per circuit
Temperature Increments	
Circumferential Cooling Water:	0.031°C/kW/m per circuit
Web Cooling Water:	0.037°C/kw/m per circuit
Average Cavity Surface:	0.38°C/kw/m
Nose Cone Surface:	0.53°C/kW/m
Frequency Shift:	16.25 kHz/kW/m
Change in Stopband Frequency Gap:	8.88 kHz/kW/m

cavity nose cones. The yield strength of annealed OFHC copper is 69 MPa for 0.5% extension[10]. After bringing the structure up to a power level of 115 kW/m, the deformation of the nose cones will decrease the low power resonant frequency by approximately 1.5 MHz. Power levels of 200 kW/m can afterwards be achieved without further deformation of the nose cones.

Table 1 gives a summary of the thermal stress analysis of the structure. Changes in the surface resistivity of the cavities with temperature reduce the structure shunt impedance by 0.05%/kW/m and average energy gradients of 3.5 MeV/m will require 200 kW/m of rf power.

Summary

A 2450 MHz on-axis coupled structure has been constructed as a prototype for a high power electron linac. Results from finite element computer modeling of thermal stresses indicate that the structure is capable of dissipating up to 200 kW/m of rf power. Preparations are under way to drive the structure at the University of Mainz with a TH2075 50 kW klystron. The prototype structure will be used to measure changes in the rf parameters during high power operation.

Acknowledgments

Contributions to the design and fabrication of the high power structure were made by S. Gowans, H. Euteneuer (University of Mainz), R.J. Kelly and J.E. Anderchek. Their participation is gratefully acknowledged.

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