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A 12.5 MHz HEAVY ION LINAC FOR ION BEAM FUSION*

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Introduction

Argonne National Laboratory (ANL) is currently developing the injector of a heavy ion beam driver for the inertial confinement fusion program. The first phase of the program is to accelerate about 20 mA of Xe^{+1} from a 1.5 MV preaccelerator to 11.4 MeV in a low-beta RF linac. The first section of the linac utilizes a single harmonic buncher and independently-phased short linac resonators with a FODO magnetic quadrupole focusing lattice. These are followed by two double-stub Wideröe linacs. A layout of the linac up to 6.4 MeV is shown in Fig. 1. The operating parameters of the low-beta linac are given in Table I. This paper gives details of the low-beta linac design and results of low power measurements on the first accelerating cavity.

Buncher and Short Linac Resonator Design

Beam capture is optimized by using a buncher immediately after the 1.5 MV preaccelerator. The buncher cavity is the single drift tube lumped inductor resonator shown in Fig. 2. The outside shell of the resonator is made of 5083 aluminum and has been coated with about 70 Å of titanium in order to prevent multipactoring. The inside coil (inductor) shown in Fig. 3, the end plates, and outside housing of the drift tube are made of copper. The buncher is separated from the first accelerating cavity by a space of 3 m containing a quadrupole triplet and beam diagnostics.

A model of the lumped inductor resonator was made of 3.2 mm thick 6061 aluminum sheet and seam welded together to form a cylinder 0.76 m in height and 0.69 m ID. The inner conductor was made of copper pipe and wound into a 0.51 m diameter coil of 2-1/3 turns with 0.18 m between turns. The coil was shorted to an aluminum end plate through a 0.28 m copper support stub. The open end was connected to a drift tube by a large rectangular coaxial transmission line of characteristic impedance 14.5 Ω. The model, designed to resonate at 12.5 MHz, had a measured resonant frequency of 11.8 MHz and gap impedance of 280 kΩ. Only about 1.8 kW of RF power will be required to reach the buncher voltage of 23 kV peak per gap.

The first accelerating cavity of the linac is the lumped capacitor single drift tube resonator shown schematically in Fig. 1. The outside shell of the resonator is made of copper plate and seam welded together to form a cylinder 0.648 m in diameter and 1.93 m in length as shown in Fig. 4. The inner conductor, capacitor plate, drift tube, and drift tube outside housing are made of copper.

To calculate its resonant frequency, the cavity was modeled as a capacitively loaded transmission line with the fringing capacitance of the large end plate also taken into consideration.[1] The bottom part of the cavity which contains the drift tube is rectangular and was modeled as a rectangular transmission line.[2] Since the accuracy of the calculations was at best about 1%, we expected the cavity to require shimming to reach design frequency.

The cavity is now on station in front of the preaccelerator undergoing low power testing. Shortly it will be put under vacuum and high power testing with beam will commence. The cavity has been tuned to the design frequency of 12.500 MHz by adding a 0.409 cm copper ring to the bottom end plate flange in order to decrease the end plate capacitance; it had a measured Q_o of 5500 and a gap impedance of 525 kΩ. Therefore, only 9.52 kW of power will be required to reach the design of 100 kV peak of the gap. Since 25 kW of RF power is available, studies will be undertaken to determine the voltage breakdown limit with beam.

The next two cavities (shown schematically in Fig. 1) are the short multidrift tube "drum" loaded resonators. They operate in the $5\pi/\pi$ mode with one internal quadrupole per cavity. The previously mentioned transmission line model and Superfish[3,4] have been used to determine the dimensions and operating parameters of the resonator. Currently the cavities are being fabricated in ANL shops. The outside shell of the cavities is to be electron beam welded copper plate; the end flanges and ports are to be brazed to the shell.

Double-Stub Wideröe Design

The double-stub Wideröe linac is shown schematically in Fig. 1, as the last two tanks on the right. The tanks were designed using a Wideröe linac code developed at the Lawrence Berkeley Laboratory[5] in collaboration with GSI.[6] The program is interactive and iterative. By varying the position and length of the stubs, the input/output energy, and line loading, we find a consistent solution for frequency, drift tube table, energy gain per cell and gap voltages. The program also contains a plotting routine for the voltage on the gaps and the current along the linac.

In order to control space charge forces and achieve maximum beam transport it is necessary to be able to control the voltage tilt along the linac. Figure 5 shows a plot of gap voltage along the linac for three different stub length settings. The proper voltage tilt can be set by varying the stub lengths without the need for tuning balls or precise model measurements. The double-stub Wideröe is superior in this regard to the single-stub Wideröe, which was previously under investigation. The single-stub has a fixed voltage tilt with no means of adjustment without the addition of tuning balls. This deficiency is felt to outweigh the single-stub design advantages of being shorter and easier to align and in having a very linear voltage distribution.

Conclusion

The buncher cavity is now undergoing assembly on station in front of the preaccelerator. The capacitively loaded resonator is on station in preparation for high power testing with beam. The "drum" resonators are currently being fabricated. RF amplifiers, rated at 25 kW pulsed for 2 ms, to drive the above cavities, are scheduled to be delivered shortly. The amplifiers were purchased from an industrial firm to our

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specifications. They utilize push pull 4CX5000A tetrodes as the final stage.

A design of a double-stub 5π/π Wideröe linac using a FODO quadrupole focussing lattice has been completed. This linac increases the ion energy from 2 MeV to 6.4 MeV. The design of the second double-stub Wideröe operating in the 3π/π mode with FODO focussing has also been completed. It increases the ion energy from 6.4 to 11.4 MeV. In order to increase shunt impedance and reduce cost, a 3π/π double-stub Wideröe linac for Tank #4 operating with a FOFODODO focussing lattice is currently under study.

Acknowledgement

We wish to express our appreciation to R. Lari for adapting and operating the Superfish program at ANL, R. Rivetna for adapting the Wideröe program, also W. Hesse for his work on the programs, N. Sesol for setting up the RF testing system and M. Rebuehr for assembly of the cavity.

References

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TABLE I

Low Beta Linac Parameters

Tank / Parameter	#1 Cap Loaded Resonator	#2 Drum Loaded Resonator	#3 Drum Loaded Resonator	#4 Double Stub Resonator	#5 Double Stub Resonator
Mode	*	5π/π	5π/π	5π/π	3π/π
Number Gaps	2	4	4	26	26
Peak Voltage on First Gap (kV)	100	112	112	220	221
Peak Voltage on Last Gap (kV)	100	112	112	280	314
First Gap Width (cm)	1.2	1.5	1.5	3.1	5.6
Last Gap Width (cm)	1.2	1.5	1.5	5.6	7.4
First Cell Length (cm)	*	38.0	40.8	43.5	49.8
Last Cell Length (cm)	*	39.6	42.3	73.6	65.7
Entrance Energy (MeV)	1.500	1.625	1.881	2.145	6.448
Exit Energy (MeV)	1.625	1.881	2.145	6.448	11.477
Excitation Power (kW)	10	14	14	98	119
Shunt Impedance (MΩ/m)	7.4	22.6	21.5	27.9	29.3

*does not apply.

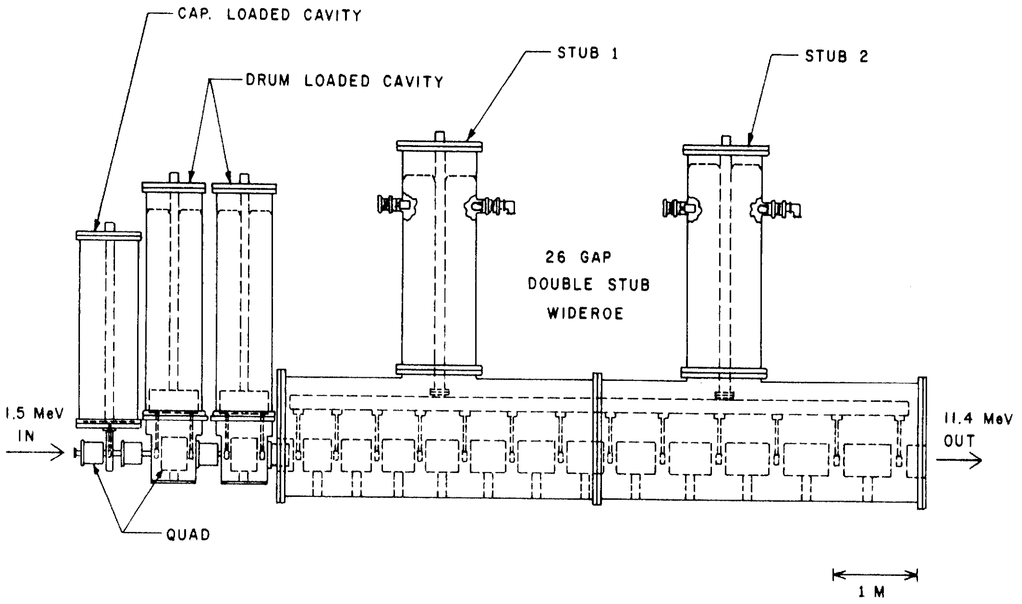

Fig. 1 12.5 MHz Low Beta Linac.

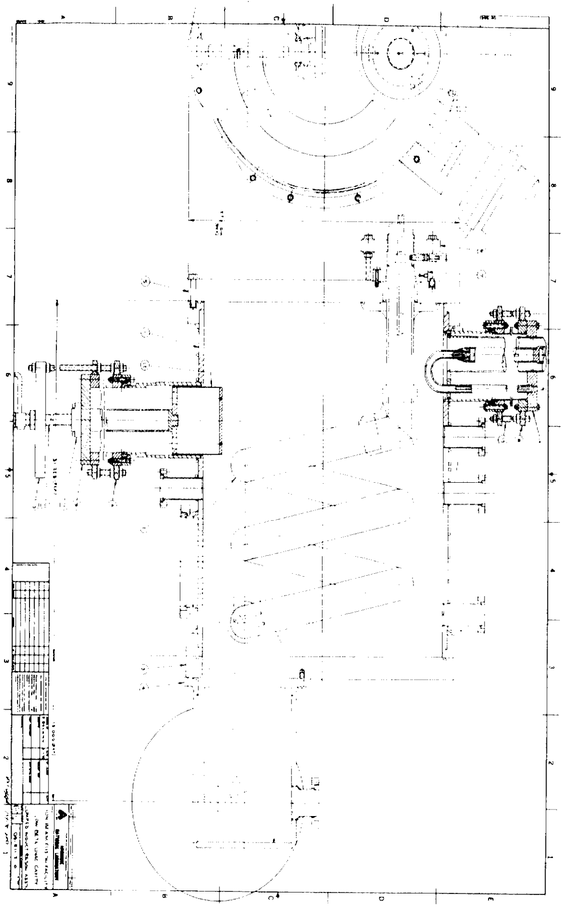

Fig. 2 Lumped Inductor Single Drift Tube Resonator.

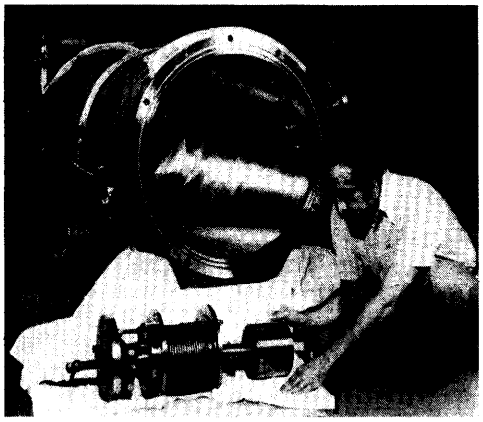

Fig. 4 Outside Shell and Tuning Ball for the Lumped Capacitor Single Drift Tube Resonator.

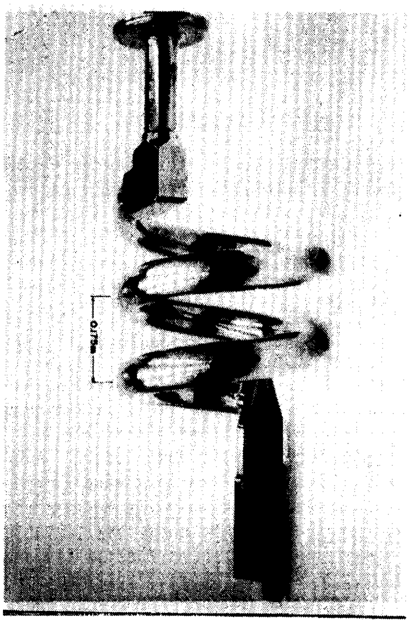

Fig. 3 Inside Coil of Lumped Inductor Resonator.

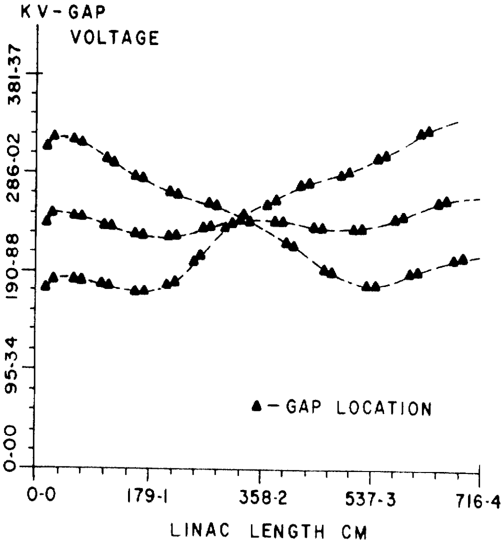

Fig. 5 Voltage Along Double-Stub Wideröe Linac for Three Different Stub Length Settings.