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Abstract

The Hanford Fusion Materials Irradiation Test (FMIT) 35-MeV linac is intended to produce neutrons for materials studies. Its operation will be virtually continuous for at least 20 years. Such operation implies that the accelerator design must be conservative to avoid excessive downtime and that the accelerator be economical of power. The initial design of the linac drift-tube section was preceded by more than 800 SUPERFISH computer runs. SUPERFISH allows the selection of a geometry for the FMIT machine that has very nearly the maximum value of ZT^2 consistent with Kilpatrick's criterion. This maximum value insures that power costs will be as low as possible while keeping the maximum surface fields at a level conservative enough to prevent sparking. The optimization procedure is examined to show how the best geometry is achieved. The drift-tube section will operate at 80 MHz with an average 1.4 MV/m gradient. As presently conceived, it will consist of two tanks, one 248 cm in diameter and about 18.-m long and the other 240 cm in diameter and about 14.-m long. The number of drift-tubes will be 73 if a stable phase of -30° is chosen.

Introduction

The FMIT accelerator is a deuteron linac to be built at the Hanford Engineering Development Laboratory (HEDL). The deuteron beam will be used to irradiate a lithium target to produce neutrons for materials testing. The accelerator is being designed at Los Alamos Scientific Laboratory (LASL) by a team of LASL and HEDL people.

As presently conceived, the machine will operate at 80 MHz with an average 1.4-MV/m gradient and produce a continuous 100-mA deuteron beam. Because the accelerator is to be an engineering test facility, it will be designed to run cw. High reliability is essential because a 20-year operational life is specified.

The drift-tube section will start at 2 MeV and extend to 35 MeV with two tanks, the break between the tanks occurring at about 20 MeV.

There are a number of specific problems that arise with the FMIT linac. The high average current and the deuteron beam require extremely low beam spill to avoid structure activation. This argues for the use of as large a bore in the drift-tubes as is feasible. Continuous long term operation in an era of sharply rising energy costs makes optimization for minimum power consumption a necessity. Resistive power consumption can be minimized by maximizing the product ZT^2 , where Z is the shunt impedance per meter and T is the transit time factor.

The tank power supply must consist of some integral number N of rf power amplifiers each of maximum power output P_{U1} . The total power to the tank consists of the beam power, P_b , plus the cavity power P_c . The cavity power is $P_c = \Delta W^2 / ZT^2 \cdot L$ where ΔW is the particle energy increase in passing through the tank. Because the beam power is fixed, this relation can be used to find critical values of ZT^2 . These ZT^2 values are those at which the power consumption of the cavity increases enough to force the addition of another power amplifier to the system supplying the tank. In the present case, the pertinent critical value for each tank is $ZT^2 = 31.4 \text{ M}\Omega/\text{m}$. This number is the theoretical value that the design must reach; it includes allowances for deratings and the transition from theory to reality.

The design must be conservative with respect to the maximum surface electric fields allowed. Serious sparking problems would not be consistent with the high duty factor required of the FMIT linac. In this respect, Kilpatrick's criterion provides a conservative value for E_{max} .¹ With present vacuum technology, this criterion may be overconservative. For the FMIT linac Kilpatrick gives a value of $E_{\text{max}} = 10.5 \text{ MV/m}$.

The usual problem of stuffing too much quad into too little drift tube is also present at the front end.

These considerations dictate the following goals in the optimization procedure for the drift-tube portion of the HEDL FMIT linac.

- A ZT^2 product as high as possible in each cell and an average value not less than $31.4 \text{ M}\Omega/\text{m}$ (theoretical).
- $E_{\text{max}} \leq 10.5 \text{ MV/m}$ in each cell.
- A bore size as large as feasible, consistent with acceptable values of ZT^2 and required quadrupole strength.
- Drift-tube diameter chosen for high ZT^2 , sufficient quadrupole space, and $E \leq E_{\text{max}}$.
- A relatively uniform input power distribution along the tanks is of secondary importance, but desirable.

Optimization Procedure

The rf cavity code SUPERFISH provides an excellent tool to carry out the optimization.² SUPERFISH can calculate the properties of single cells of a proposed design so different designs can be compared. By surveying cells at different energies, it is possible to form a picture of the properties of an entire drift-tube linac. The code also accepts slanted faces on drift tubes and such geometries appear to be an excellent way to increase the value of the transit time factor T and possibly to reduce multipactoring.

*Work performed under the auspices of the U.S. Department of Energy.

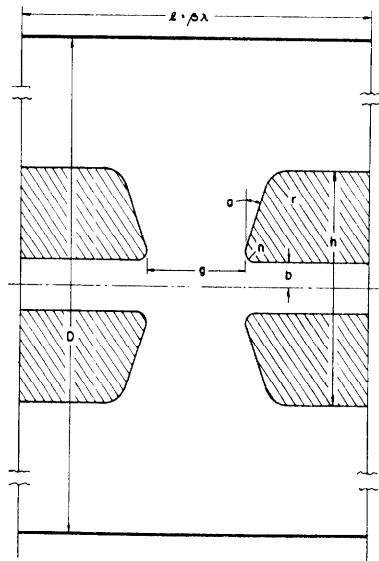
SUPERFISH can also provide the information necessary for beam dynamics codes such as PARMILA.

As an initial step SUPERFISH was used to carry out an extensive parameter study of the possible geometries at a single energy, 20 MeV. Parameters varied were the tank diameter D , the drift-tube diameter h , the outside corner radius of the drift-tube r , and the face angle of the drift-tube a . Variables held constant were the nose radius n and the bore radius b . The gap length g was used to tune the cavity to 80 MHz. These parameters are shown in Fig. 1.

This study showed the existence of maxima in the product ZT^2 as a function of the tank diameter D . Figure 2 shows sample plots of ZT^2 vs length for sets of a and D values with h, r, n and b fixed.

As expected, the maxima are higher with increasing face angle. The product ZT^2 is also larger with larger corner radii and it increases with decreasing drift-tube diameter.

Also shown in Fig. 2 is the approximate position of Kilpatrick's limit. This value is only approximate because the maximum surface field varies with the face angle a and the tank diameter D . Varying the face angle appears to shift the surface on which the maximum occurs. For $a = 0^\circ$ the maximum field occurs on the outer corner of the drift-tube. As the angle is increased, the position of the maximum field shifts down the face to the nose. At the same time, the magnitude of the maximum first decreases then increases as the maximum shifts from the corner to the nose. The minimum of the maximum field occurs at a face angle of about 3° .



SUPERFISH CELL NOMENCLATURE



Figure 1. Labeling of SUPERFISH parameters.

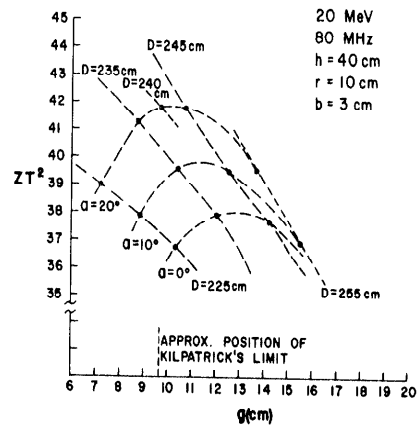


Fig. 2. Maxima of ZT^2 as functions of D . The approximate position of Kilpatrick's limit is shown. To the right of the line indicated, the maximum surface electric field is less than 10.5 MV/m.

After completing the parameter study at 20 MeV, less elaborate studies were made at 2 MeV, 5 MeV, 11 MeV, 27.5 MeV and 35 MeV. These studies showed that the tank diameter at which the maximum of ZT^2 occurred varied with energy. At the 2-MeV end of the machine, the maximum ZT^2 occurred at a tank diameter of about 248 cm. At 11 MeV, the physical center of the first tank, the maximum was at about 243 cm while at 20 MeV a diameter of 241 cm was best. At 35 MeV, the optimum diameter had dropped to about 237 cm.

These surveys also showed that it is not possible to keep ZT^2 above 31.4 MΩ/m in all the cells at the low energy end of the machine while at the same time keeping below Kilpatrick's limit. However, because the cells past 5 MeV all have ZT^2 values above 31.4 MΩ/m, a satisfactory average value of ZT^2 can be reached. The present design should have an average ZT^2 for the first tank of more than 37 MΩ/m and the second tank should average about 38 MΩ/m.

A compromise 240 cm tank diameter appears the best choice for the 20- to 35- MeV tank. With this value, the ZT^2 product has a maximum near 22 MeV and falls off by less than 4% at the high energy end of the tank. This choice coupled with a bore radius of 4 cm and a drift-tube diameter of 38 cm, allows the use of 15° face angles throughout the tank without exceeding Kilpatrick's limit. It is possible that slightly smaller drift-tubes could be used but the 38 cm choice allows greater freedom in the design of the quadrupole magnets.

In the 2- to 20- MeV tank the choice of a single face angle for the drift-tubes is ruled out because the power costs are too high. The front end drift-tubes are forced to have small face angles because of space limitations. The very low (4°) angles at the front end result in cell ZT^2 products of about 24 MΩ/m. If the low angles were used throughout the tank, a severe power penalty would result and another rf amplifier would have to be added. The present design uses sets of

increasing face angles reaching 15° at about 13 MeV. At this point the cell ZT^2 product equals 42.75 M Ω /m.

The drift-tube diameters will be as small as can accommodate the quadrupoles. At this time, it appears that the front end tubes will be 42 cm in diameter with a bore radius of 2.5 cm. At about 5 MeV, the outer diameter will decrease to 38 cm, provided a quadrupole with the necessary strength can be fitted into this diameter. At the same position, the bore radius increases to 3 cm.

We are now studying the beam dynamics of the FMIT linac. We are examining the influence of space charge on the beam with PARMILA runs using SUPERFISH generated input data. The best focusing for minimum beam spill may require stronger quadrupoles than those considered up to this point. This could change the present design by requiring larger diameter drift tubes. The feasibility of fixed length, fixed strength quads in several groups is being investigated because a simpler overall system would result. The dynamics work also shows that a -40° synchronous phase angle at 2 MeV, tapering to -30° at about 8 MeV, may be advantageous in matching to the input from the rf quadrupole structure and for controlling beam spill.³ If the stable phase is increased, there would be an increase in the number of drift tubes and in the length of the drift-tube section of the machine.

In any event, the investigation of the geometry using SUPERFISH will enable the resulting

design to be as energy efficient as possible under the constraints.

Summary

The rf cavity code SUPERFISH has been used to investigate the relation between the geometry and the product ZT^2 for the FMIT linac. The information so obtained will allow the design of a machine that attains very nearly the maximum average value of ZT^2 consistent with holding the maximum electric surface field below 10.5 MV/m. The final choice of the design parameters will depend on beam dynamics calculations and on the design of the quadrupole magnets. A final iteration using SUPERFISH will produce a machine of minimal power consumption.

References

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