A Proposal for Varying the Frequency of a Fixed-Frequency Cyclotron

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At MIT there was some thought that it would be nice to be able to vary the radiofrequency of the cyclotron. I have been familiar with some materials which have recently become generally available and which I thought might make this feasible. This is only by way of a note, not a formal presentation.

The question was: If you wanted to take an existing cyclotron and make it a variable-energy cyclotron, what could you do without drastically altering the existing r-f system? For one thing, I guess you would not normally want to raise the frequency very much, because you are probably already running into bad saturation of the magnet. You want to lower the frequency, and moving a node forward, toward the dees, isn't going to help you unless you go to harmonic operation. The other thing about nodes, from what I have heard here, is that the current density is so high that the contact surfaces give a lot of trouble.

My thought was that it would be better to use a displacement current than a real current. The dee-line is a transmission line driving the dee. It is short circuited at the node and loaded capacitively by the dee at the other end. Since a cyclotron operates in the pi-mode, with the dee voltages in phase opposition, the effective loading capacitance for one line is the capacitance between the dee and ground plus twice the capacitance between the dees. Now the voltage distribution on this line is just the beginning of a sine wave owing to the heavy capacitive loading. If a perturbing dielectric solid is put in the line and moved along it, then it moves in a region of ever increasing electric field and increases the local capacitance, if you wish, and in general lowers the frequency.

The dielectric that is favorable for this is titanium dioxide in a crystalline form called rutile. According to the first book I looked into, the loss tangent for this stuff is only about twice that of fused quartz, which seems very favorable, and its dielectric constant is 90.

We talked to a man who fabricates the stuff, and the difficulty seems to be getting a big piece of it fabricated, but it does not seem to be impossible. It is probably impossible to get a big piece sintered, but it is not necessarily impossible to put together what you need out of a lot of little pieces. Rutile, even in a big melt, should have a breakdown field, this man told us, of the order of 200,000 volts/in.; one would have no great difficulty with dielectric breakdown. He estimated that it would cost $30 per cubic inch, which is rather expensive. Certainly there would be a lot of problems involved in sticking this into an existing cyclotron where, in fact, you have a coaxial line and, somewhere along the line, some coupling, inductive or otherwise, to the oscillator. If you want to try to slide a hunk of this stuff along the line, you are going to run into coupling devices, and that is a problem that has to be solved for each individual cyclotron.

I made a calculation with a reasonable sized piece of rutile to determine what kind of frequency variation could be expected just by moving the piece from the node to the dee. For this calculation I regarded the resonant system as the transmission line loaded in one place by a material with a dielectric constant of 100, so that the

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characteristic impedance of this section is down by a factor of 10 and its propagation constant is up by a factor of 10. For a length of 5.5 ft., which is the length of the dee-line of the MIT cyclotron, and for a width of the rutile piece of 1 ft., you can get a high-low frequency ratio of 2, which seemed to be a reasonable thing to undertake.

What has me most discouraged right now is not the fields in the dielectric, but when this thing is slipped up toward the dee, the field at the inner conductor will be fierce. I expect a lot of trouble there, field emission and all sorts of difficulties.