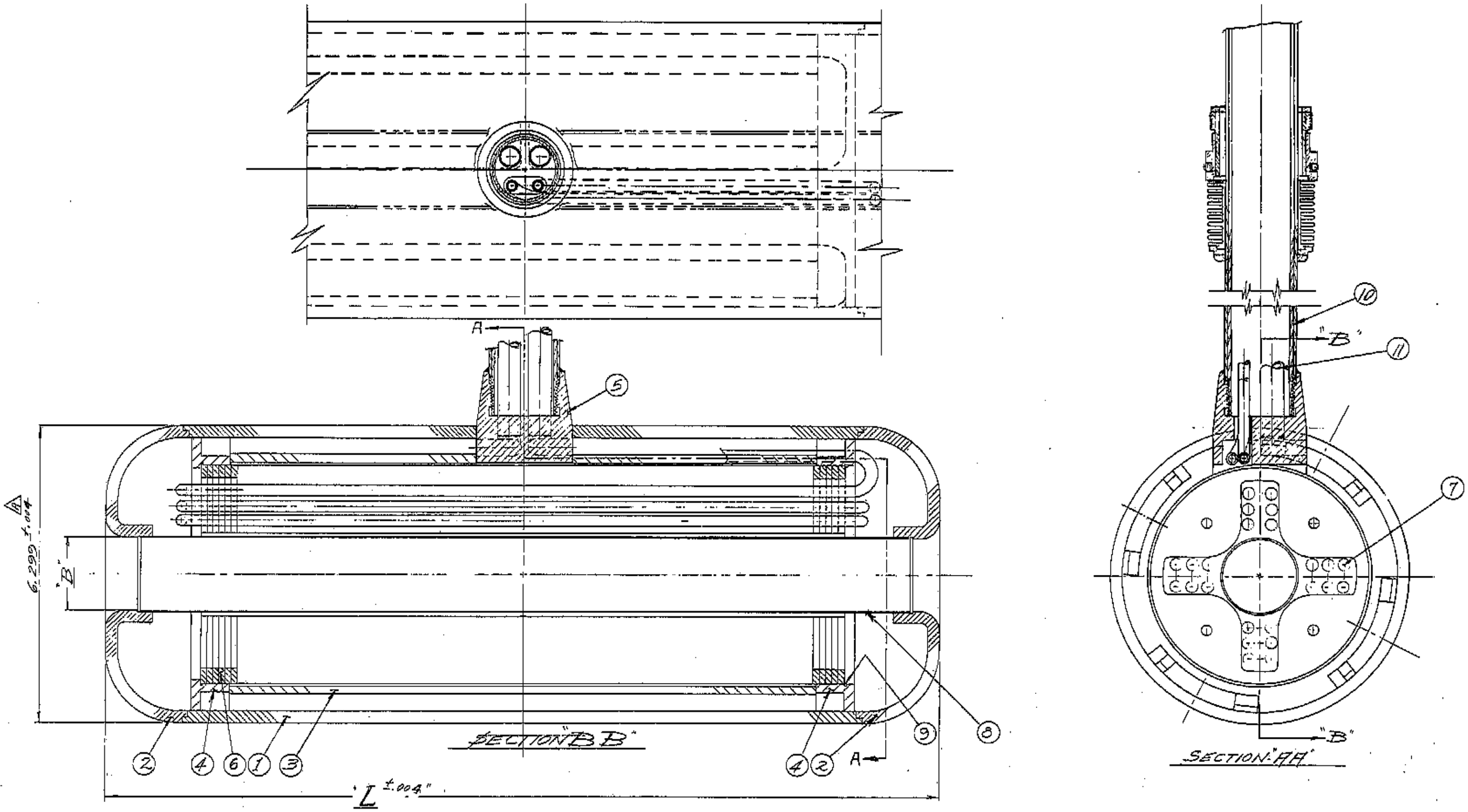

FIG 2 200 MeV DRIFT TUBE

methods of construction that could be used for drift tube stems. The stem in Fig. 2 is of stainless steel clad with copper. An alternate method of construction suggested by Grand would be to use solid copper rod and gun-drill the necessary holes for cooling and power leads. Another possibility would be to have a stainless steel tube surrounded by a still larger copper tube, the stainless steel tube furnishing the mechanical rigidity. All these methods are being considered by the major laboratories.

YOUNG: Can you describe the cooling used in the drift tube?

O'MEARA: Figure 2 shows two water tubes in the stem. These tubes are joined to a block at the drift tube. Water is distributed from this block to a liner cylinder on the inside of the drift tube body. This liner, along with the end caps, provides a labyrinth passage for the water. In connection with adjustment and alignment, we have three translational adjustments but only one rotary. We would like to have all six degrees of freedom. Brunk of Argonne National Laboratory is working on a design for such an alignment plate where each motion is completely decoupled from all other motions.

DICKSON: Do you feel that it is necessary to have some adjustment of the position of the quadrupole within the drift tube?

O'MEARA: It is our intention to locate the quadrupole in its proper position during assembly and hold it in that location. After the drift tube is completely sealed, our only reference to the position of the quadrupole is the body and bore of the drift tube.

Someone raised a question about rf joints. There was general agreement that a number of designs work well for static seals. Los Alamos representatives encountered difficulty with spring rings in adjustable rf seals. They also reported that they were able to overcome this problem by using a relatively coarsely pitched large diameter helix which had long travel without permanent set.

WHEELER: Have you given up the thought of evacuating the inside of the drift tube?

O'MEARA: No, we feel that we should be able to do this. In the Brookhaven-Argonne design, a roughing box provides a means of pulling rough vacuum in the interior of the stem and the cavity of the drift tube. In order to provide the same capability for the tank design in Fig. 1, two enclosures would be utilized on each stem.

(There was discussion questioning the necessity of providing this rough vacuum.)

Guilbaud of CSF described a copper electroforming process* that had been used for their 18-inch diameter by 1-inch wall waveguide. They are able to buy this at 50¢ per pound, which is less than we pay for copper sheet in the U.S.

HENDRICKS: What are the largest dimensions that they can fabricate?

O'MEARA: We understand that one meter in diameter by 8 meters in length is possible. This process could be an alternate means of fabricating tanks.

HENDRICKS: Can they form the water channels in the copper itself?

O'MEARA: Yes, the process is to plate on top of a wax-coated steel mandril. After the plating is completed, they are able to melt the wax and recover the mandril. Half-way through this process they stop and machine a number of cooling passages which are filled with wax. Resumption of the plating process results in a buried cooling channel.

GRAND: We would like to design a tank for better operation and make it less costly. My idea is to make an all-steel tank, machine and completely assemble it, and then copper-plate the interior. Some people do not agree with this idea, but I would like to pursue it and possibly build a short section.

O'MEARA: The German electroforming process was described after Pierre's suggestion was made. The electroformed copper has been reported to have high conductivity and high Q devices have been made using it. I think the earlier experience has shown that copper plating was porous, gassy, and had fairly high resistivity.

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*Elmore's Metal Aktiengesellschaft, Schaladern/Sieg, West Germany.

SUMMARY OF EVENING SESSION ON BEAM LOADING EFFECTS

J. Leiss
National Bureau of Standards

On Wednesday evening a group gathered at the Ivy Inn to discuss informally beam loading effects in linacs. I am not sure anything was concluded at this session, but I can report that we did have a spirited discussion.

Beam loading in electron linacs is extremely important. There exist several machines that have reached large conversion values from the rf power in the wave guide to the beam (as high as 60 to 70%). There are many things that have been calculated and observed in the electron linacs. In proton linacs these beam loading effects have only recently become popular. In the proton linac beam loading effects are both more difficult to calculate and more important to understand. Rather than try to summarize what was discussed at this session, I would prefer to list various things that have a relation to beam loading. I personally believe that for the proton machines now being studied, many of these effects have not been studied to the extent that is really required.

1. Detuning

If you are running a tank as a self-resonant cavity and a beam passes through, does the cavity resonant frequency change or not? From the standpoint of doing a mathematical analysis of beam loading, this is an extremely important question because if detuning occurs, the problem becomes nonlinear and the analysis is extremely complicated. I believe that for the currents that are being considered, the detuning effect is not a serious problem and it can be ignored.

2. Transient Effect

There is a fairly clear indication, as indicated in some of the papers presented on Wednesday, that transient effects really do need to be considered in beam loading. The transient beam loading effect from the turn-on time, for a square wave beam, will occur for the same amount of time as the rf filling time of the tanks and this is an appreciable time. The data presented by Jameson[1] showed wiggles and oscillations in the rf transmission for amplitude step changes. Beam loading causes similar effects although their appearance will be different because in beam loading the source is spread throughout the tank. The time delay for transient beam loading to be complete will be very important in designing phase and amplitude regulating systems to correct for beam loading effects.

3. Subharmonic Effects

Subharmonic effects were mentioned by Gluckstern[2] in the discussion on the resonant excitation of beam blow-up modes. There is additionally an effect in the fundamental mode. We have analyzed the subharmonic beam loading in electron linacs and for the particular case of our accelerating guide find, for injection of beam at the third to the fifth subharmonics, incorrect estimates of the magnitude of beam loading in the fundamental mode by as much as 15%. When this is done for the resonant cavity case, similar numbers will probably be obtained.

4. Tank Flatness

When a tank is flattened by making small tuning or local group velocity changes, one is partially compensating for a nondistributed excitation of the tank. However the beam loading is distributed by beam bunches moving at just the right speed, and there is reason to believe that the tanks would become nonflat. In particular, if you tune for one particular phase velocity which corresponds to the proton's velocity in the middle of the tank, the velocity of the source is too slow in one direction and a little too fast in the other direction. This will result in a tilt to the field in the tank. These effects can be evaluated by a detailed analysis.

5. Phase Shift Effects

For a proton linac one operates at a nonzero phase relative to the rf in the wave guide, say at 30° from the peak. The beam loading wave is just opposite to this, that is at 180° out of phase with the beam. Relative to the initial rf in the guide one can consider a component in phase with this normal unloaded cavity field, and a component 90° out of phase with the normal cavity field. The resultant field in the cavity will therefore be phase shifted. This will be changing during the transient period. For the beam currents now being considered, the phase shift will amount to 4 to 6 degrees in the total field and corrective measures will have to be taken. This is not a detuning effect. The beam loading would be the same if we had no external rf to use as a reference.

6. Beam Blow-Up (resonant and nonresonant)

We can say very little at this time about this phenomena. The first mixed mode that is experienced in most of the disc loaded guides for electron linacs occurs approximately one and one-half times the frequency of the fundamental mode. The backward wave oscillator is for the excitation of this mode and is classified by Gluckstern[2] as the non-resonant effect. The resonant effect predicted for subharmonic injection is really the same thing and will undergo the same backward wave oscillator characteristic. The difference is that the coupling of the beam to this mode, due to the time dependent parts, is going to be greater for injection of beam at even subharmonics of the fundamental rf frequency because the beam pulse train just happens to have a high frequency component at this mode. If the structures that are chosen turn out to have this first mixed mode at approximately one and one-half times the fundamental frequency, there should be a worry about enhanced excitation of this deflecting mode. More calculations are needed, and experiments should be done on operating electron linacs by putting a first subharmonic buncher in front to see if a big beam blow-up occurs.

7. Space Harmonics

This topic considers beam excitation of the various possible modes in the pass band at the same frequency. These are generally considered to be sufficiently incoherent with the beam so that one does not have to worry about them. That is, they oscillate past the beam so fast that they have an average zero effect. We have done calculations which indicate that in the π mode (or more correctly, modes with zero group velocity) the cancellation of the effects of these spatial modes does not exist for beam excited rf waves and in fact these modes stay coherent with the beam as a steady-state affair. This is because the beam occurs as a series of discrete pulses and not a true sine wave as most theories assume. This can cause additional beam loading.

8. Beam Loading Limits

Techniques for the design of wave guides to reduce beam blow-up phenomena at any desired current are reasonably well known so that this need not be a limit unless the guide is already built. Other limits are economic, that is, how big to make the power supply or how large to make the tank. One will eventually reach a limit determined by true detuning of the tank.

9. Reaction Back on the Source

In traveling wave electron linacs the power from the klystron is sent down the wave guide to a terminating load and there is no reaction back on the power supply. The coupling is one way, just as if an isolator were present. In proton linacs the coupling between the resonant tanks and the driver is tight. If the fields change due to beam loading, there will be a reaction back on the source. Beam loading calculations will have to include the interaction with the driving source.

MILLS: I would like to make several comments about beam-loading effects and instabilities. At the evening session, Leiss suggested a clever model for these effects. This was to treat the problem by simulating the electron beam by a dielectric rod. It may be possible to use this simple model to help anticipate the problems to be encountered in proton linacs. Since the beams are moving with high velocity, the "dielectric susceptibility" to be used differs by a factor of γ^2 between transverse and axial directions. Thus the fields excited by a given beam current would be expected to disturb primarily the transverse motion in an electron linac, as is the case so far. In these proton linacs, however, the value of γ is near unity, so fields excited by the same beam current may be expected to disturb the axial motion as well as the transverse motion. Then the studies made to date of "beam blowup" in electron linacs will be a guide to related phenomena in proton linacs but will probably not be the whole story.

The second comment concerns the relationship between instabilities presently observed in circular accelerators and those to be expected to occur in linacs. We see currently two instabilities, one in the direction of beam motion and one in a direction transverse to the beam motion, which are due to the phase shift of the beam-induced fields at the resistive walls of the "wave guide." Certainly we must expect to see similar phenomena in linear accelerators. It would certainly give us a good feeling to understand the relation between "beam blowup" and these instabilities.

LEISS: The dielectric rod may be a good way to help understand the difference between proton and electron linacs. On the second point, I believe we must be very careful in trying to extend results from circular to linear machines, since the same particle traverses a given locality many times in the circular machine. Further, the momentum compaction of circular accelerators can allow greater phase changes for a given field excitation than will occur in a linear machine.

GRAND: You mentioned that the major difference between the electron and proton machines is the running vs. standing wave. Other differences which may possibly be important are the separate couplings and the relatively long drift tubes. The beam fields might not have any effect around the coupling holes.

LEISS: It seems to me that you may reduce the group velocity by this means and thereby reduce the loading effects. On the other hand, this can be inferred immediately from the dispersion diagram.

GRAND: Another difference is that in the proton case, energy is being taken out during only a short phase interval, while in the electron case, the effect is spread out over the whole wave.

LEISS: I believe that questions like this can be handled only by detailed calculations. Keith Symon has told me of calculations they are making in which the real fields induced by a beam are allowed to modify the beam distribution. Such calculations give the complete answer and will be very valuable.

LAPOSTOLLE: In thinking about beam blowup, I wonder if anyone has any knowledge of the transverse modes in typical proton structures--even the Alvarez structure? Of course there is focusing in the Alvarez structure, but this will not reduce the blowup.

LEISS: Focusing helps a little in electron linacs, but not much.

WHEELER: The TE modes should not exist in the Alvarez structure, but we saw a few of them in the heavy ion machine at frequencies below that of the TM_{010}. They are very difficult to excite and we didn't work very hard at it.

LEISS: It certainly would be valuable for someone with a test cavity to do some measurements of these modes.

REFERENCES

1. R. A. Jameson, "RF Phase and Amplitude Control," page 505.

2. R. L. Gluckstern, "Transverse Beam Blow-Up in Standing Wave Linacs," page 186.