THERMAL DESIGN OF DRIFT TUBES FOR HIGH-GRADIENT LINACS*

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Summary

We designed high-intensity drift tube linacs at Los Alamos using copper drift tubes capable of very high duty-factor operation, limited only by beam-loss heating in the bore. The drift-tube bodies are cooled by a peripheral, full-length cooling jacket that effectively clamps the drift tube at the average coolant temperature and shields the samarium-cobalt quadrupole from excessive heating caused by rf dissipation. The bore tube is thick-walled copper that is split to provide a gap for thermal-expansion, beam-diagnostic instrumentation, and vacuum relief of the drift-tube body. The magnet pole pieces are isolated from the bore tube by a 0.2-mm thermal gap that is very effective in preventing beam-loss heating from degrading the magnetic properties of the quadrupoles. We discuss thermal studies that explore the capabilities of this design concept. The design features of the quadrupoles include a technique for precision shimming using captive screws and guide slots. We also present results of tests on prototype quadrupole assemblies.

Drift-Tube Design Features

A 34.5-MeV drift tube is shown in Fig. 1. The principal features are the split quad and bore-tube gap. Although only high-energy drift tubes will be discussed to illustrate the capabilities of these concepts, they will work for lower energy drift tubes also, down to 4-MeV. The drift-tube body is fabricated in three OFHC pieces and brazed to a stainless steel stem. The body consists of an outer shell, furnace brazed to the inner shell with the stem, thus forming the entire cooling circuit along with half of the bore tube. Following brazing, the body is machined to precise dimensions, which also serves to work harden the surfaces and stiffen the structure. Then, the quadrupole elements are inserted in indexed positions and are aligned to the outer bore with slip-fit precision; they do not make contact with the bore tube itself. A 0.025-mm thermal gap between the pole tips and the bore tube protects the neodymium-iron pole pieces from bore-tube heating related to possible beam loss. The bore tube, 3-mm-thick copper, readily conducts this energy into the end cap and thence to the cooling jacket. The downstream end cap is inserted, and thermal contact with the cooling jacket is assured by means of either shrink fit, screw threads, roller swaging, or electron-beam welding. A prototyping program is now under way to determine the best method for obtaining good thermal contact.

These high-energy drift tubes are almost 17 cm long with a consequently elongated cooling channel. To further reduce thermal distortion at high duty factors, the cooling water is cross directed (see stem cross section in Fig. 1) to counterflow in both the stem and around the drift-tube body. These two units are furnace brazed together. To assure turbulent, nonstagnated flow in the body, a plenum is brazed into the cooling jacket, which incorporates flow-equalizing orifices. By this means, uniform flow can be achieved even in elongated, high-energy drift-tube bodies. Water entering the annular chamber first strikes a stainless steel impingement plate at the stem base in order to prevent erosion of the inner-shell copper wall.

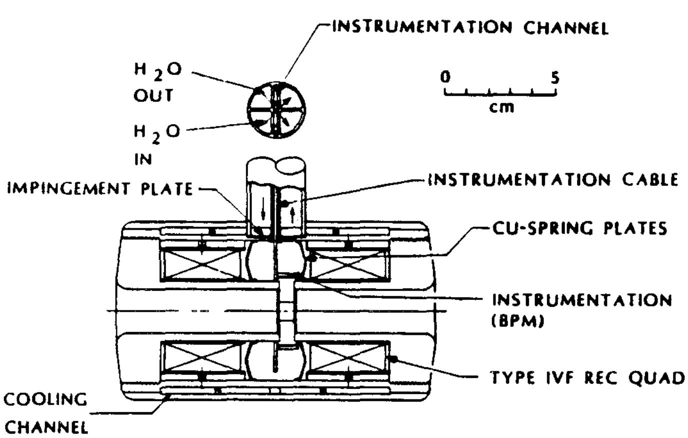

Fig. 1. Instrumented drift tube.

Diagnostic Probe

The diagnostic probes are designed to fit into any split-quad drift tube above 4 MeV. They consist of a transmission-line circuit board that encircles the beam in the bore-tube gap and supports four microstrip circuit boards that form orthogonal beam-position capacitive pickups. The rf signals are delivered to the circuit board and up a flexible strip line inserted through the diagnostic slot in the drift-tube stem. At the top end, outside the vacuum boundary, SMA connectors are attached to permit easy access to the diagnostic signals.

By using two probes along the beamline, beam current, position, longitudinal profile, and energy can be determined in a noninterceptive manner. This information will allow all temporal and spatial beam variations to be detected simultaneously and, therefore, permit experiments on remote automatic control of the accelerator.

Quadrupoles

A 2-cm gap is required to provide space for the diagnostic probe; thus, the quadrupole must be split into two equal half-length segments. Precise shimming of the magnets is needed for harmonic distortion control. A prototype quadrupole is shown in Fig. 2. The pole-tips flats are ground to achieve a precision slip fit into the toothed yoke. A threaded insert is secured by epoxy into a blind hole drilled into the neodymium-iron before magnetization (although this procedure has proved to be practical even after magnetization). Captive screws allow radial adjustments of up to 0.05 mm, needed for accurate harmonic control. The entire assemblage is then potted in a high-vacuum grade epoxy such as DOW 332 or EPON 828.

Thermal Studies

Thermal analysis have been done on this design concept for several different lengths of drift tubes (corresponding to different levels of beam energy). Thermal contours for the 34.5-MeV drift tube at 5% duty factor, using a "standard" beam-loss heating

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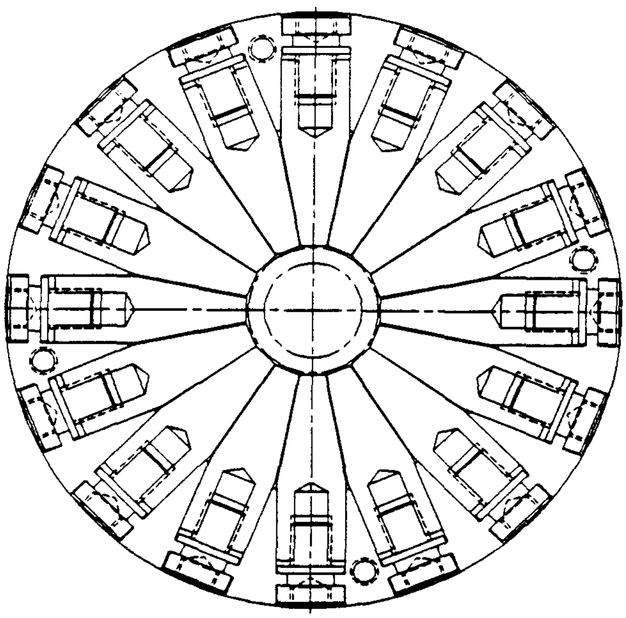

Fig. 2. Adjustable REC quadrupole.

value of 30 μA/m, are shown in Fig. 3. The 30 μA/m amounts to about 5 W, at 5% duty, applied on 0.5-cm-length region along the inner radius of the drift tube and is considered to be a conservative upper limit on bore-tube heating. The rf power deposited on this drift tube at 5% duty factor is 952 W, with most of the power (about 75%) being lost on the outer radius near the cooling jacket. As can be seen, the expected temperature rise for these conditions is about 10.5°F.

The major thermal problem at higher duty factors is the beam-loss heating; although it is not an extremely large thermal source, it occurs in a remote area. Shown in Fig. 4 is a thermal contour plot for cw (100% duty) rf heating with no beam loss. As seen in the figure, the temperature rise is large, but manageable. With proper coolant-supply temperature, including the 30-μA/m beam-loss value, the maximum duty factor obtainable for this design is about 77%,

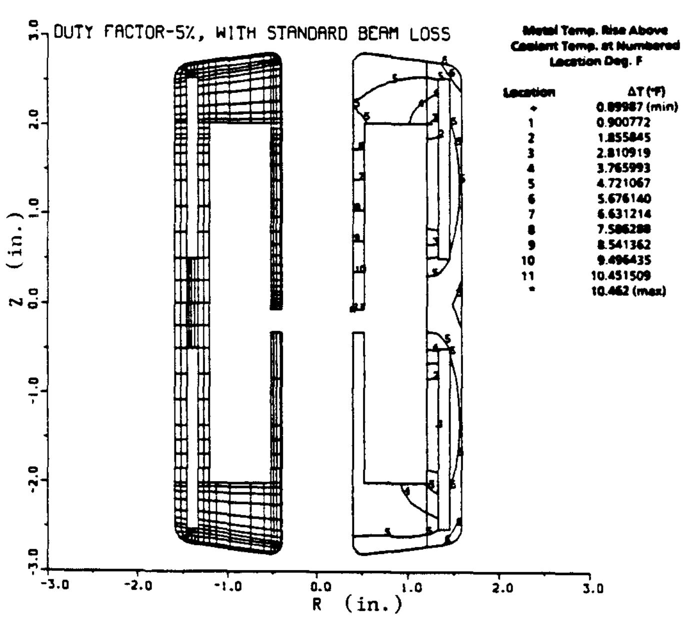

Fig. 3. Thermal profile--5% duty factor with beam loss.

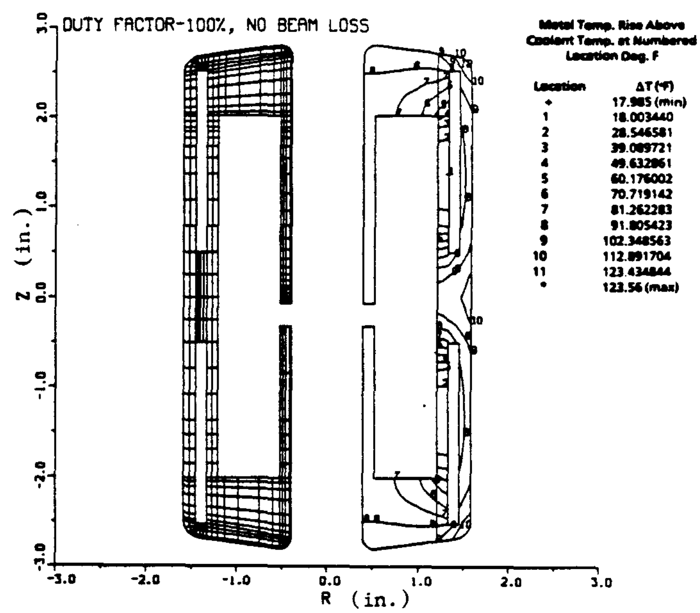

Fig. 4. Thermal profile--cw without beam loss.

as shown in Fig. 5. The maximum temperature rise for any region was set at 162°F as determined by using a maximum component temperature of 212°F and a minimum, available coolant temperature of 50°F. These studies were conducted with constant copper resistivity. Accounting for increased resistivity with temperature will reduce the maximum duty factor proportionally.

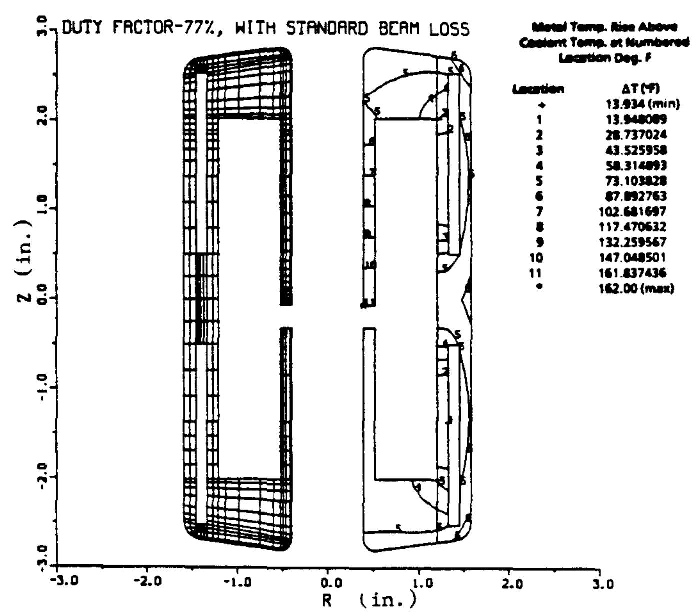

Fig. 5. Thermal profile--maximum attainable duty factor with beam loss.

Conclusion

The split-quad concept for high-duty drift tubes is a significant departure from conventional techniques. Opening the drift-tube quads to vacuum through a split drift tube permits the insertion of instrumentation. Thermal studies of the new design are very promising, and preliminary design studies are continuing in order to thoroughly test this concept.