# DRIFT TUBES FOR A FOCUSING CHANNEL OF ION LINEAR ACCELERATOR

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## Introduction

As practice showed in a RF linac focusing channel operating with one type of ions it's enough to fix once calculated values of the magnetic field gradient. This circumstance opens wide prospects for application of permanent magnet quadrupole lenses which allow to reduce substantially the drift tube size and consequently to increase the operating frequency and the ion linac efficiency. In a number of laboratories several lens designs were developed where separate magnets were mechanically fixed by epoxy compound, several reports on this subject are available [1-3].

However, the problem of encapsulation of an epoxy-containing lens into the vacuum-tight envelope is rather complicated. On the one hand the epoxy matrix is quite close to the welding site and needs cooling and on the other hand strong magnetic field affects the quality of welding. All mentioned above stimulated the idea to design a drift tube opened to high vacuum. We have experience of reliable operation of a single REC epoxy-containing lens which was installed a few years ago directly in a high vacuum chamber of the I-2 linac [4]. Nevertheless in case of a focusing channel with a large number of open-to-vacuum drift tubes it is essential to expel from their design all materials which could deteriorate vacuum quality and lead to more difficulties in accelerating channel operation. Some types of epoxy compounds with relatively low gas emission are discussed in paper [2].

The design of open-to-vacuum drift tube with non-organic elements was developed at ITEP. It allows to avoid almost completely local deteriorations of vacuum quality causing multipactor RF discharges. At present the drift tubes for the first resonator of the 56 MeV proton linac[5] are manufactured and installed. The resonator would provide the output energy of 10 MeV.

## Permanent magnet lenses

The set consists of thirty three 50 mm long lenses, two 25 mm long semilenses and, besides, two 25 mm long semilenses for the buncher. In the first ten lenses (counting from the input of the resonator) the gradient is monotonously decreasing from the maximum value of 60 T/m to 56 T/m, and then remains constant up to the end of the focusing channel. The drift tube beam aperture is 18 mm.

Each quadrupole lens comprises two circular layers of rod permanent magnets fixed in duralumin cylinders (see Fig.1). The first layer contains 12 rods, the second - 18 rods. Each rod is magnetized in the direction perpendicular to its longitudinal cross-section. The rod diameter is 7.4 mm, length - 25 mm. The rod material is $SmCo_5$ alloy. The lens magnetic aperture is 21.2 mm. The lens is mounted in the third duralumin cylinder where it was originally planed to place some aditional rods in order to achieve the rated value of the gradient. By proper selection of cylinders fitted with the rods we had managed to choose the appropriate pairs of cylinders and thus to avoid using of additional rods. The outer diameter of the lens is 73 mm, but it could be decreased up to 55 mm. The minimum wall thickness between the adjacent rod holes is 0.2 mm. Each rod magnet is mechanically fixed in the appropriate hole in the cylinder. In order to prevent the rod from turning in the hole each rod has a keyway on its side surface and there is a corresponding bulge on the surface of the hole.

The rated value of the gradient was achieved by proper relative orientation of the layers. It leads to partial compensation of the layer fields but is possible due to a somewhat excessive summary value of the gradient.

In order to provide high magnetic parameters of lenses all rods passed special selection. The spread of rod magnetic properties within a set of 3,500 magnets reached 30% . To reduce the spread each rod was tested on parameter $\Phi/l$, where $\Phi$ - magnetic flux excited by the magnet in the measuring inductor core, l - geometric rod length. By plotting the histogramm of rod distribution according to the parameter mentioned above and choosing the area with the most dense population of the representative points we managed to select for each layer a set of rods with the spread not more than 0.5%.

At the stage of lens assembling each cylinder fitted with rods underwent measurements during which the gradient and the possible displacement between the geometric and magnetic axes were determined. The rod sets were chosen so as to provide the above mentioned rated value of the gradient and to minimize the displacement between the geometric and magnetic axes by partial compensation of the layer fields on the axis. As a result the displacement was decreased up to 0.03 mm (rms over all lenses of the focusing channel).

Since in the drift tube manufacturing the lens might be heated up to the temperature of 80-90°C (during welding) all rod magnets had undergone preliminary thermostabilization for half an hour at the temperature of 130-150°C. As a result the magnetic parameters of the lens did not degrade after the drift tube manufacturing was completed.

At the lens manufacturing stage the magnetic measurements were carried out by means of the four Hall probes system. The probes are placed on the sides of the 3 mm edge cube at the top of the cylindrical gauge body. The position of the sensitive zone of each probe was determined with the accuracy better than 0.005 mm at the special measuring microscope.

The data for lens magnetic performance

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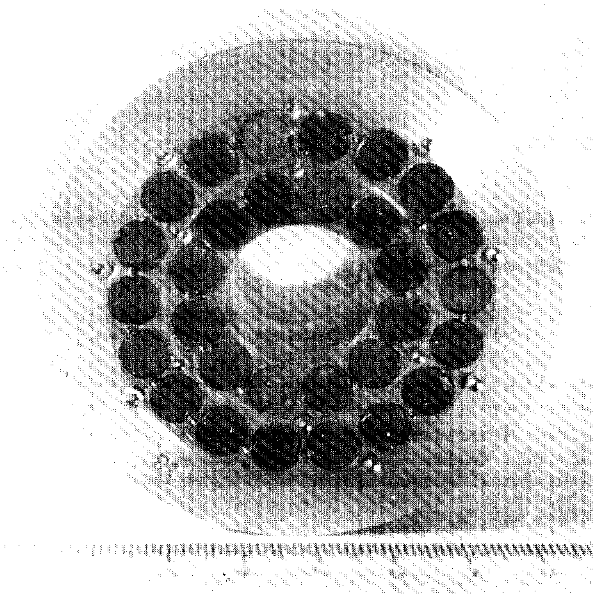

Fig.1. Rare-earth quadrupole lens for open-to-vacuum drift tube.

certificates and more complete information about the field space distribution in the working area of each lens were obtained after computer processing of the results of the measurements carried out at the precision measuring stand.

## Drift tube mechanical design

All copper elements comprising the drift tube body are connected by welding. The mounting seats in the main drift tube body are manufactured after the cooling jacket is welded and tested for vacuum tightness. The aperture semi-tubes are welded to the cups at the preliminary stage also. After the mounting of the lens (see Fig.2) and two side cups in the main drift tube body the final welding is made. The weld depth in this case is only 0.3-0.5 mm, nevertheless in order to prevent overheating of the lens we had to remove heat by water cooling.

Pumping of the interior of the drift tube is provided by eleven holes drilled in the central part of the main drift tube body. In this case the main residual gas flows are directed to the resonator volume but not to the aperture area.

## Magnetic performance

The magnetic parameters of all manufactured drift tubes were thoroughly measured at the high precision stand equipped with Hall probe. The integral values of the field gradient satisfy the tolerance of 1%. Harmonic contents in the middle of the drift tube (for most of them) is of 0.5-0.7% (see Fig.3 cur-

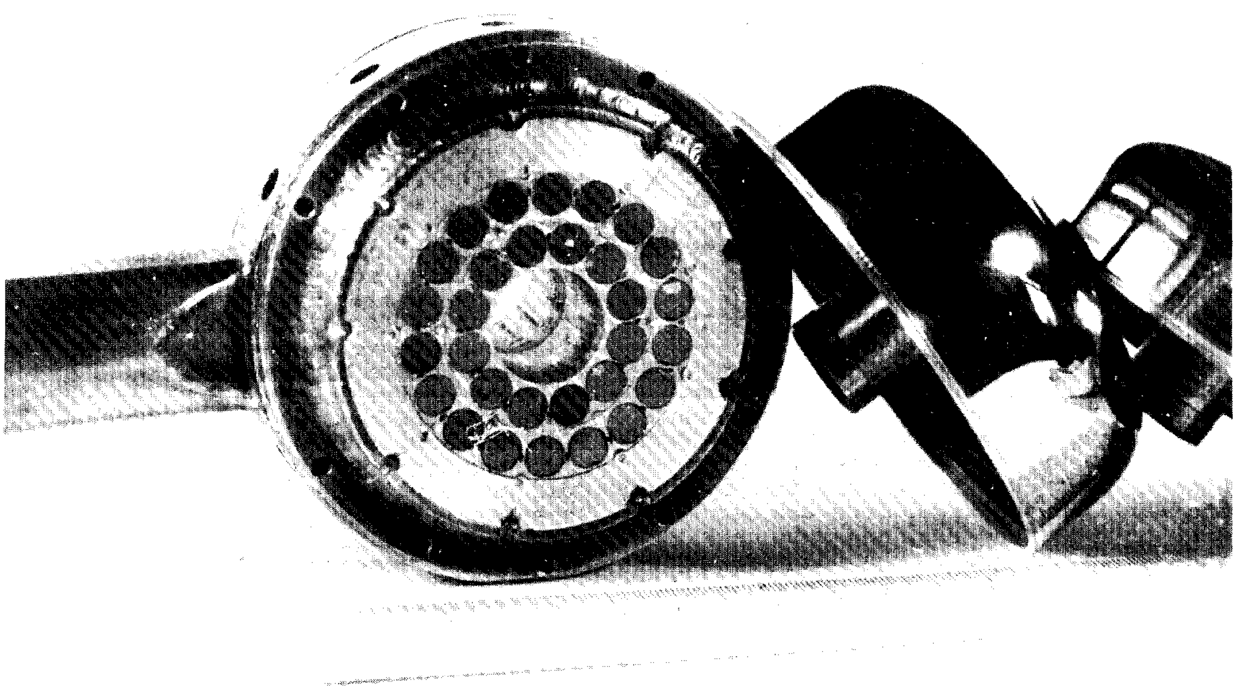

Fig.2. Open-to-vacuum drift tube with rare-earth quadrupole lens (the side cups are removed).

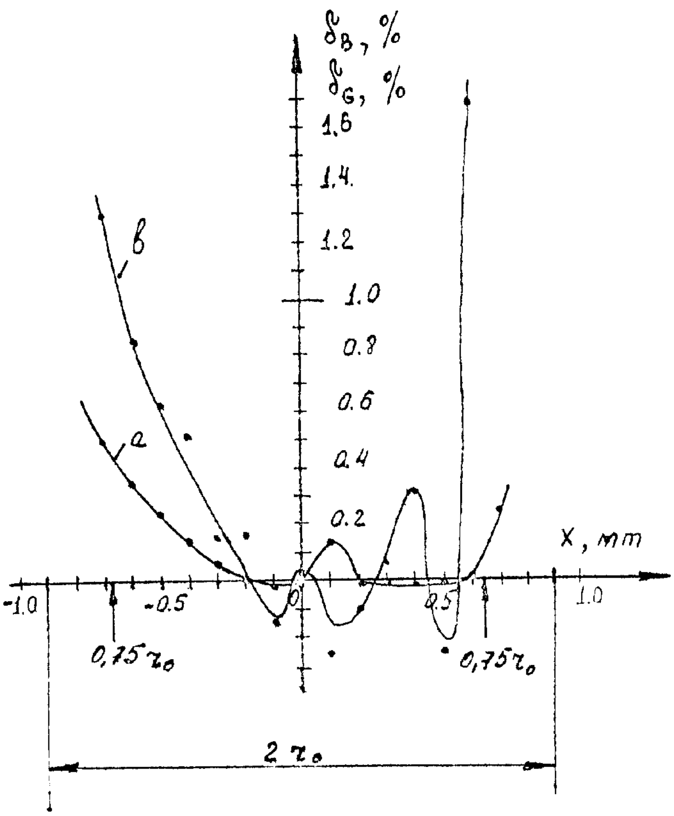


Fig.3. Typical distribution of field nonlinearity (curve a) and gradient nonlinearity (curve b) in the middle of the drift tube. The tolerance for r=0.75ro is satisfied.

ve "a"). The field gradient nonlinearity is of 1-1.5% (see Fig.3 curve "b"). For the whole drift tube set the values of the parameters do not exceed 1% and 3% respectively. The slope of linearized magnetic axis is mainly in the range of 0.5-1.0 mrad. The rms deviation of the real magnetic axis from the linearized one is in the range of 0.01-0.02mm.

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