DEVELOPMENTS IN GRIDDED ION LENSES*

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Abstract — For most applications, the use of grids in focusing elements can improve beam current densities per unit solid angle by a factor of 10 or more. The coupled problems of high grid transparency and long grid life have limited their usefulness in accelerator systems. The development of machined grids with a 10 fold increase in life expectance will be described. These grids are for the Einzel lens of the ORNL Nanosecond Pulser in which wire mesh grids had an average life to failure of 75 hrs. The grids were machined by electrical discharge (Elox) techniques in a sheet of tungsten or molybdenum. Transparencies as high as 84% have been obtained. The sheets can be pre-shaped to compensate for residual spherical aberrations in the lens. Shaped grids have shown further increases of beam brilliance of 30-40%. For fast pulsing operating in which there is no space charge neutralization, beam brilliance figures of 1 amp per sq cm per steradian have been obtained with beam currents up to 3 mA.

Introduction

In most electrostatic lens-systems for ion-beams, except for those systems with very large magnifications, the use of grids in the focusing elements can improve beam current densities per unit solid angle by a factor of 10 or more. According to Liebmann[1] and subsequent measurements made at Oak Ridge[2] the grids greatly reduce the spherical aberrations of the lens by effectively removing the divergent parts of the field pattern in the lens gaps. The mild divergent nature of the individual apertures of the grids makes them impractical to use in lens-systems having very large magnifications i.e., electron microscopes. Figure 1 illustrates the reduction in focus diameter which can be obtained by using grids. The traces were made by slowly sweeping the beam across two closely spaced apertures at the lens focus. The beam diameter as determined for the sharper traces (grids in lens) was about 1/3 the diameter obtained from the broader traces (grids removed).

The main disadvantage to using grids is that they are gradually sputtered away. In the Nanosecond Pulser[2] installed in the ORNL 3 MV Van de Graaff, average grid life to failure has been 250 hrs. The development of a compact pulser, which has an overall length and lens diameter of approximately 50% that of the pulser used in the 3 MV Van de Graaff, accentuated the sputtering problem; for the same beam current, the current density on the grids was 4 times greater. The result was to reduce the time between grid replacements to an unacceptable interval of 75 hrs. As may be seen in Fig. 2, the Duo-Plasmatron Pulser Terminal on the ORNL 5 MV Van de Graaff, there was not sufficient space for the installation of the larger pulser. Also, test bench data indicated that the compact pulser lens could handle a larger peak current without adversely affecting the pulse duration.

Machined Grids

It was concluded that the grids would have to be made with a depth (parallel to the ion beam axis) to width ratio greater than one if the grid life were to be increased without a corresponding decrease in grid transparency. At the suggestion of R. M. Farnham of ORNL Fabrication Department, machining deep grids by electrical discharge techniques was attempted. The method used consisted of cutting or to be more accurate burning through an 0.015 in. thick sheet of tungsten with a brass tool cut to form the negative of the desired gridded area. The tool was gridded with an 0.006 in. thick slitting saw to a depth of at least 5 times the thickness of the sheet to be cut. The time required to make the tool was reduced considerably by continuously cooling the tool with liquid nitrogen. This kept the thin sections of the tool from softening from the heat of cutting and from bending out of position. Also, ice, frozen out of the air, acted as support as it filled up the slits behind the saw. Figure 3 shows the developmental cutting tool and grid which proved the technique practical.

The electrical discharge machine used was a model M-500 with PS-28 power supply made by the Elox Corp. of Michigan, Royal Oak, Michigan. The power supply was run at 200 Kc.

Because of the wear on the cutting tool which may be seen in Fig. 3, it was necessary to use two cutting tools per grid, one for the roughing cut and the other for finishing. Careful re-alignment of the finishing cutter was, of course, necessary.

Grids with a transparency of up to 84% have been made; however, 80% seems to be a reasonable average value for transparency which can be routinely obtained with the present techniques and equipment.

Grid Life Test

A compact pulser was set-up and run on a test bench to life test the machined grids. The ion source, a Duo-Plasmatron,[3] and the pulser were operated at the same conditions in which 0.0015 in. W wire grids had failed after 70 to 80 hrs. The total beam current from the source was about 2.6 mA, and the pulser was run at 2 Mc. The test was concluded after 200 hrs. when it was found that there had been no noticable decrease in the depth of the grids. The only evidence of sputtering was a slight rounding of the surface of the first grid facing the beam. This sputtering may be seen in Fig. 4 which is an enlargement of the center of the grid area. The grid mesh is 40 x 40 per in. and the webs width averages 0.0037 in. This greatly reduced sputtering rate probably was due to a lower grid temperature since the machined grids have much more heat transfer area than the wire grids.

Curved Grids

The development of practical grids machined in sheet material led, naturally, to attempts to make further improvements in beam quality by shaping the gridded surface. The only shaped surface tested to date was spherical with a radius equal to 2 times the lens diameter. The convex surface of the grids face the center element of the Einzel lens as may be seen in Fig. 5. The lens diameter is 2 in. and the overall length from image to object is 7.1 in. The diameter of the gridded area of the machined grids, also shown in Fig. 5, can be limited to 1 in. because the beam diameter is only 0.75 in. at that point.

The curved grids were made by forming an 0.010 in. thick sheet of molybdenum to the desired radius and then cutting the grid in the same manner as previously described.

Since our major interest is in fast beam-pulse work, the flat and curved grids were compared on a basis of results produced during pulsed operation on a test bench. The beam pulses were collected on an ultrahigh frequency Faraday cup located immediately below the sweep aperture of the pulser. From the trace displayed on a sampling oscilloscope (Tektronix 661) the beam current and shape were determined. The traces in Fig. 6 were produced for the flat vs. curved grids with no change in the ion source or extractor geometry or operating conditions. The peaks are H_1^+, H_2^+, and H_3^+ beams, left to right, respectively, as separated by transit time effects during fast sweeping. As may be seen in the table in Fig. 6, the beam brilliance and current density, as determined from H_1^+ peaks, for the curved grids are 37% higher than that of the flat grids. The higher H_1^+ peak current from the curved grid set-up was due to higher transmission of the curved grids and was normalized out for the determination of beam quality. The significant information from trace was obtained from the full width at half maximum (fwhm) and was used to determine the beam diameter.

Discussion

Under normal operating condition in a Van de Graaff accelerator the life of machined grids is expected to exceed 1000 hrs. This type grid recently was installed in the lens-pulser in the ORNL 5 MV Van de Graaff; therefore the grid life in this machine should now exceed the operating life of other items in the terminal. The 12-16 hr loss of operating time every 75 hrs to replace wire mesh grids should be eliminated.

Further increases in transparency of machined grids should be possible with improved machining techniques and equipment. Personnel from the ORNL Fabrication Department think that the newer models of the electrical discharge machines will give better surface finishes and therefore better dimensional control. This should allow for a reduction in grid width without endangering the mechanical integrity of the mesh.

Optimizing the shape of curved grids is being approached empirically. The unknown effect of the rf sweep voltage on the focus and the distortion of the lens fields by secondary electrons makes analytical methods impractical in this application.

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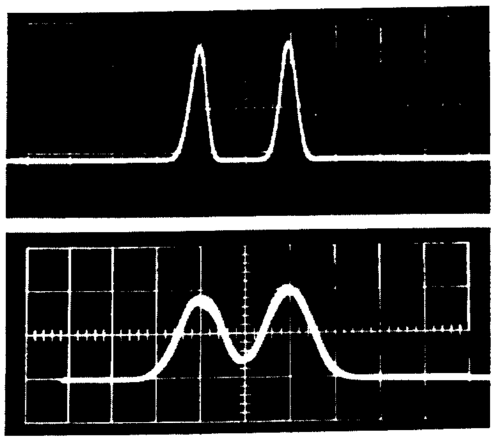

Fig. 1. Effect of Einzel lens Grids on Focus.

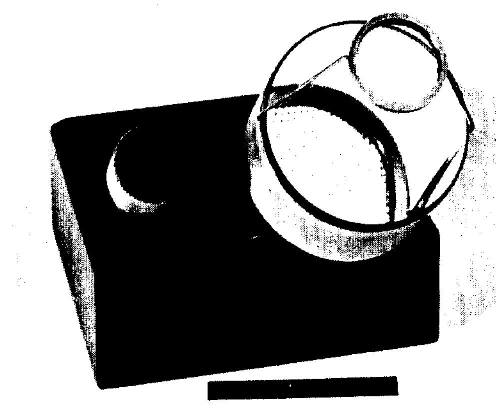

Fig. 3. Developmental cutting tool and grid.

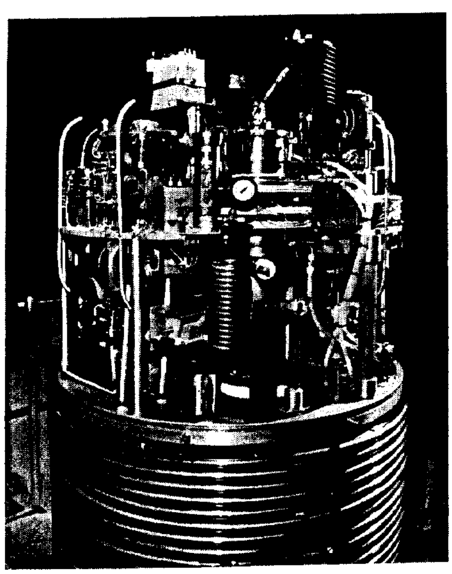

Fig. 2. Duo-Plasmatron pulser terminal for ORNL 5 MV Van de Graaff.

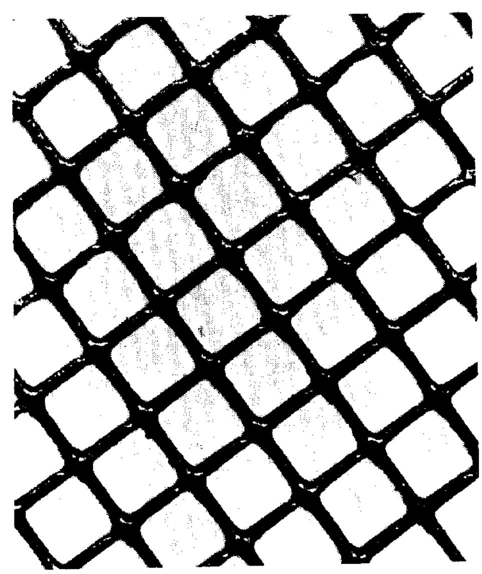

Fig. 4. Enlargement of machined grids.

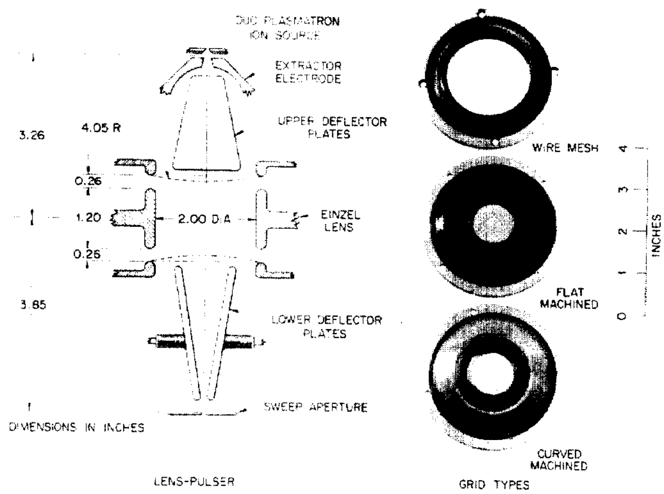

Fig. 5. Compace Lens-Pulser and grids.

GRID SHAPE	CURRENT DENSITY $\frac{I}{A}$	BEAM BRILLIANCE $\frac{I}{A\theta^2}$
FLAT	$0.043\ \frac{amp}{cm^2}$	$0.77\ \frac{amp}{cm^2 \cdot steradian}$
CURVED $(r=2D)$	$0.059\ \frac{amp}{cm^2}$	$1.06\ \frac{amp}{cm^2 \cdot steradian}$

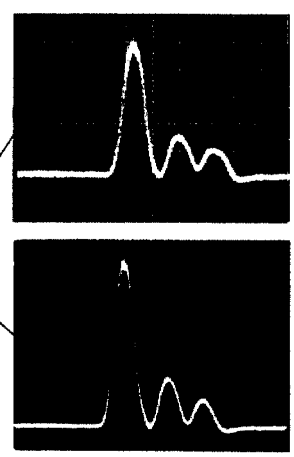

Fig. 6. Beam Quality; Flat vs Curved Einzed Lens Grids.