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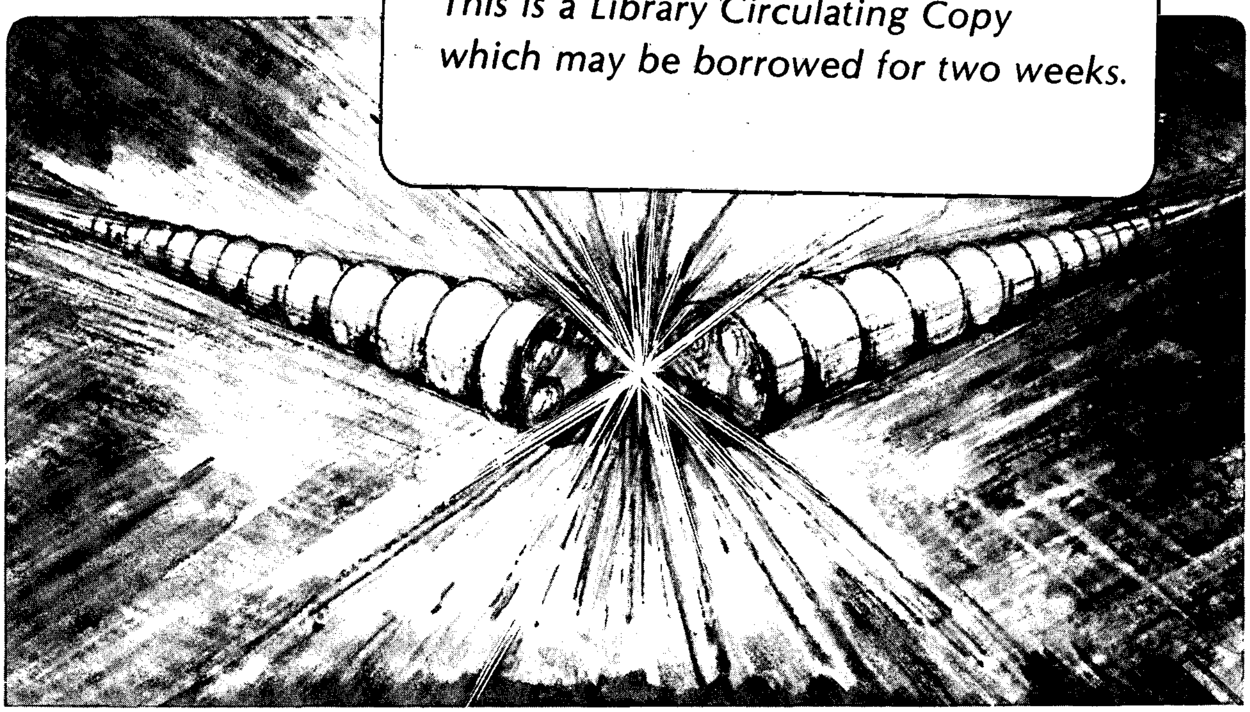

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Abstract

A sixteen beam injector to supply 500mA per beam of C^+ ions, which was initially designed and partially constructed at Los Alamos National Laboratory, is under further development at LBL. We report on development work involving single and multiple carbon arc sources. These sources are useful because they can easily supply the 25 mA/cm^2 needed for the device. They are pulsed sources which do not cause unacceptable background gas loads in the column. We present emittance and reproducibility data. Acceleration is by a high gradient column using a succession of aperture lenses to focus the beam. The electrodes are arranged with holes for parallel beams inside 28 inch alumina insulators. Data on beam propagation and electron trapping in the column is presented. The acceleration potential is provided by a Marx bank with inductive grading along the structure. The resulting 34 µsec rise time pulse allows the accelerating potential to equilibrate along the column before the current is injected. Acceleration occurs during a 1µsec window at the peak of the pulse, in which the voltage is flat within 0.1%.

1.0 Introduction

An injector to provide sixteen beams of C^+ ions for the Induction Linac Systems Experiment (ILSE) [1] is being built at LBL using a design and some components which originated at Los Alamos National Laboratory [2]. The machine will provide 500 mA per beam of C^+ ions accelerated to 2 MeV energies. So far, a small section of the 2 MV generator, some carbon arc ion sources, the acceleration column insulators, and a pressure vessel have been constructed. This paper will report on the recent progress in the source development, the development of the high voltage system, and the design of the electrode for the acceleration column.

2.0 Carbon Arc Source

The source chosen for the injector is a carbon arc. The physics of the source and the plasma switch is described elsewhere [3,4,5]. This source approach is an outgrowth of previous work on an aluminum arc done at LANL and the University of New Mexico [4,5]. The arc source is used in conjunction with a double-grid plasma switch whose function is to stop plasma drift into the extraction diode prior to application of the extraction potential. The use of the grid allows one to have a pre-established ion extraction surface (virtual anode). The desired parameters from the source are 500 mA total current (25 mA/cm^2) per beam for 1 μsec with a normalized emittance of 5 x 10^{-7} π-radians.

The source, its associated plasma switch, and the test extraction gap are shown in Fig. 1. This figure shows the first version of the source. The cathode for the main arc was a carbon cylinder approximately .5 inches in diameter. Inside the cylinder was a coaxial trigger consisting of a copper inner conductor, an Al_2O_3 insulator, and the cathode itself as the outer conductor. The trigger was powered by a capacitor discharge coupled through a trigger transformer reaching 20 kV on the transformer output. The flashover across the ceramic surface provides a trigger plasma which drifts into the main arc gap. The main arc gap is powered by an L-C pulse forming network which generates a 100 μsec pulse with up to 350 A. The PFN is pre-charged and the trigger plasma simply shorts the main gap causing the PFN to discharge. When a high potential is applied across the planar extractor gap, ions are extracted from the virtual anode and pass through a 1 inch exit aperture hole with 81% transmitting stainless steel mesh across it. The beam is diagnosed about 1 inch behind the exit aperture. A faraday cup is placed in this location to check plasma shutoff and emitted current density.

Plasma shutoff data has been shown before [4, 5] for a metal arc source. The grid used in the plasma switch for the single arc source was a 100 x 100 mesh with .001 inch stainless steel wires

(81% transmitting). For the single carbon arc the shutoff range was ~110-150 V negative. Going much higher resulted in switch breakdown evidenced by ion leakage late in the pulse. Later on we switched to a 200 x 200 mesh with .016 inch wires (46.2% transmitting). These later tests were done with a three arc source discussed below. In this case the plasma ions were shutoff with 50-75 V on the grid.

Fig. 2 shows extracted current density from the single carbon arc taken with a gridless faraday cup described by Humphries [4]. The gridless cup has no bias grid which can be a source of secondary electrons, thus giving a more accurate current measurement than the shallow gridded faraday cup that we use to measure plasma shutoff. The solid line shows the expected Child-Langmuir current density for the extraction gap used in the gun corrected for the 81% mesh that covers the exit aperture. The arc current was 175 A for this data. The current density has a $V^{3/2}$ slope and did not saturate over the available voltage range of the gun. Current densities of ~ 25 mA/cm^2 are available from the source.

The emittance of the source was also measured. Problems in source reproducibility were encountered. Considerable effort was devoted to adjusting the trigger position inside the cathode to obtain an optimum plasma ion pulse shape but to no avail. Different triggers were tried including a trigger used by I. Brown in the MEVVA source [6] which was used to obtain the data in Fig. 2. The idea that plasma non uniformities generated in the arc were responsible for the non-reproducibility resulted in the construction of a three cathode arc source, using most of the components of the old source. The three carbon rods fit within the envelope of the original cathode and were symmetrically placed around the trigger. The trigger was changed to a two wire flashover on a ceramic surface electrically isolated from the cathodes, and located inside the circle of three cathodes. The three cathodes were connected to the PFN by ballast resistors to make them all fire. Time integrated photos of the arcs indicated that if the source fired, all three arcs fired. However, the luminosity of the arcs varied shot to shot. Ideally, the variations of the three arcs would be smoothed out by adding the plasmas together. However, these changes did not improve the source's reproducibility and we had to run the main arc current up to 300 A in order to keep the current density from saturating near the top of the operating range of the gun (80 kV). Fig. 3 shows an emittance scan taken with 160 V on the plasma switch, 300 A main arc current, and at a beam energy of 57.2 keV. This particular scan is one of the better behaved ones obtained with any of the trigger-arc designs using the 100 x 100 mesh for the plasma switch. The front slit of the double slit emittance measuring system is about 1 inch behind the exit aperture of the gun. Each point is taken on a separate shot and the bar lengths reflect the signal strength from the faraday cup behind the second slit. The normalized emittance obtained by drawing an ellipse around the non-zero data points is $1.3 \times 10^{-6}\ \pi$ m-radians, which is more than a factor of two above the design target. It must be remembered that the target value is for a two inch diameter beam while the beam in this gun is one inch in diameter. This emittance scan contains some holes in the distribution and was not reproducible. The existence of these holes, the lack of smoothness in the signal variation, and non-reproducibilities were the main reasons for trying a triple arc.

Burkhart [7] had obtained very high transverse ions temperatures with his arc source using the same plasma switch mesh. The transverse ion temperature implied by the emittance plot in Fig. 3 is 33 eV which is comparable to the 25-32 eV he obtained in his measurements. The high ion temperatures obtained by Burkhart were correlated with high arc current used to keep the ion flux high enough to ensure that his gun did not become emission limited. His pepper-pot measurements also showed spots with octagonal structure which correlated with the plasma switch mesh orientation. One can estimate a Debye length in the arc plasma from the plasma ion flux during shutoff tests of the plasma switch. Assuming a neutral singly ionized plasma and an electron temperature of 10 eV [3], one gets a Debye length of .063 mm for the case of Fig. 3. The mesh opening was .227 mm. Thus, twice the Debye length was smaller than the mesh opening. Nevertheless, the mesh did shutoff the plasma even with the single arc which gave more than twice the ion flux of the three arc source. Burkhart's data implied that he was extracting from the arc plasma directly as well as from the virtual anode. The considerations led to replacing the second switch grid with a 200 x 200 mesh with 0.16 inch stainless steel wire.

After the mesh was replaced the arc current was set to 350 A which is the highest possible. This gave an extractable ion flux of 41.7 mA/cm^2. The transmission of the second grid was now 46.2% compared with 81% previously. Excellent plasma shutoff was obtained at 70 V with near shutoff at 50 V. Current density curves were obtained which showed no saturation over the range of available gun voltages. The emittance scans were now reproducible and the signals varied smoothly as the second slit was scanned in x'. Scans were done at 66 kV and 47 kV gun voltages to see if being far from the emission limit degraded the emittance. It did not. A 66 keV scan is shown in Fig. 4. The normalized emittance for this run is 6.88 x 10^{-7} π m-rad. Tests with a 50 x 50 stainless steel mesh with .001 inch wires showed that it became almost impossible to shutoff the plasma unless one used very low arc currents.

3.0 High Voltage Generator

The 2 MV accelerating potential will be provided by an inductively graded Marx generator. The stray capacitances in the accelerating column are such that a slow risetime pulse must be used if the accelerating potential is to be properly distributed along the column. The original LANL design [2] called for a 6 μsec fast rise Marx pulse at 2 MV. The generator will reside inside a pressure vessel, which has already been constructed, as shown in Fig. 5. The generator is the long assembly mounted on cantilevered beams on the left side of the figure. The accelerating column with its electrodes is shown on the right. In between are two separable domes which will contain the motor generator, source electronics, and controls. The vacuum system and diagnostic tank are on the extreme right. The pressure vessel is filled with a 30% SF_6-70% N_2 gas mixture at 65 psig for high voltage insulating purposes.

The generator itself consists of 18 plastic trays each with two, 100 kV, .06 μfd capacitors. The two end trays each have one 50 kV .120 μfd coupling capacitor. The capacitors are charged symmetrically at ± 50 kV. Around each tray shown in Fig. 5 is an inductive corona ring each consisting of a 38 inch diameter lucite ring which has 96 turns each and winding length of 3 inches. The turns are enclosed in alumimum spinnings which shield them from the vessel wall.

The waveform of the circuit is critically damped with a risetime to peak voltage of approximately 34 μsec.

A five tray section of the original Marx design was obtained from LANL and tested at full voltage by firing into an 8 kΩ dummy load consisting of two 4 kΩ - 500 kV resistors. The system operated successfully for about 50 shots. Due to the compactness of the design, components were subject to flashover problems and the circuit was reconfigured to avoid them. Four of the inductive corona rings have been tested under a 220 kV impulse voltage and all have operated satisfactorily in a 10% SF_6-90% N_2 mixture at 65 psig. These rings are now being installed in a five tray section of the full inductively graded Marx generator. This section will have only half of the spark gaps triggered as compared to the original design which had all gaps triggered. If the jitter is satisfactory (~ 50 nsec) this approach will reduce probability of failure and the crowding of components on the trays.

4.0 Accelerating Column

The acceleration column is actually a series of aperture lenses. The design was carried out with the EGUN code [7]. the trajectories are shown in Fig. 6. The first gap is a gridded diode which is set at 13.6 kV and is used to switch on the current pulse after the 2 MV generator has put the main acceleration potential on the column. The next gap is a 69.4 kV gap and all the rest are 175 kV gaps. After the first two gaps the electrodes become paired plates. This configuration gives an alternating set of aperture lenses. These aperture lenses are used to deflect back streaming electrons generated on the electrode surfaces. The upstream electrode in each pair has a radius of 29 mm compared with the downstream electrode which has a 28 mm radius. The recess into the solid electrode is 6 mm from the inside radius of the downstream electrode. The last electrode is contoured to reduce the electric field stress in the exit aperture. The peak value is 125 kV/cm. Finally there is an electrostatic electron trap to prevent electrons made in the background gas from entering the column and being accelerated toward the source. The electrodes will soon be constructed and they will be made of titanium to reduce secondary electron generation both from beam halo and electrons.

Acknowledgment

This work was supported by the Office of Energy Research, Office of Basic Energy Sciences, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

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Figures

Fig. 1 Carbon arc ion source with plasma switch and extractor. Dimensions in inches.

Fig. 2 Extracted current density from single carbon arc source using gridless cup. Solid line is ideal Child-Langmuir value corrected for 81% transmitting exit grid.

Fig.3 Emittance scan using triple arc and 100 x 100 mesh.

Fig. 4 Emittance scan using triple arc and 200 x 200 mesh.

Fig. 5 2 MV Injector.

Fig. 6 Acceleration column optics. a) First part showing current valve. b) c) middle sections with "split end" electrode. d) exit region showing electron trap. Dimensions in mm.

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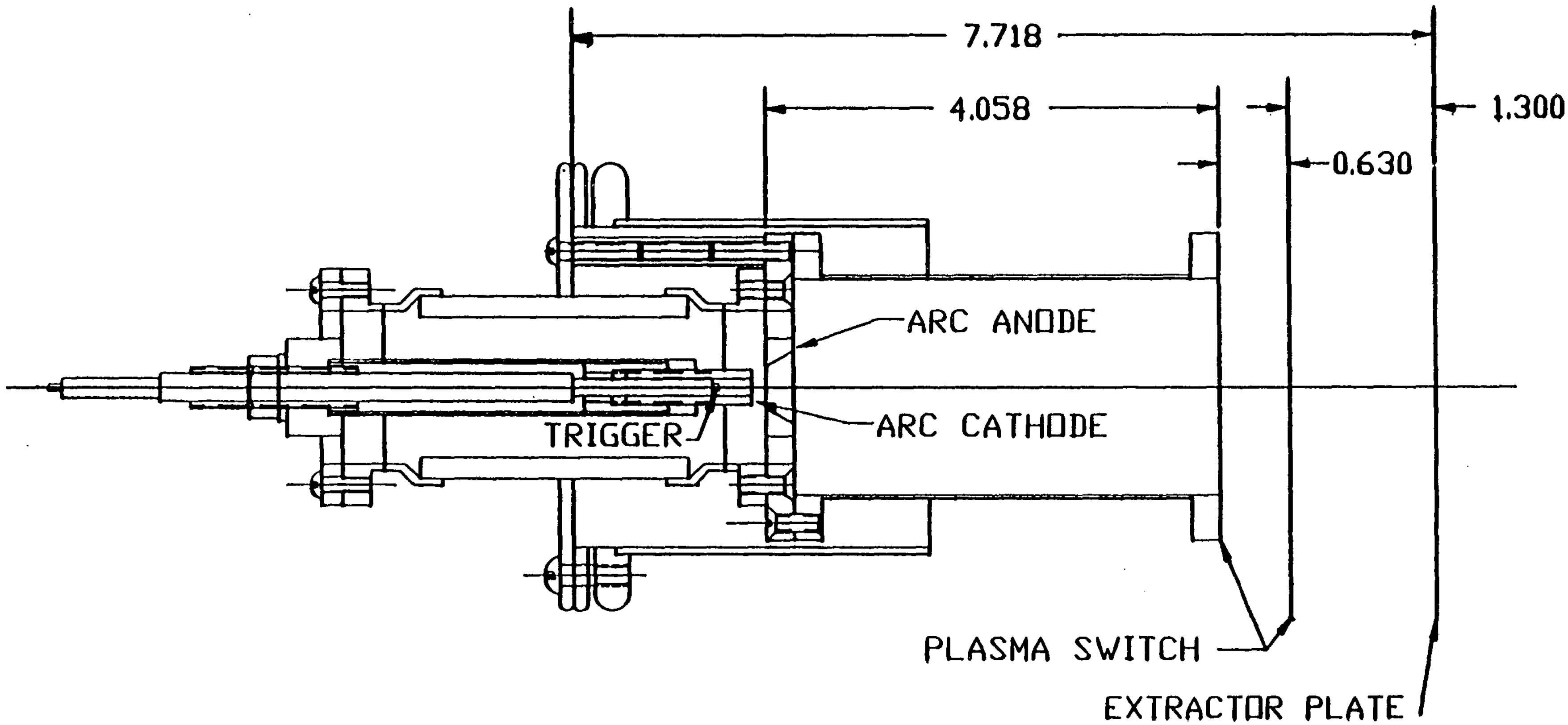

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Fig. 1

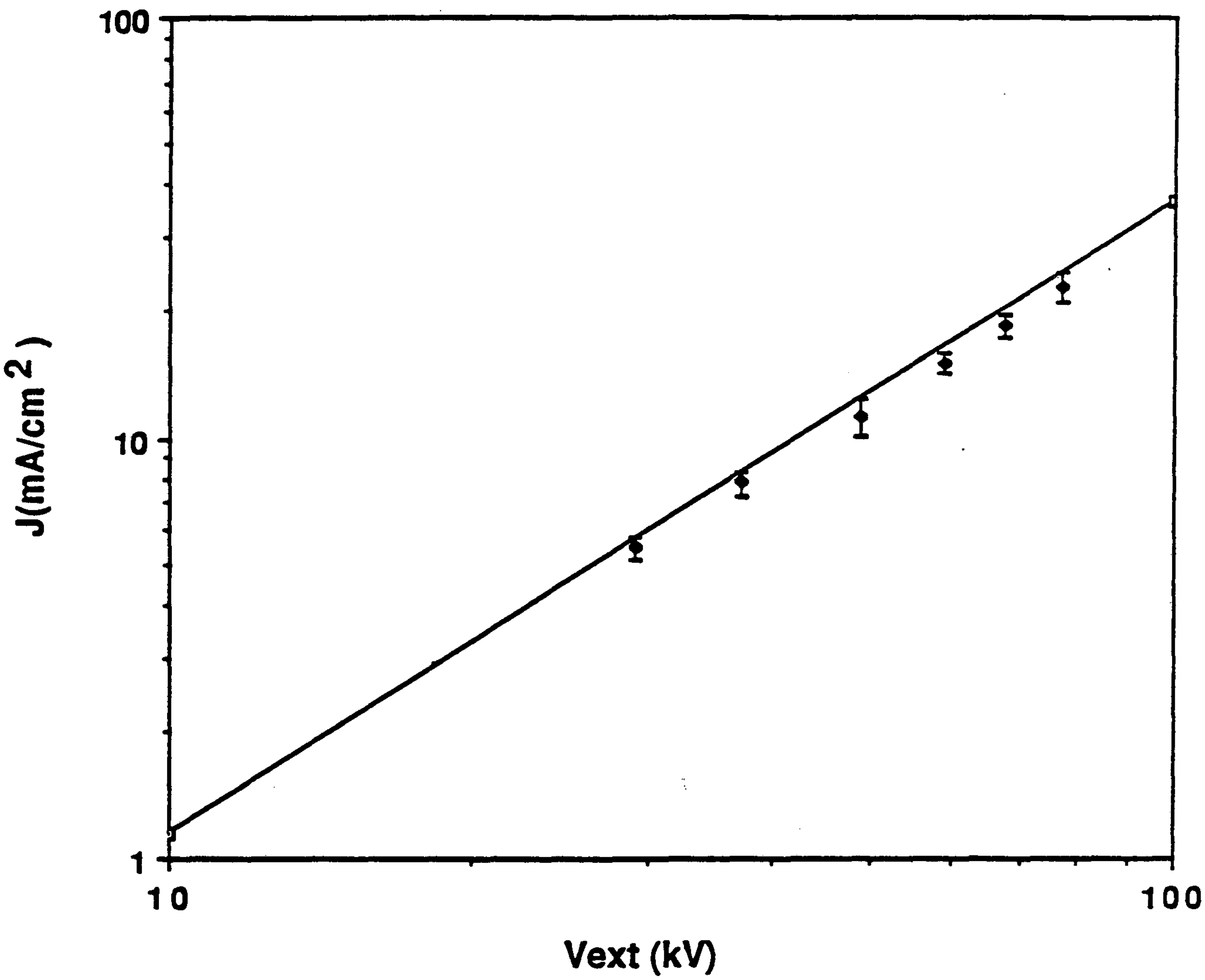

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Fig. 2

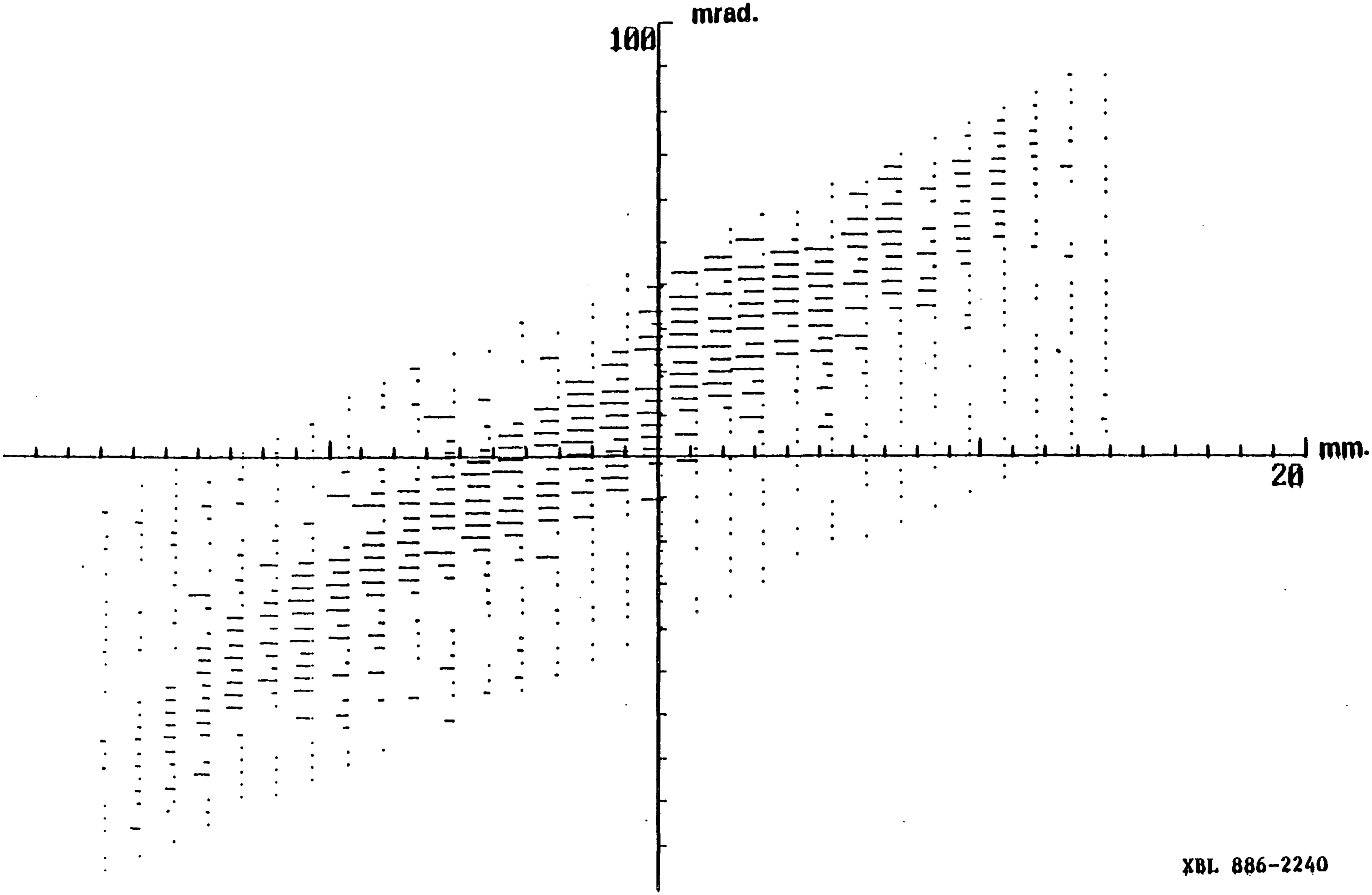

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Fig. 3

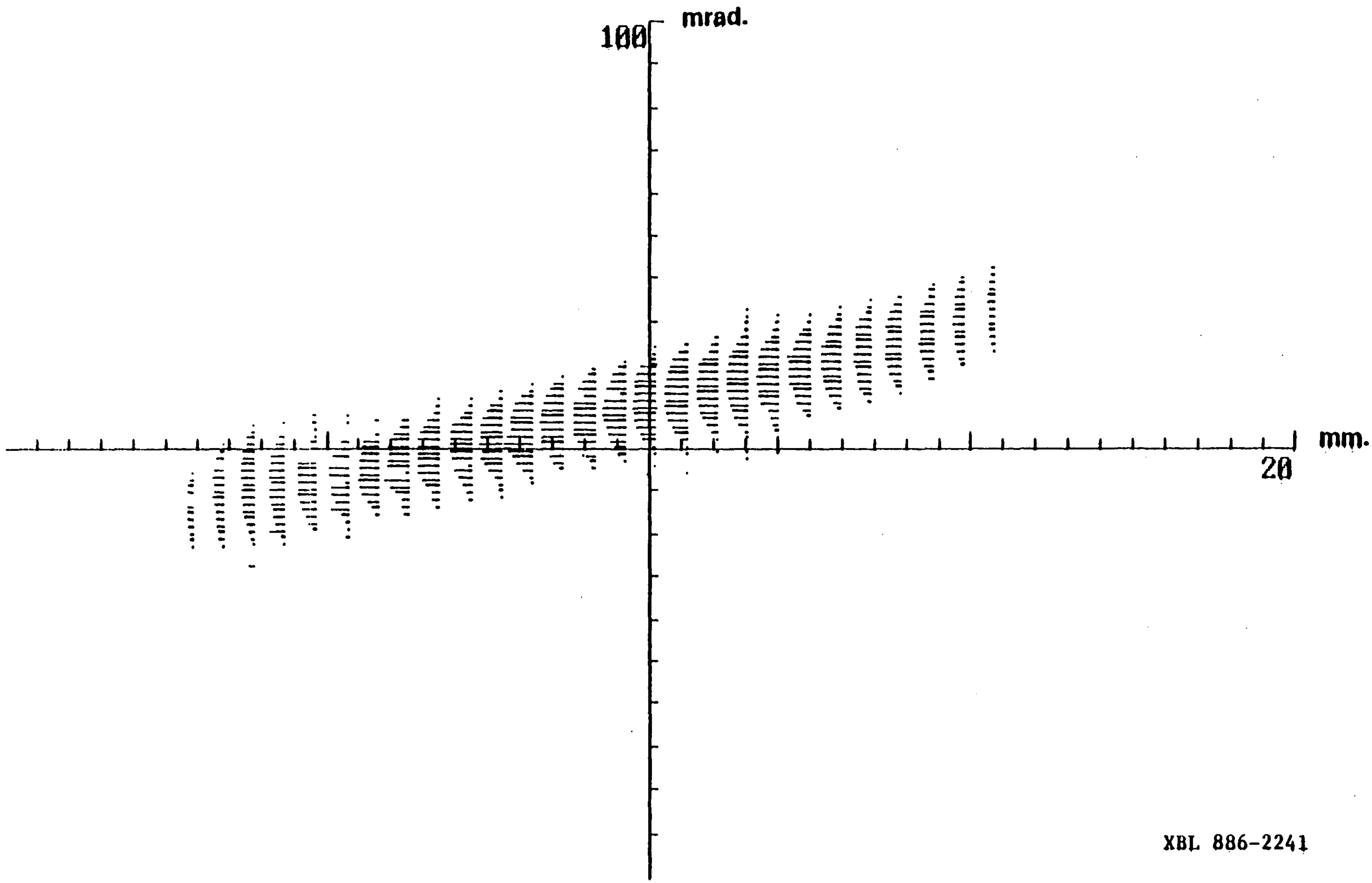

Fig. 4

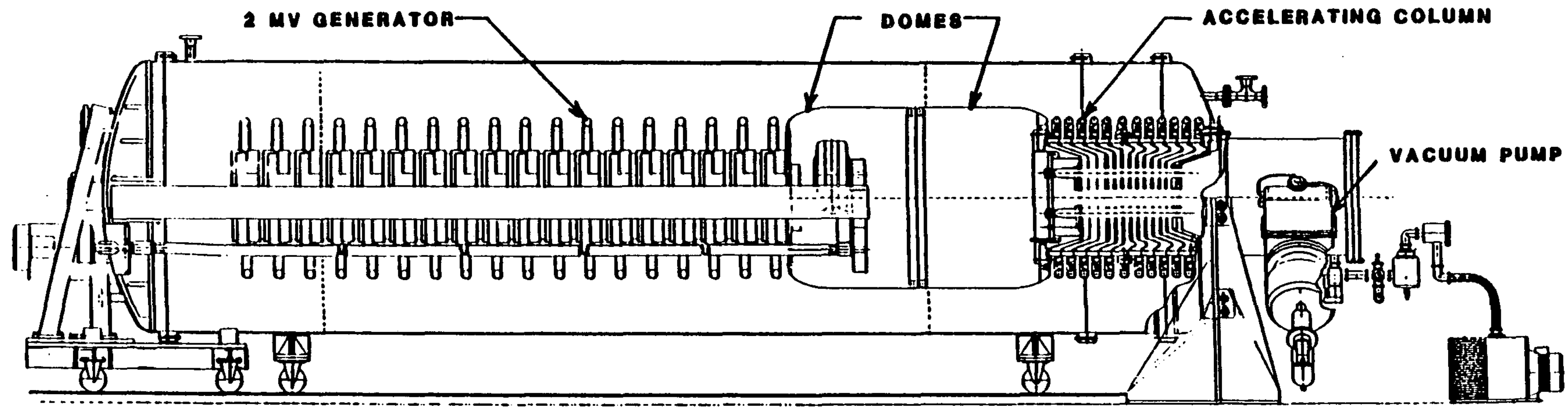
2 MV GENERATOR
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Fig. 5

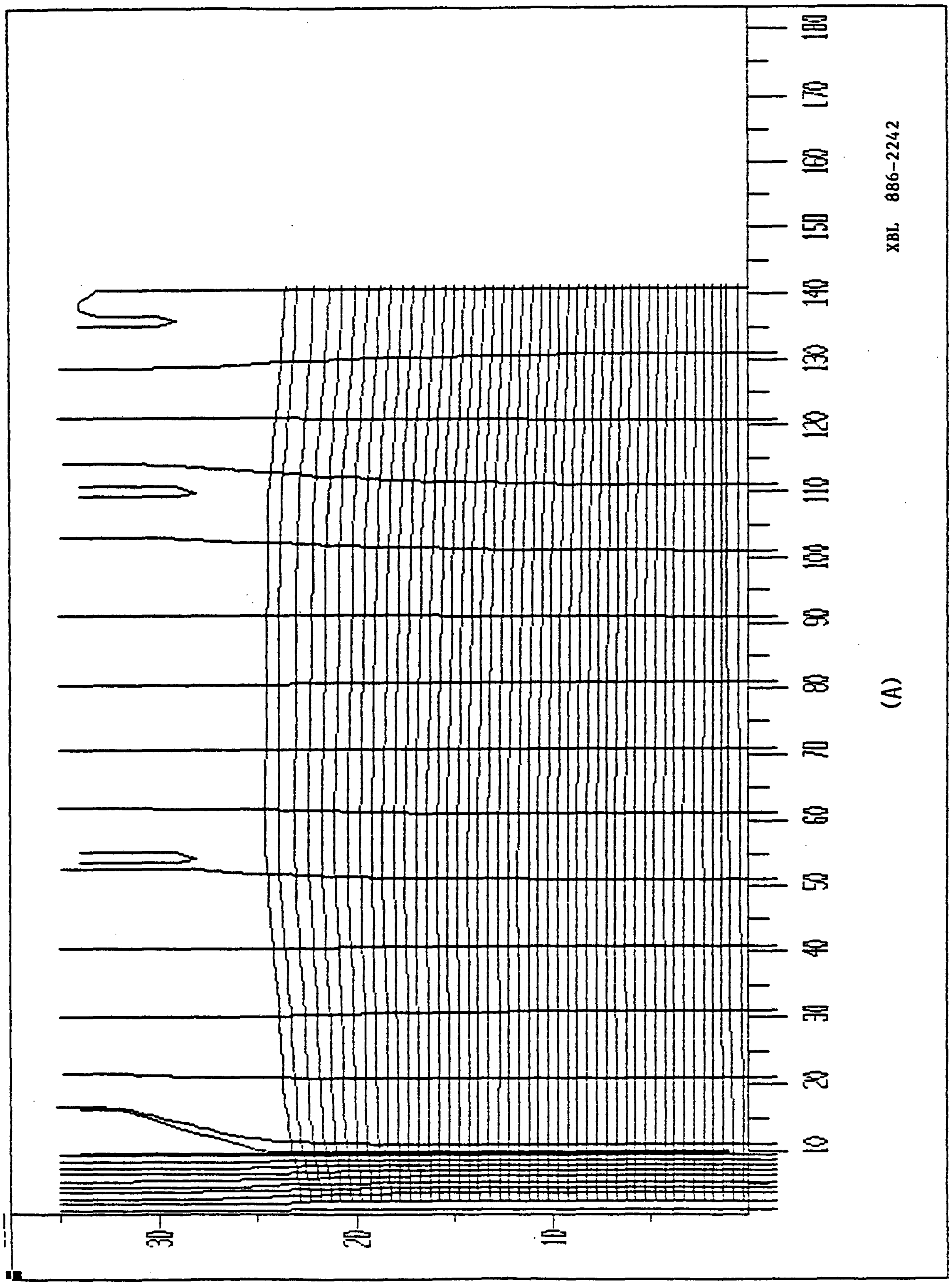
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Fig. 6

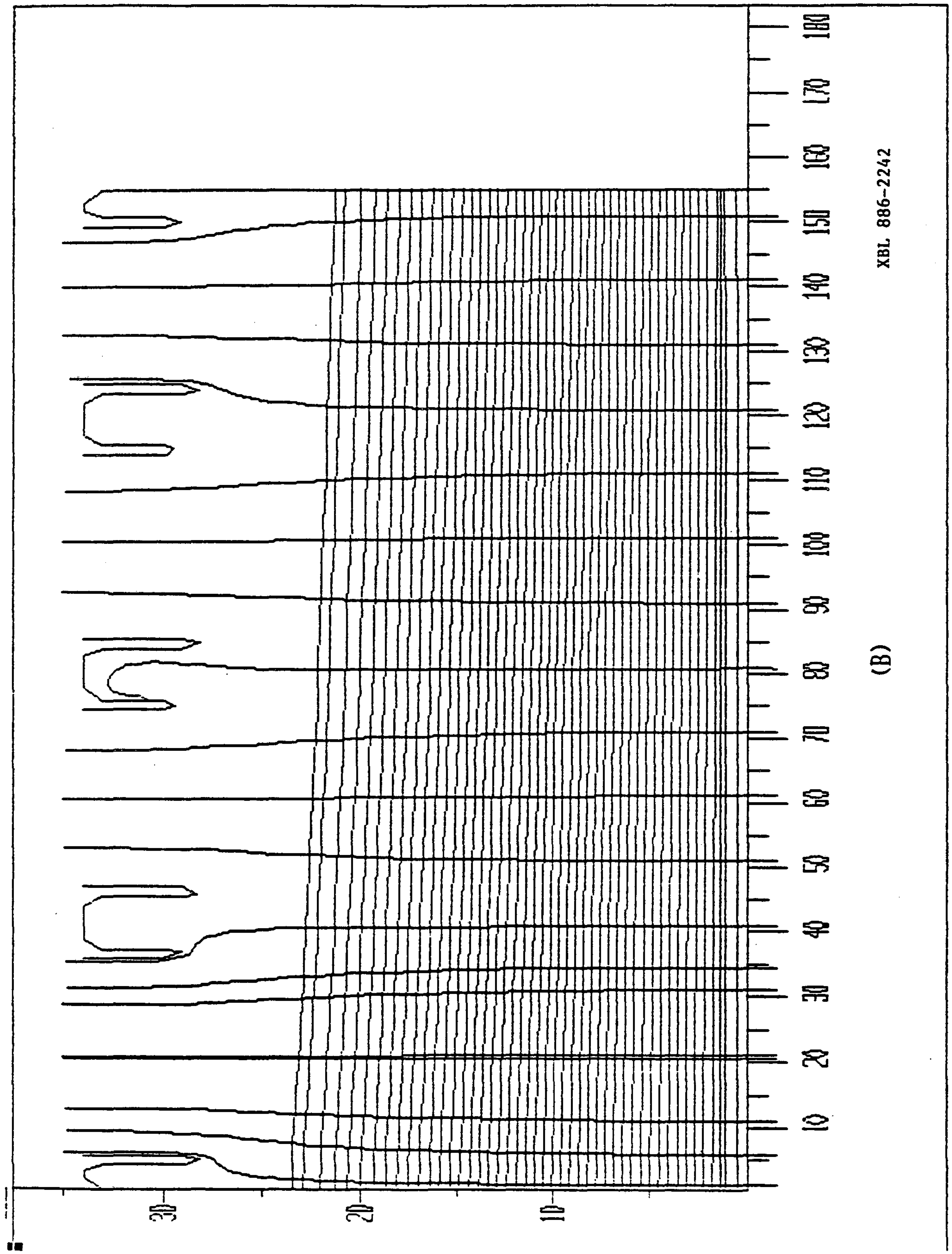
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Fig. 6

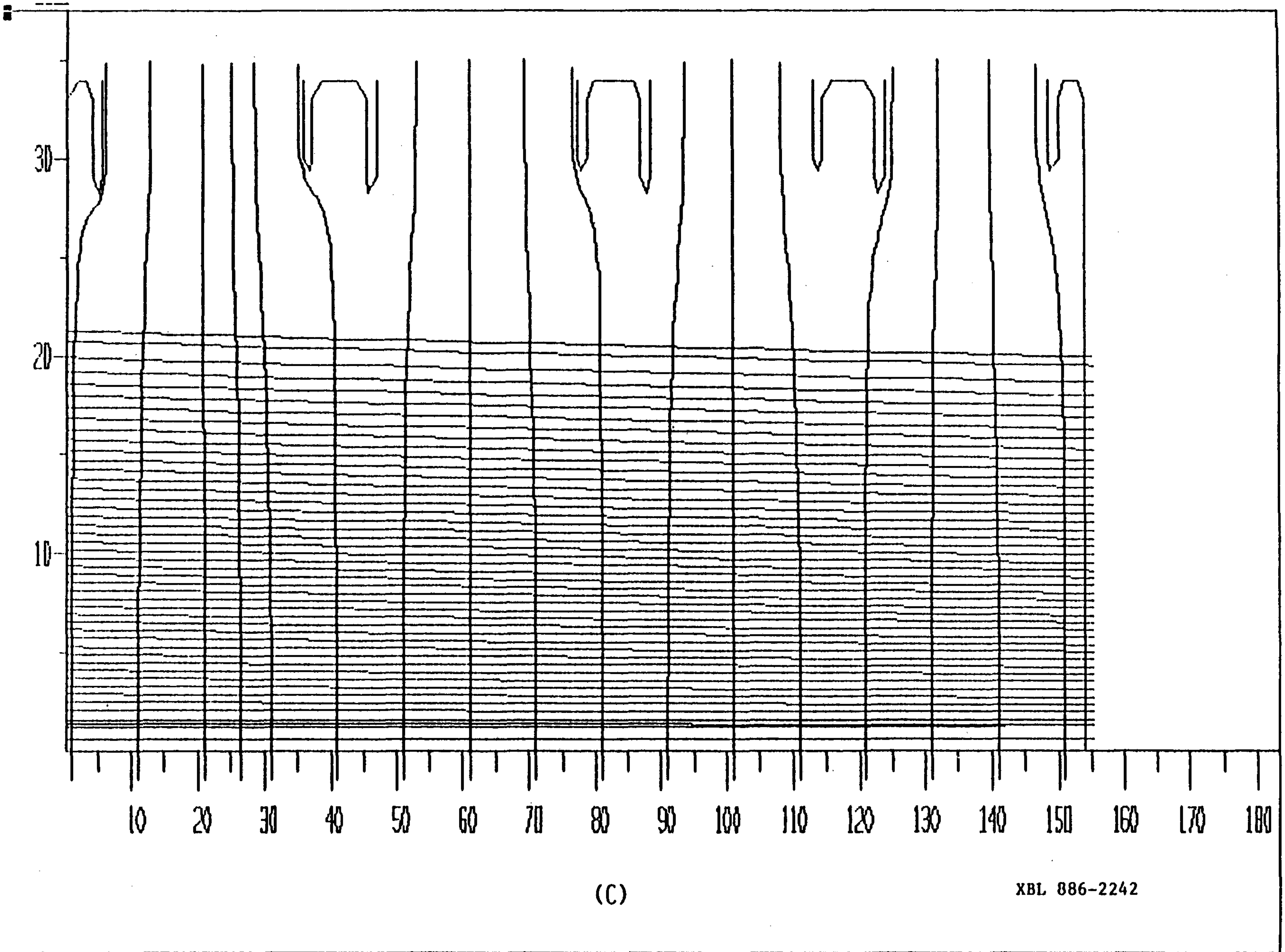
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Fig. 6

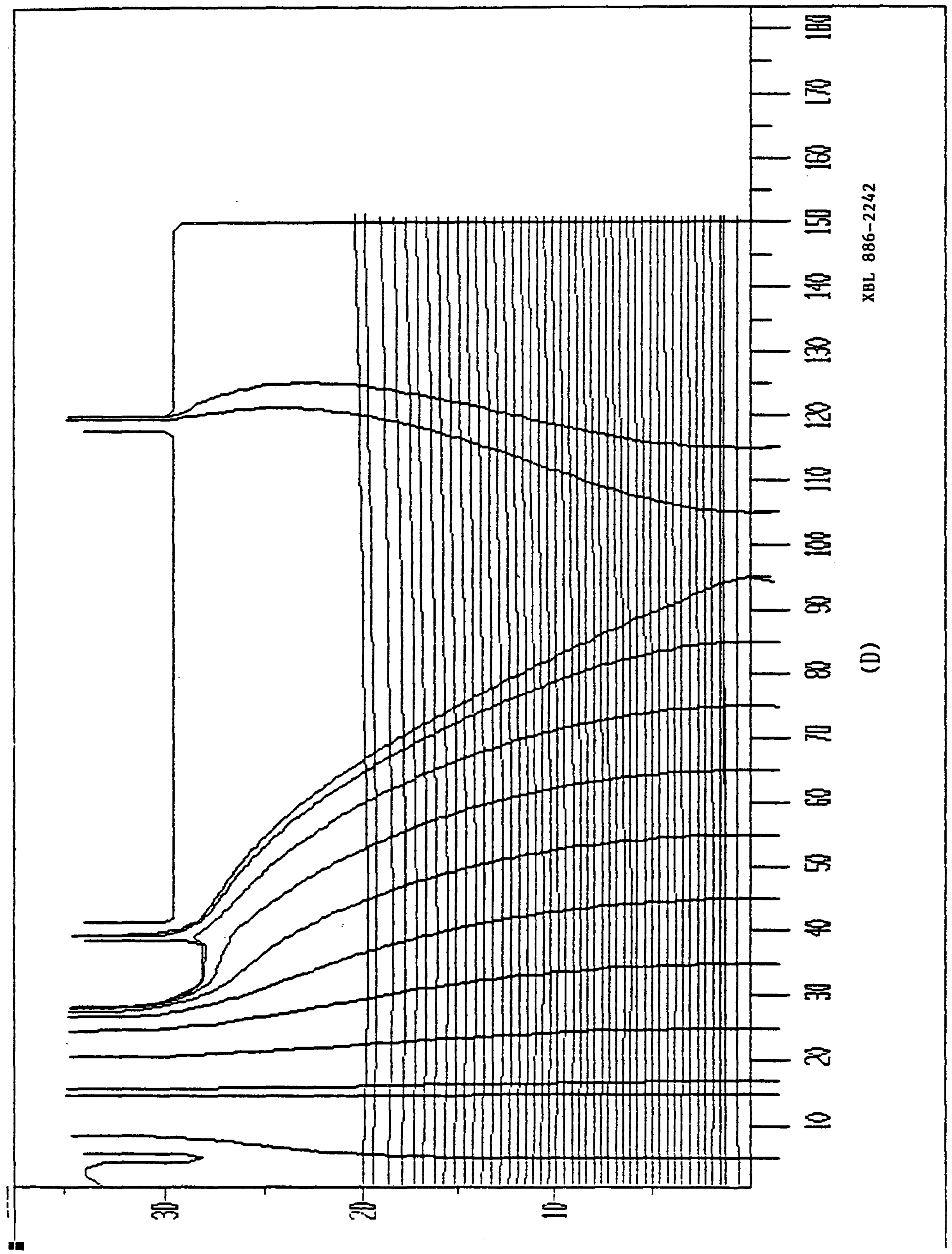
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Fig. 6

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