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An Inverted-Geometry, High Voltage Polarized Electron Gun With UHV Load Lock*

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Abstract

The design of a high voltage electron source with a GaAs photocathode and a load lock system is described. The inverted high voltage structure of the gun permits a compact and simple design. Test results demonstrate that the load lock system provides a reliable way to achieve high quantum efficiency of the photocathode in a high voltage device.

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1. Introduction

Semiconductor photocathodes with negative electron affinity surfaces (NEA) are widely used in photomultipliers and night vision devices. The quantum efficiency of such devices has a very long lifetime and approaches 20–30% near the photoemission threshold. The ability of III-V semiconductors to emit polarized electrons has led to the successful application of GaAs photocathodes in polarized electron sources [1] for electron accelerators.

Polarized electron beams at high energy electron accelerators have provided important experimental opportunities. Polarization of the electron beam at the source approaching 80% has been achieved using photoemission from a strained lattice GaAs photocathode in a high voltage gun [2]. However, GaAs photocathodes are delicate, and there have been problems achieving reliable high voltage performance and quantum efficiency (QE) with previous gun designs [3]. The requirements of ultra high vacuum (UHV) imply baking of the gun structure, while high voltage operation implies “processing” of the gun by slow upward ramping of voltage during which discharges occur. Both of these activities tend to damage the photocathode. The obvious solution is to remove the photocathode during baking and high voltage processing, and then replace it while maintaining UHV. This paper describes a gun structure and “load lock” to solve these problems. The gun was designed for possible future use at SLC at SLAC.

We have developed a polarized electron gun which combines the high voltage structure with a load lock system in a natural way. An engineering solution in this case is to support the HV electrode of the gun with insulators placed inside the vacuum volume, in contrast to designs in which a large cylindrical insulator is the body of the vacuum chamber. In our design, the load lock mechanism is directly connected to the gun body and, as a result, all external parts of the system are at ground potential. This inverted insulator scheme significantly simplifies the system and eliminates any high voltage corona domes.

2. Construction and Operation

The inverted structure polarized gun system consists of three distinct devices: the gun itself, for the production of a beam of up to 200 keV polarized electrons; a preparation chamber to clean and activate photocathodes with successive applications of cesium and NF_3 or O_2 [4,5]; and a transporter to move the photocathode between the preparation chamber and the gun in UHV.

2.1 High voltage chamber

A schematic of the gun is shown in fig. 1. The main components are a stainless steel gun body (2); an anode electrode (20); a cathode electrode (16) supported on three insulating ceramic tubes (13); and the replaceable photocathode crystal mounted on a transport “puck” (21), which is shown in greater detail in fig. 5. The gun is characterized by a simple open design allowing easy insertion of the photocathode through the axially located access valve (8). In this configuration, the anode, gun body, and load lock all operate at ground potential. The high voltage connection to the cathode is in gas through the interior of one of the support insulators, rather than to an end of the insulator whose interior is at high vacuum, as in the typical design.

The UHV environment limits the choice of materials to those with suitable purity and temperature characteristics. All interior metallic surfaces exposed to high electric fields are made of highly polished stainless steel. The cathode and anode electrodes are machined from *304 L* forgings to minimize impurities and maximize homogeneity of the surface. After final polishing with 1 μm diamond paste, the electrodes were cleaned, examined for pits and scratches, and fired at 1000°C in a hydrogen atmosphere.

The cathode assembly includes a docking mechanism for the cathode puck, transitions and supports from the insulators, and cooling tubes. These parts are placed inside the cathode electrode or behind polished shield rings (3) to isolate them from large electric fields.

All of the gun body openings have edges with graduated radii. The large pump ports are made of an array of 20 mm diameter holes (5).

The cathode electrode is bolted to the support plate (17) which in turn is cantilevered inward from the end flange (6) on three ceramic insulating tubes (13). The tubes are 300 mm long, 50 mm outside diameter, and 25 mm internal diameter. The insulator is 95% alumina, smooth on the inner and outer surfaces, and metalized on the ends to permit brazing. The insulators were fabricated by the HiTemp Co. [6]. Each of the upper two tubes can carry a temperature controlled gas flow to provide independent temperature control of the photocathode and of the cathode electrode. Heat exchange is minimized between these zones through the use of thermal bridges in the support plate, which is made from type *316 L* stainless steel. The lower ceramic tube which houses the high voltage cable also carries away exhaust gasses from both zones. The coaxial high voltage cable shield stops at the base flange, and the polyethylene insulated inner conductor connects to the support plate with a banana jack. The cable is sealed with "O" rings at the base as part of the gas flow system.

The three support tubes are subjected to thermal and pressure stresses as well as structured cantilever stresses which reach critical levels at the joints terminating each tube. Here thin Kovar weld rings (11) are brazed to the ceramic material. The design of these braze joints and weld rings was studied using finite element analysis. It is here that permanent deformation is most likely should the gun be subjected to vertical accelerations exceeding 3.2 g or too rapid heating during a bake cycle. Stresses at these joints are minimized during transport and bake by orienting the gun vertically.

At the center of the cathode support plate (17) is a docking mechanism (1) which positions the puck (21) with its photocathode (24). The docking mechanism utilizes a detent feature consisting of three sapphire rollers attached to molybdenum leaf springs to latch the puck against a conical depression. This ensures electrical contact and accurate, secure, and repeatable placement of the photocathode.

The gun has provision for the maintenance of the NEA surface with cesium and NF_3. The cesiator (23) consists of four 17 mm cesium dispensers [7] arrayed in a square through which the electron beam passes. The dispensers are connected in two circuits which provide redundancy. The cesium flux is easily controlled by varying the dispenser current. NF_3 from a pinch sealed tube can be introduced to the vacuum through a standard leak valve.

The gun vacuum is maintained by a 120 l/s ion pump mounted on the top port (4) and a 200 l/s Non-Evaporable Getter (NEG) pump mounted on a side port. Other ports accommodate a Residual Gas Analyzer (RGA), a roughing pump, and a N_2 purge system. Ports shown rotated out of their true positions are a window (19) which may be used for illumination of the photocathode via a mirror machined into the anode base, and one of the two windows (15) used for observation of the puck while docking. Also omitted from fig. 1 are temperature control tubes brazed to the outer can surface and end flange.

The tolerances for the electrode assembly, derived from the electron optics requirements, are 0.2 mm radially and 0.25 mm axially between cathode and anode. These tolerances were met by making precise optical measurements of the relative position of the anode center line with respect to the end flange center line while both were mounted on the gun body. These measurements were then transferred to a fixture which rigidly supported the end flange and cathode support plate in the correct relative position. The three ceramic tube assemblies were then welded in place.

This procedure was carried out with the gun axis vertical for convenience. Since the cathode assembly weighs about 7 kg there is a 0.25 mm drop when the gun axis is rotated into a horizontal plane. Compensation for this gravitational deflection was included in the fixture adjustment prior to welding.

2.2 Preparation chamber

The preparation chamber, used for the thermal cleaning, first activation, and QE evaluation of the photocathodes, is shown in fig. 2. At the right end is an access valve for the photocathode on its supporting puck (4). The central feature of the preparation chamber is an induction heating station with a docking mechanism similar to the gun's.

A water cooled copper induction heating coil (11) coupled to a “flux concentrator” surrounds the puck, which is latched into position against a ceramic ring by means of a three roller detent. The flux concentrator improves the magnetic coupling from the induction coil to the puck. The induction coil transfers energy to the molybdenum puck. The puck and crystal assembly are shown in fig. 5. Since the rf energy losses in the crystal itself are negligible, the crystal receives energy from the puck by radiation and thermal conductivity at the points of the crystal support. An estimate indicates that thermal conductivity provides only about 2 W out of the 20 W required to maintain the crystal at 650°C.

One of the three rollers is titanium and provides an electrical pathway from the puck to the coil assembly, necessary for photocurrent measurement. The roller is made of titanium to prevent welding of the puck at the processing temperatures.

The induction heating coil leads come through ceramic feedthroughs to a matching transformer, and the coil is powered by a commercial generator (120 kHz, 500 W). The water cooling system may also be used to control the temperature of the crystal.

The flux concentrator is open toward the cesiator array (12), which is identical to that of the gun. A window (1) is placed on the central axis of the puck for pyrometric measurement of the crystal temperature. Two windows (13) are provided on the horizontal center plane, each at 45° to the center line, for laser illumination of the crystal. Another window (3), shown here rotated 45° out of position, is used for observation of the puck while docking.

Preparation chamber vacuum is provided by a 30 l/s ion pump on the large top port (2), and by a 100 l/s NEG pump mounted on a port which is not visible in this view. There are additional ports for an RGA and a leak valve for NF_3.

2.3 Transporter

The transporter is shown in fig. 3. It is partially derived from a commercial magnetically coupled manipulator [8]. The manipulator was modified by the addition of two magnets (4) to transmit greater torque and force, a baffle (6) to separate the very clean cathode chamber from the manipulator tube with its movable parts (ball bearings, etc.), and an additional pump port (2) for differential pumping of the clean and "dirty" volumes. A 2 l/s ion pump is fitted to this new port. The actuator shaft end is fitted with a short titanium threaded section (12) which engages a threaded hole on the axis of the puck (11) carrying the cathode. Titanium is used to eliminate cold vacuum welding of the shaft to the puck.

The cathode chamber of the transporter is a special 40 mm vacuum tee. It has the bottom port (10) for a 2 l/s ion pump and connects to the manipulator with a bellows (9) and a three screw positioning device (1). The jack screws facilitate accurate positioning of the manipulator shaft (8) when it is extended beyond the valve (13).

The parking "Y" is shown in fig. 4. It is a chamber which mounts to the preparation chamber valve shown in fig. 2 (7). During use, the transporter mates to the end flange (4) of the parking "Y". The parking "Y" provides a place in the system where a puck with a crystal can be introduced. Its major component is an adjustable detent assembly (1) consisting of three sets each of two sapphire rollers, a molybdenum spring, and an adjustable mounting plate. The insertion force of the puck (3) can be adjusted with set screws.

Docking of the puck is facilitated by the windows (5). The bottom port has a 20 l/s ion pump and roughing valve.

A chamber similar to the parking “Y” is mounted on the gun valve. This chamber is a standard vacuum cross equipped with a 20 l/s ion pump and with provisions for roughing. This chamber does not have a detent mechanism and serves only as a load lock when mated to a transporter for introduction of a new cathode to the gun.

This cross and the parking “Y” contain the only volumes in the entire system that are ever exposed to air or N_2.

2.4 The electric field configuration

The electron optics of the gun are similar to other SLAC electron guns [3]. The configuration of the electrodes and equipotentials of the electric field are shown in fig. 6. The gradient of the electric field at the crystal surface is 3 MV/m at 200 kV gun voltage. The cathode electrode is shaped in a such way that the maximum gradient of the electric field at its surface is only about two and a half times the gradient of the electric field at the crystal surface. The space charge limited current is 30 A at 200 kV.

2.5 Operations

Operation of the system begins with preparation of the GaAs photocathode. The GaAs disk is chemically cleaned [4] and mounted on the puck under clean conditions. The puck is inserted into the parking “Y” detent. A transporter is mated to the parking "Y", and the parking "Y" is pumped down to 10^{-8} to 10^{-9} torr. The transporter valve is opened and the manipulator rod is advanced until its threaded tip engages and is screwed into the puck. Observation through the window ports facilitates this process.

The preparation chamber valve is opened, and the manipulator rod is advanced further until the puck is held by the docking mechanism detents. The manipulator shaft is then unscrewed from the puck and returned to the transporter. The valves are closed, and processing of the photocathodes commences.

After cathode processing is complete, the valves of the preparation chamber and transporter are opened, and the puck is moved to the transporter by inversion of the process described above. Both valves are closed, and the parking "Y" is back filled with dry N_2. The transporter vacuum pumps are attached to portable power supplies, and the transporter is disconnected from the preparation chamber parking "Y".

The transporter is then moved to the gun location and connected to the gun cross which is evacuated to 10^{-8} to 10^{-9} torr. The gun and transporter valves are opened, and the manipulator rod carries the puck through the cross into the gun. The correctly aligned manipulator rod is advanced and latches the puck into the detent. The rod is withdrawn, the valves are closed, and the gun is ready for operation.

3. Performance

All system components are baked under vacuum at 250°C for 48 hours after their final closure. Pressure in the preparation chamber and gun are typically $1–2 \times 10^{-10}$ torr total (mostly hydrogen), with a mass 28 partial pressure of $3–6 \times 10^{-12}$.

3.1 Preparation chamber

Only bulk GaAs crystals [9] 21 mm in diameter were used in the gun tests. An rf induction system is used to heat the crystal to 600°C, as measured by an infrared pyrometer [10]. The radiation heating ensures good thermal uniformity of the crystal surface, but requires the puck temperature to be about 800°C for a crystal temperature of 600°C. It takes about 15 minutes for the crystal to reach the processing temperature. This temperature is maintained for one hour. Temperatures higher than 620°C resulted in a frosted appearance of the crystal surface. An hour is needed for the crystal to cool to room temperature. Then the photocathode was activated with alternating "Yo-Yo" [4] or codeposition [5] of Cs and NF_3. The activation of the crystal with a cesiator current of 4.5 A takes about 10 minutes. The NF_3 flow is monitored by an RGA at mass 52. A partial pressure of 10^{-8} torr at this mass is typical during activation. The activation is monitored by measuring the photocurrent. The light source was a low power diode laser operating at 775 nm, or a HeNe laser operating at 633 nm. The photocurrent was collected either by operating the photocathode assembly at –100 V or the cesiator assembly at +100 V. The illumination of the photocathode was set so that a photocurrent of 1 μA corresponded to about 10% QE.

Five crystals were tested with several heat treatments and activations for each sample. In all cases a high level of QE was achieved, typically 12% at 775 nm and 20% at 633 nm with a few percent relative variation across the crystal surface.

The QE decay time varied widely from activation to activation, from several hours to several hundred hours at room temperature. We do not understand this. It was possible to maintain a high level of QE with a small flux of cesium to the crystal surface [11] (continuous cesiation). Continuous cesiation requires a cesiator current of 2.2 A. At this flux of cesium, the cesiators would be expected to last for many years. No discernible decay of the QE was observed over a period of one week.

3.2 High voltage processing

The gun was HV processed up to 200 kV after it was baked. During the processing two distinguishable kinds of discharges were observed.

The first type of discharge occurred around 100 kV and produced large outgasing. The current of the 120 l/s ion pump increased to about 1 mA, while the gun HV power supply current also went up to 1 mA. Television cameras were set up to look into the gun through two different windows. The one viewing the region between the cathode and anode showed nothing, while the one which looked at the back of the cathode showed diffuse light. It was not possible to find a hot spot on the outside of the vacuum vessel, where the 100 watts generated by the power supply were dissipated. The large current ratio and observation of the light in the first type of discharge indicates that some ion generation process has to be involved.

The second type of discharge caused little outgasing. While the gun HV power supply current was about the same as in the previous case, the current of the 120 l/s ion pump was about one hundred times smaller. A TV camera showed no light from either window, but a hot spot was evident on the gun body side near the leak valve. The hot spot was consistent with point-like electron emission from the cathode electrode near a region of maximum electric field. The ratio of pump current to HV supply current of 10^{-2} is typical for neutral atoms released when electrons with energy range from 100 to 200 keV strike the wall of the vacuum vessel. A desorbtion coefficient can not simply be calculated because of uncertainties of the pumping speed in the presence of the NEG pump.

After processing, the gun drew a dark current of about 10 uA at 200 kV with an ion pump current of less than 0.1 uA. Figure 7 shows the HV dependence of the residual dark current for the processed gun.

3.3 Photocathode behavior in the gun.

The QE of an activated crystal introduced into the gun was typically about 10% at 775 nm. The lifetime of the QE varied as widely as in the preparation chamber. The typical QE lifetime at low voltage (100 V) was about 30 hours at room temperature.

The QE lifetime demonstrated a strong dependence on the gun dark current. At 1.5 uA dark current (160 kV), the observed lifetime was 20 hours, and at 10 uA (200 kV), the QE lifetime decreased to 5 hours. The QE drop related to the gun dark current was not recoverable even with heat treatment of the crystal. One possible explanation of this phenomenon is the ion bombardment of the crystal surface. We are considering an alternative shape for the anode electrode to decrease the ion bombardment of the crystal.

The gun was then tested with pulsed HV. The DC power supply was replaced with a low impedance modulator which could deliver 100-ns-wide pulses of up to 130 kV, on top of a DC bias voltage of 50 kV. A beam line consisting of a focusing solenoid, a bend magnet, and a Faraday Cup was added to the output of the gun. A nitrogen laser with a pulse width of approximately 2 ns, a pulse energy of about 40 uJ, and 20 Hz repetition rate was used to illuminate the cathode. Figure 8 shows the current pulse shape measured at the Faraday Cup by a 400 MHz bandwidth oscilloscope. The oscillations are due to an impedance mismatch of the Faraday Cup assembly. The peak current of 25 A is close to that expected from the space charge limit. The total charge in a single pulse was about 50 nC.

4. Conclusion

Operational experience with the system demonstrated the ability to provide a photocathode with high QE and acceptable life time with a DC HV at the gun of up to 120 kV. With pulsed HV, operation of the gun is possible up to at least 180 kV. We hope that the DC HV limitation may be relaxed with the modified contour of the anode electrode.

The load lock system eliminates baking or HV processing in the presence of the photocathode crystal. This leads to a higher QE of the photocathode. Photocathode replacement in the gun takes only a few hours. This scheme permits the preparation and utilization of high QE photocathodes in a high voltage gun.

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Figure Captions

Fig. 1. Gun: (1) docking mechanism and puck holder, (2) gun body, (3) shield rings, (4) ion pump port, (5) pumping holes, (6) end flange, (7) jacks for aligning transporter to puck holder, (8) access valve, (9) high voltage cable, (10) bellows, (11) Kovar welding, (12) gas seal flange, (13) ceramic insulator, (14) transporter rod (only in place while changing photocathode), (15) docking window, (16) cathode electrode, (17) support plate, (18) gas tubes, (19) illumination window, (20) anode electrode, (21) puck, (22) exit port to beam line, (23) cesiator, (24) photocathode.

Fig. 2. Preparation chamber: (1) pyrometer window, (2) ion pump port, (3) docking window, (4) puck, (5) bellows, (6) jacks for aligning transporter to detent, (7) access valve, (8) parking "Y", (9) ceramic feedthroughs, (10) RGA and leak port, (11) heating coil, (12) cesiator array, (13) to lumination window, (14) housing.

Fig. 3. Transporter: (1) positioning jacks, (2) pump port, (3) ball bushing, (4) coupling magnets, (5) manipulator, (6) baffle, (7) manipulator flange, (8) manipulator shaft, (9) bellows, (10) pump port, (11) puck, (12) titanium screw, (13) access valve.

Fig. 4. Parking "Y": (1) detent assembly, (2) photocathode, (3) puck, (4) flange-mates w/transporter, (5) window.

Fig. 5. Puck assembly: (1) puck, (2) photocathode, (3) clamp.

Fig. 6. Potential distribution between cathode and anode for –200 kV cathode potential: (1) crystal, (2) support plate, (3) cathode electrode, (4) anode, (5) can, (6) ceramic insulator.

Fig. 7. Dark current as a function of voltage.

Fig. 8. Faraday Cup signal.

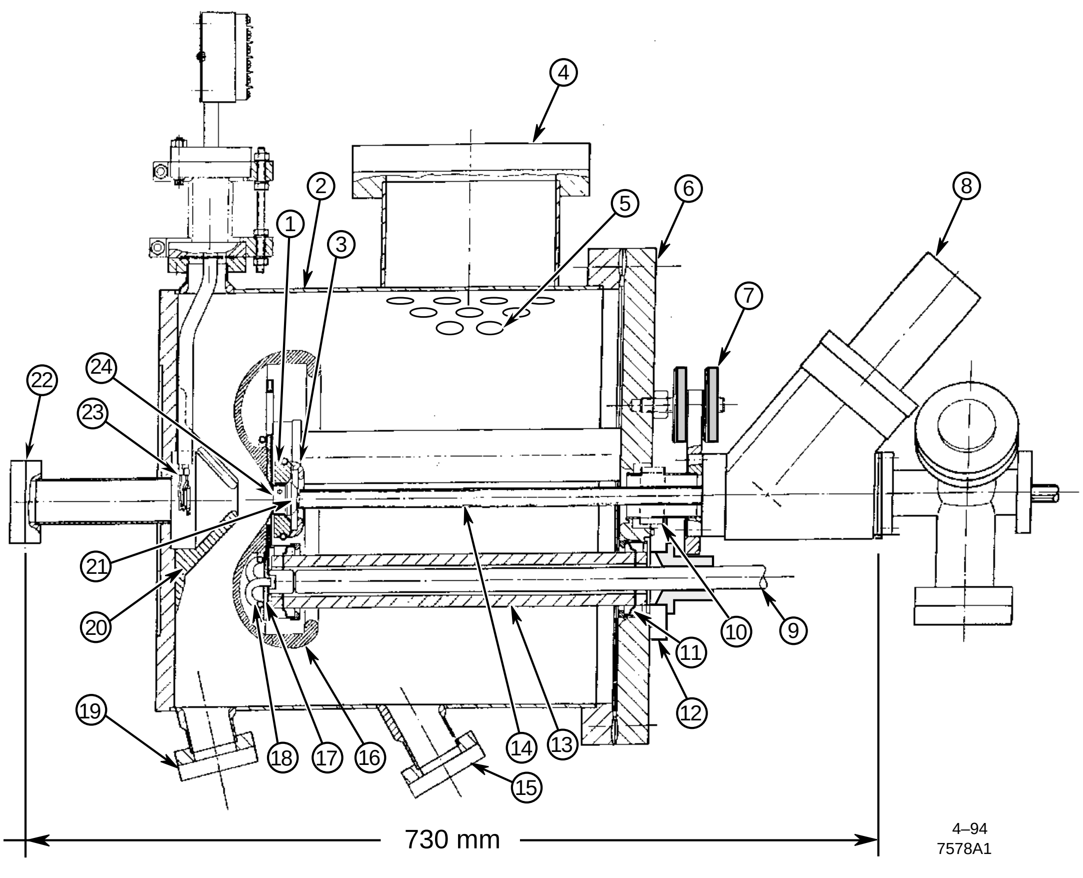

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Figure 1

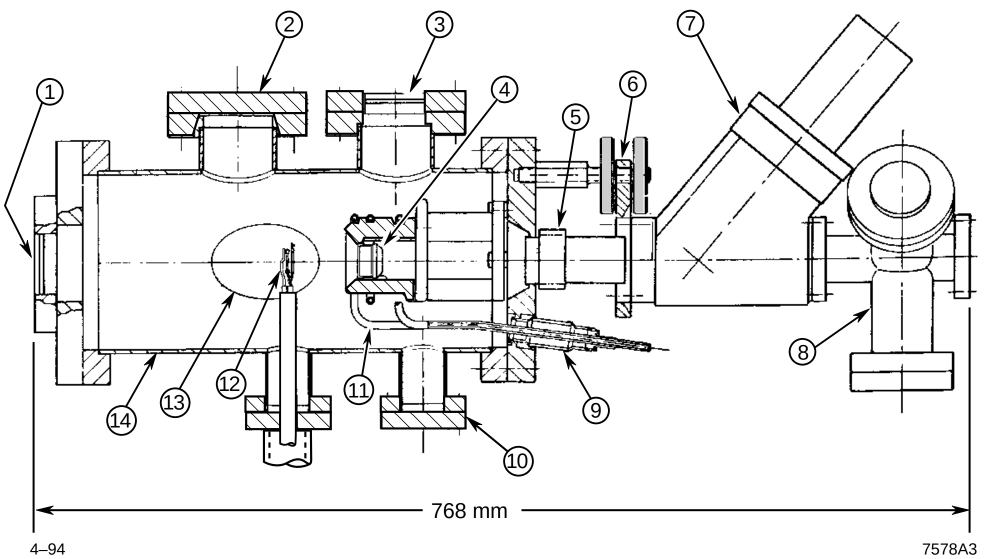

Figure 2

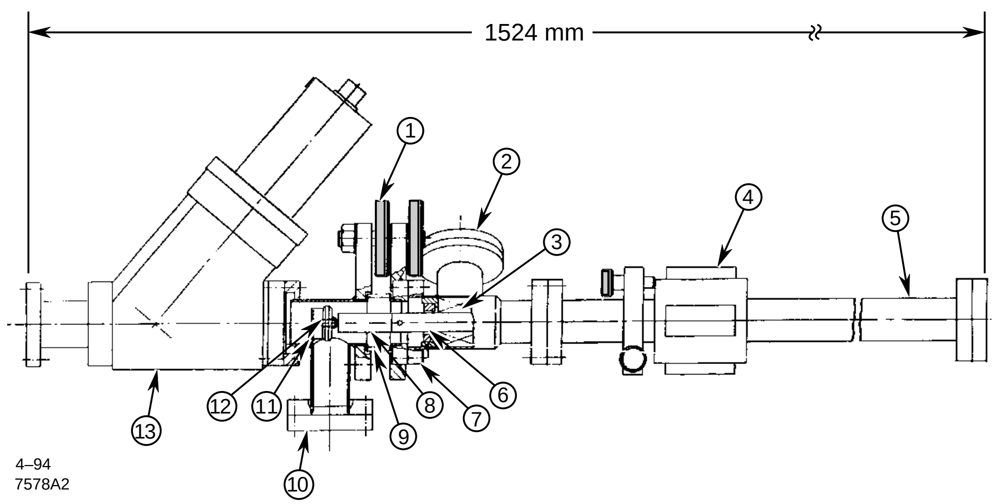

Figure 3

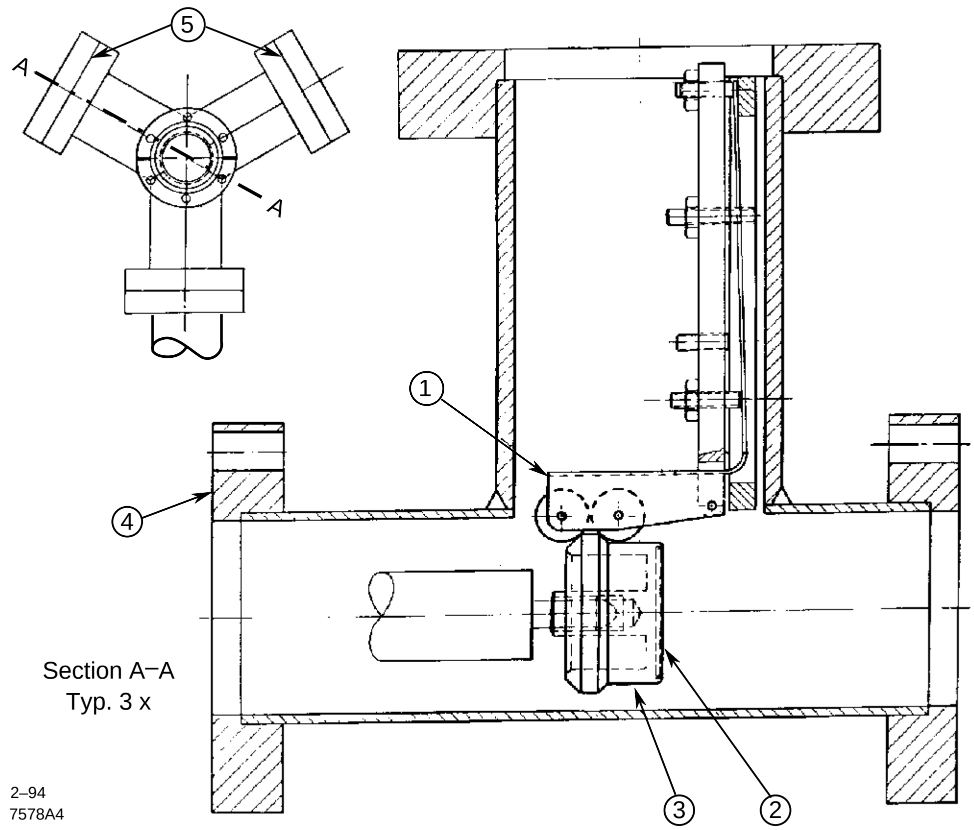

Figure 4

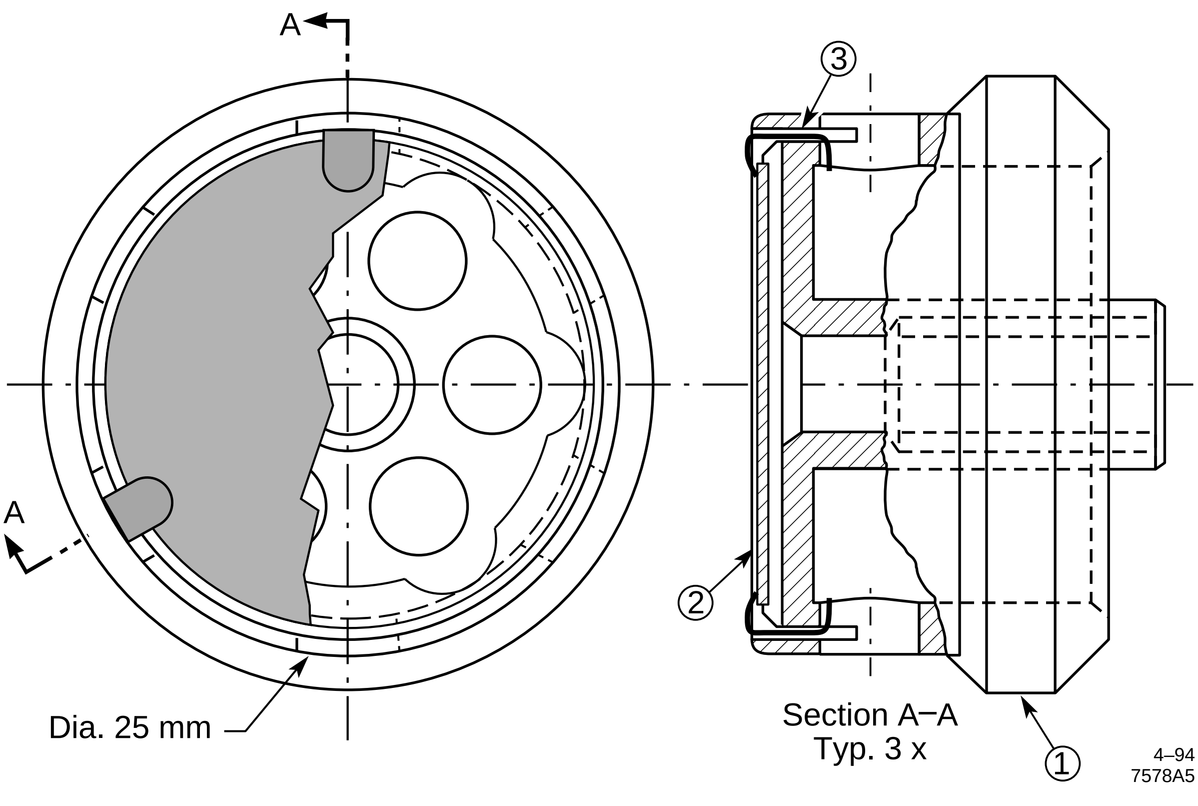

Figure 5

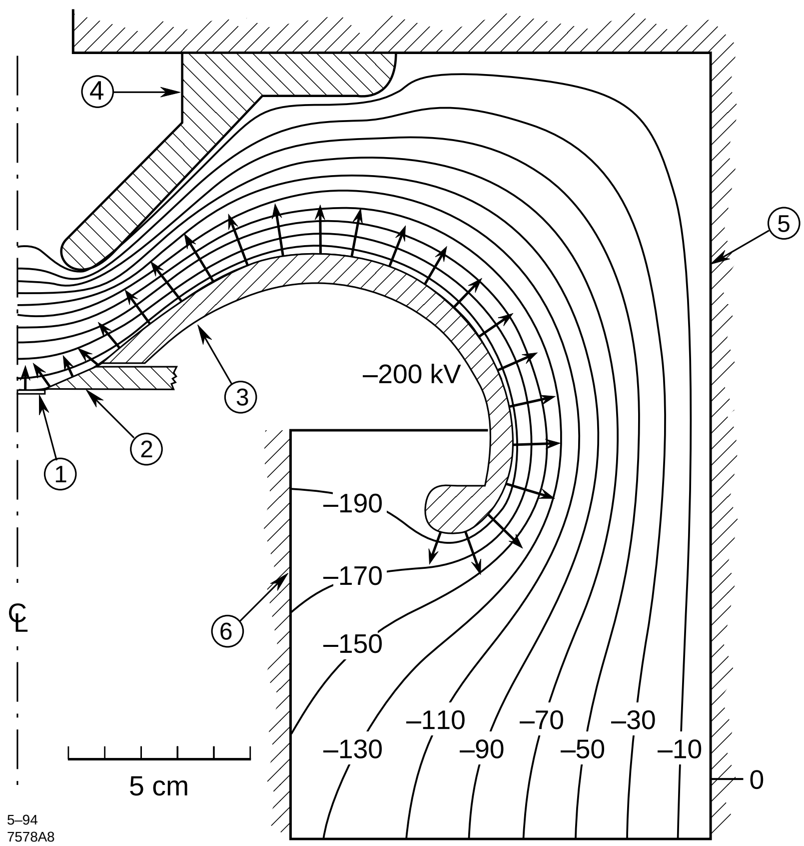
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Figure 6

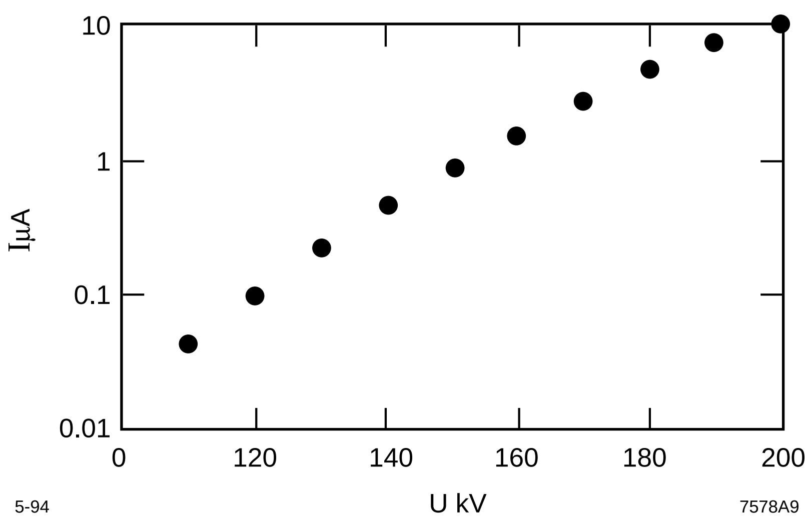

Figure 7

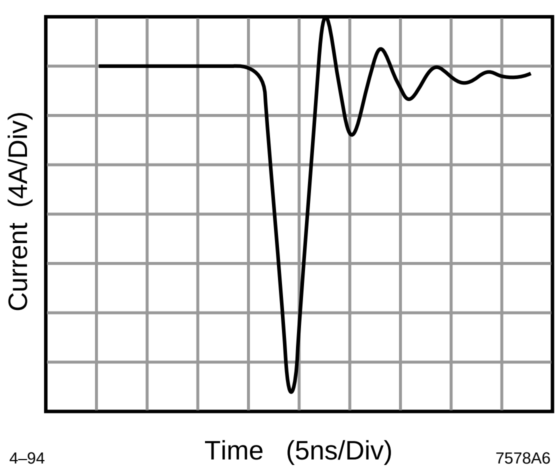

Figure 8