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Low Energy Electron Gun Power Control Unit

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ECE 391 Senior Project Proposal
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I. Spacecraft Charging

Near-Earth orbiting spacecraft are subject to a variety of physical environmental elements. Of these, natural space plasma and solar radiation produce spacecraft charging. Spacecraft charging consists of surface (external) and deep (internal) dielectric charging.

Natural space plasma is composed of electrons and positively charged atoms called ions. The plasma is generated by energy from solar radiation and high energy particles emitted by geomagnetic storms. The electrons produce a negative current and the ions produce a positive current. Positive photoelectron currents produced by solar radiation of spacecraft surfaces also add to the electrical fluxes[i].

As spacecraft move through the atmosphere, they may be subjected to an unequal flux of electrons and ions. These unbalanced electrical fluxes induce charges on the surfaces and inside spacecraft. In the lower regions of the earth's atmosphere the electrons and ions tend to be of a lower energy level than those at a higher altitude. Therefore, greater charges are generally induced at higher altitudes. Also, the higher energy particles tend to be the ones that penetrate deeply into the spacecraft and produce the dieletric (internal) charges.

Often, the entire surface of spacecraft is not crafted of the same material, resulting in uneven charge distribution on the surface and inside of spacecraft. This unequal charging may produce arcing which often causes equipment malfunction and failure, false instrument readings and poor sensor performance. Arcing may also cause physical damage to the spacecraft structure and contamination of the surface. Many cases of anomalies due to spacecraft charging have been recorded [ii].

Modern electronic systems employ low voltage and low current circuitry and are being designed in smaller and smaller packages. These new systems tend to be much more sensitive to space charging effects than the more robust systems employed in older equipment. Also, spacecraft are being deployed into orbits comparitevly higher than in past missions. The higher orbit particles pack a lot more punch, producing higher charging potentials and greater arcing possibilities[iii].

II. Spacecraft Charging Prevention Plan

To help design engineers prevent spacecraft charging anomalies, research must be done to understand how the spacecraft and its surface materials react to contact with the electrical fluxes encountered in the natural space plasma. Fortunately, electron gun technology exists which allows researchers to simulate the natural space environment and the effects of plasma on spacecraft. Research in this field has been undertaken by R.E.Davies and J.R. Dennision[iv]. As a result of their experiments they were able to determine that spacecraft do suffer severe space charging and surface contamination due to space charging. They also determined a characteristic equation including coefficients which indicate the rate of secondary electron emission- the ejection of low-energy electrons from surfaces as a result of energetic electron bombardment.

An electron may strike and alter a surface in three ways. First, the electron may strike the surface and be absorbed increasing the surface's overall negative potential. Second, electrons may enter a surface and bounce around a few times, shuffling energy levels and then leaving the surface (backscatttering). Third, electrons may penetrate the surface and knock other electrons off the surface. They may themselves be absorbed or be backscaterred R.E. Davies and J.R. Dennision performed these experiments with electron energy levels in the 1-5 KeV range.

The results of similar studies will allow design engineers to develop more charge resistant, safer spacecraft and electronic modules. The results may also be applied in electron microscopy and for the increase of basic physics knowledge.

III. Design Motive

R.E.Davies and J.R. Dennison's studies involved the use of an electron gun that furnished electron energy levels in the 1-5 KeV range. R.E.Davies and J.R. Dennison wish to perform similar studies but with a much more versatile and stable electron gun. They need an electron gun that will provide them with electron energies below the 1 KeV up to the 5 KeV range to cover a greater energy spectrum. Also, they wish to have a unipotential power supply unit for the electron gun. The unipotential design permits the lenses and focusing devices of the electron gun to be controlled by a single voltage source. With a single voltage source adjustment, the other lense and focusing voltages will follow proportionally. This will eliminate the need to hand adjust each lense and focusing element with each desired change of voltage level.

III. Design

Under the supervision of J.R. Dennison, I will design and develop the power control unit for an electron gun that will emit electrons in the 0-5 KeV energy range. My design is closely based on the electron gun design by Yijan Cao and Edward H. Conrad[v] at the University of Missouri, Columbia, Missouri. As stated in their article, " It is a unipotential electron gun design for low energy electron diffraction. The unipotential design offers independent beam energy and current control without refocusing, and operates at beam currents as high as 25 nA."

A copy of the figure of the electron gun and its power control unit as found in Cao and Conrads' article is included below. It is a rather simple and straightforward design. The gun itself consists of a cathode and two apertures. The cathode is a LaB_6 (Lanthanum HexaBoride) made by Kimball Physics Inc. Typical cathode operating parameters are 2.5 V and 1.9 A or approximately 4.75 W. The cathode will be running at a temperature of approximately 1700 Kelvins for the above parameters. Lenses follow the gun for electron acceleration and focusing. A single system voltage source, Vs, will provide the various potentials needed to operate the gun. A power source that will be floating on a proportional value of Vs will be used to control the cathode current.

A voltage network divider will distribute Vs across the system to provide the accelerating and focusing voltages necessary for the electron bombardments. A determined proportion of Vs (negative with respect to ground) will be applied to the cathode section of the circuit. This voltage difference with respect to ground will determine the energy of the emitted electrons. The power source will float on this voltage and deliver the necessary current to emit the electrons from the cathode. Higher potential apertures will suck the electrons into the gun's tube. As the electrons move down the tube they will be focused according to the voltages applied across the lenses, E1 through E3. Generally, the voltages across these lense will increase respectively to ground. The end of the gun's tube is at ground potential.

Figure from Cao and Conrad

The power control unit as described above has been put into place and tested by F.-K. Men, B. L. Clothier and J.L. Erskine, Department of Physics, University of Texas at Austin, Austin, Texas[vi]. They followed Cao and Conrads' design and provided an exact report of the equipment and values they used in their design implimentation. The power control unit can be broken into three sections: the voltage (Vs) divider portion, the cathode portion and the emission current amplification circuit and meter. Below is a copy of each final section design figure that they used:

Voltage Divider Circuit

A single voltage source, Vs, fuels the apertures, lenses and energy level (V_Cathode) for the electron emmitting cathode. V_Cathode is found at the negative terminal side of Vs. A series of parallel potentiometers in parallel control the distribution of Vs. There are two apertures, A1 and A2, and three lenses, E1 through E3. E2 is actually subdivided into four parts. The four lenses (all at right angles to one another) allow for horizontal and vertical focusing of the electron beam.

In unipotential electron gun design, Cao and Conrad concluded that the following voltage level proportions for the apertures and lenses referenced to V_Cathode provide optimum results. The ratios are simply V_Lens/Aperture to V_Cathode ((V_L/A)/V_Cathode). The desired value of V_Cathode is .4Vs

Operating Parameters Table

In Men, Clothier and Erskines' implimentation, a Valhalla Scientific Model 2701C Programmable precision DC Voltage Calibrator was used as Vs. The Valhalla ranges from 0 to 1200 Volts DC and can source 120 mA. 200 K Ohm ten-turn potentiometers were used to tune the voltage outputs across the aperture and lens elements. A single 50 K Ohm ten-turn potentiometer provides control for the V_Cathode value.

My design and implimentation of the voltge divider network will be similar to Men, Clothier and Erskines' implimentation but will contain some slight modifications. Dr. Dennison desires a unipotential voltage range (Vs) between 0 to 10000 volts. Large voltage sources provide much lower current values than low voltage sources. The 200 K Ohm potentiometers would draw too much current for such a high voltage source. Greater resistances that will withstand the power ratings are needed to decrease the current demands placed on Vs.

Dr. Dennison and I originally intended to replace the 200 K Ohm ten-turn potentiometers will higher valued ten-turn potentiometers. The switch is not possible however. Values greater than 200 K Ohms are not common for ten-turn potentiometers. The largest we could find was 500 K Ohm. Their extremely expensive, $150-200, and it would have taken 6-8 weeks for them to be especially manufactured. Also, 500 K Ohm would still not be large enough to significantly slow the current or handle our power ratings associated with a large voltage source. We finally decided to impliment fixed resistors in series with 200 K Ohm ten-turn potentiometers. Our broad range voltage tuning abilities across the apertures and lenses will be cut, but with careful design we should be able to maintain around 20 percent control over the voltage levels. We will follow the (V_Aperture/Lens)/V_Cathode proportions as stated above to determine our fixed resistor series locations.

Another change will be the lens setup. The gun which Dr. Dennison will use is not equipped to function with E2 broken into four parts. Instead, we will have a single voltage across E2 and another group of lenses which we shall call Deflectors 1 through 4. They will perform the same purpose as the four lenses making up the original E2 design did. Roughly, 10 percent of Vs will be used on the deflectors. The absolute value on the deflectors will be equal, although two will be negative and two positive. They will be positioned at the end of the gun.

The following schematic is our projected voltage divider network design.

Our Voltage Divider Network

We have chosen 2.2 M Ohm as our base value across the lens and deflector bridges. We will put 2 M Ohm across the aperture bridges. With 200 K Ohm ten-turn potentiometers we will still have almost 10 percent control over the voltage output to the various lenses. We need a slightly greater control across the apertures and ten percent should allow us this. We are looking for roughly ten percent of Vs values to be found at our deflector voltages. A set and leave potentiometer value is controlled by a smaller fixed resistor in series with a 200 K Ohm potentiometer.

The cathode filament will be heated by a 0-7 Volt power source capable of supplying up to 2 Amps. The source will be floating on the V_Cathode voltage tapped off from Vs. A 100 Ohm trimmer potentiometer at the entrance to the cathode circuit will control the balance of V_Cathode across the cathode filament. An ammeter will be used to monitor the current output of the 0-7 Volt source.

Men, Clothier and Erskines’ implimentation of the cathode circuit follows. We will follow their design exactly. Our power source is equipped with both a current and voltmeter. We will not need to include another meter as they have done.

Cathode Circuit

Much of the electron beam emitted from the cathode filament will be attracted and collected by the gun's apertures. This small current will be used to measure the electron beam current. Roughly ninety percent of the beam is soaked up by the apertures. This current will be returned to the power control unit circuit at the V_Cathode node. The current can re-enter the system through the voltage divider network or it can pass through a 10.05 (equivilent) K Ohm resistance and enter the power source circuit. Most of the current should flow back into the power source circuit. As it does so, it will cause a slight change in the voltage across the 10.05 K Ohm resistance which will be monitored by an emmission current circuit. This emmission current circuit is comprised of an operational amplifier and an ammeter. The operation amplifier will serve as a buffer and stabalizer to the ammeter circuit. This circuit will allow us to determine the total emmision current based on the 90 percent rule. The circuit schematic employed by Men, Clothier and Erskine follows.

Amplification Circuit for Emission Meter

[i]Spacecraft pamphlet

[ii]Spacecraft charging pamphlet.

[iii]Spacecraft charging pamphlet.

[iv]R.E.Davies and J.R.Dennision,"Evolution of Secondary Electron Emmission Characterictics of Spacecraft Surfaces", *Engineering Notes*, Vol. 34, No. 4, July-August 1997.

[v]Yijan Cao and Edward H. Conrad, "High q-resolution electron gun for low energy electron diffraction", Rev. Sci. Instrum. 60 (8), August 1989.

[vi]F.-K Men, B.L. Clothier and J.L. Erskine, “Low-energy-electron-diffraction system using electron gun and position-sensitive detectors”, Rev. Sci. Instrum. 64(7), July 1993.