1 Overview

The complete control circuit for the electron gun, including all power supplies, current measurement points, and part of the control and measurement circuitry from the Data Aquisition system is shown in Figure **??**.

2 Electron Optics

A diagram of the electron gun without attached electronics is shown in Figure **??**, and a photograph of the gun is shown in Figure **??**.

2.1 Focusing the Gun

The electron gun was been salvaged from an old Cathode Ray Oscilloscope (CRO). The original phosphor screen was also saved, which allowed for very rough focusing of the beam by viewing the illuminated region of the screen through a porthole in the vacuum chamber. Figure **??** and **??** are photographs of the illuminated spot under focusing conditions chosen to create the largest and sharpest possible spot sizes respectively.

The distance between the gun and target sample was different to the distance from the gun to its original screen. In addition, the original screen consisted of a cylinder with conductive coating at the same potential as the final electrode. These differences in configuration mean that the gun must be refocused for use in TCS.

The electron gun may be considered "focussed" if the beam is paraxial to the surface of the sample.

By a process of trial and error

3 Current Measurements

3.1 Total Current

Total Current Spectroscopy methods measure the slope of current through a sample with respect to the energy of electrons relative to the sample surface. Often lock-in amplifier techniques are used [**?**]. These have the advantage of reducing system noise whilst determining the slope directly, but require more time to set up than measuring the current through the sample as a function of incident electron energy. Hence lock-in amplifier techniques were not used for this project, instead current was measured through a conventional ammeter (Keithley 610B electrometer).

3.2 Emission Current

Ideally, the electron gun should produce a constant emission current for fixed electrode potentials. In reality, the emission current changes as the filament reaches thermal equilibrium or "ages", and so it was desirable to measure the emission current. Applying Kirchoff's current law, it can be seen that the current flowing into the initial energy set point is equal to the total current leaving the filament. This current was measured using a Keithly 602 electrometer.

3.3 Leak Current

"Leak" currents are currents flowing through the electrodes of the gun. These can be reduced by optimising the potential of the gun electrodes, but are almost impossible to eliminate entirely. The leak current is expected to be equal to a constant (and usually large) fraction of the emission current.

A measurement point was included for the total leak current through most of the gun electrodes.

3.4 The Ammeters

An ideal ammeter has no input resistance. In reality, it is not the current that is measured, but the voltage accross a fixed input resistor. This voltage can either be amplified, or the resistance increased, for measuring a smaller current.

The 602 and 610B electrometers both provide a large range of scales and amplifier settings for current measurement. Using a low scale setting increases the input impedance, which increases the potential drop accross the ammeter. However, using a large amplifier gain increases noise; hence there is a trade off. For the 602 and 610B electrometers, a significant drift (typical +5% of scale in 10min) in the zero level was also observed at high amplifier gains, whilst low gains appeared more stable (+10% noted after 2 days).

4 Data Aquisition and Automation

4.1 ADC Measurements

4.2 DAC Control of Initial Energy

5 Vacuum Chamber and Sample Holder

5.1 Vacuum Chamber

5.2 Sample Holder

6 Sources of Error

6.1 Accuracy of ADCs

Figure **??** shows the ADC counts vs time measured for a controlled input voltage. The input voltages were set using a GW Instek GPS-1850D Power Supply, which has a quoted noise of

Figure **??** shows the same output voltages of the GPS-1850D Power supply measured using an Agilent Oscilloscope.

Based on these figures, an estimate of ± 1 count for the error of the ADC seems reasonable. This corresponds to $3.2mV$.

6.2 Noise due to Instruments

The Keithly 602 electrometer quotes a minimum noise value of $10mV$ and maximum of , whilst the 610B electrometer quotes The noise was found to increase with the amplifier gain setting on each electrometer. Figure **??** shows the

6.3 Noise due to Ground Loops

By far the greatest source of noise encountered in this project was a 50Hz sinusoidal "hum". The amplitude of this sine noise varied with instrument from $\pm 10mV$ (610B) to $\pm 1V$ (602).

The 50Hz nature of the noise suggests that it is related to mains power. So called "Ground Loops" arise when a circuit incorporates multiple paths to mains Earth. This is indeed the case with the circuit in Figure **??**.

In an ideal situation, mains earth would never be used as a signal ground source. Unfortunately, the use of mains earth as signal ground was unavoidable in this project due to safety and practicallity reasons. The turbo-molecular pump attached to the vacuum chamber was housed within a steel casing, which was grounded to mains earth for obvious safety reasons. This in turn grounded the entire steel vacuum chamber and the table upon which it rested to mains earth. The sample holder must be kept at the same potential as the surrounding vacuum chamber and shielding, and hence it was also connected to mains earth.

The DAQ box itself became grounded to mains earth both through the RS-232 connection to the laptop, and also through the input from the sample current electrometer (610B).

6.4 Reduction of Noise

The simplest way to determine the DC level of the ADC inputs was use of a large number of averages. Performing averaging on a signal is equivelant to passing the signal through a low pass filter **??**.

Software averaging alone is not always sufficient to reduce noise. If the sinusoidal noise has a larger amplitude than the DC level, part of the signal will be negative with respect to ADC ground. ADCs are only capable of measuring positive voltages with respect to ground. A negative voltage is measured as a zero. Hence the averaged signal will be larger than the DC level of the input. This was found to be the case for measurements of the emission current.

To solve this difficulty, a physical low pass filter was added at the input for the differential ADC. The cutoff of the low pass filter is: Although some sinusoidal noise was still observed after the addition of the filter, it was reduced to a level that made software averaging feasable.

6.5 Time variance of measured current

There are two effects:

1. When the initial energy is changed, the sample current trends towards an assymptote. The trend is exponential with a very large time constant (2min to 5min).
2. The general shape of successive I-V curves changes noticably

Possible causes:

- Capacitance of Sample holder