MCP Scrubber for Large-Area Picosecond Photo-Detectors

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Helmholtz Coil Design for MCP Scrubber

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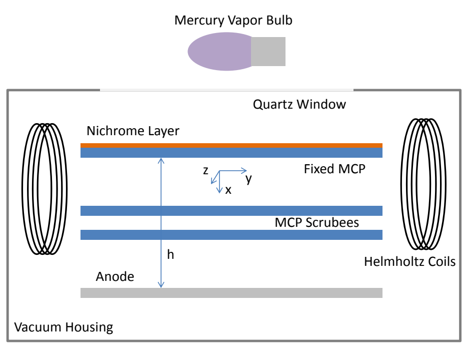
Abstract

We would like to build a device which scrubs multichannel plates (MCP's) by bombarding them with electrons. When light above a certain energy threshold strikes a metal, electrons are liberated from the metal by the photoelectric effect; we propose to accelerate these photoelectrons towards MCP's using an electric field. In order to ensure that the electrons are distributed over the plates with reasonable uniformity and to smear out any "hot-spots" which might develop, we apply a dithering magnetic field in the region between the MCP's and the electron source using two pairs of Helmholtz coils. If the magnetic field is too weak we will see minimal spread of electrons; an excessively strong magnetic field will cause the electrons to either miss the MCP's altogether or curl back up to the metal layer from which they were liberated. The focus of this paper is on determining the dimensions of the device—specifically, the strength of the magnetic field, the distance from the electron source to the target MCP's, the frequency of oscillation in the magnetic fields, and the radius and separation of the coils—which optimize both the spread and flux of electrons on the MCP's.

1 Overview

A schematic diagram of the device is presented below:



Light emitted from a mercury vapor bulb passes through a quartz window into the vacuum chamber which encloses the remaining components. Upon incidence with a layer of nichrome (80% Nickel, 20% Chromium) alloy, the light releases electrons from the alloy by the photoelectric effect. The number of electrons is amplified by the fixed MCP, and the resulting stream of electrons is accelerated towards the target MCP's by a voltage applied between the nichrome layer and the anode.

To further ensure a uniform spread of electrons on the scrubees, two pairs of Helmholtz coils are placed orthogonally to each other along the edges of the MCP's—these are designed to create a uniform magnetic field between the stationary MCP and the MCP scrubees. We vary the magnitude of the fields in order to spread out any hot spots which might arise.

Not depicted in the diagram are the second set of Helmholtz coils, the flange in the vacuum chamber necessary for easy removal and insertion of the MCP scrubees, the vacuum pump and electrical feedthrough, and the spacers holding all of the components in place within the vacuum chamber.

2 Electron Trajectories

In the limit of constant electron momentum (equivalently, in the absence of any external electric fields), electrons liberated from the nichrome layer will follow circular trajectories through the magnetic field. The electron trajectories deviate from circular paths in our case since we will be applying a large accelerating voltage simultaneously with the magnetic fields. To find the electron trajectories we will use the full electromagnetic Lagrangian, which takes both fields into account.

The Lagrangian for electromagnetic fields is given in general by:

$$\mathcal{L} = \frac{1}{2}m(\dot{x}^2 + \dot{y}^2 + \dot{z}^2) - q\phi + q(\mathbf{v} \cdot \mathbf{A}) \tag{1}$$

We create the electric field by applying a voltage between the nichrome plate and an anode placed beneath the MCP's. We can thus approximate the electric field as that of a parallel plate capacitor; if V_0 is the voltage difference between the nichrome layer and the anode and h is the separation between them, we can assume a uniform electric field given by $\mathbf{E} = -\frac{V_0}{h}\hat{x}$, and consequently a potential of $\phi = \frac{V_0}{h}x$. It can be easily checked that the following vector represents the general form of the vector potential for a uniform magnetic field of magnitude B_0 in the $\hat{z}$ direction:

$$\begin{pmatrix} -rB_oy & pB_0x & 0 \end{pmatrix} \tag{2}$$

Here r and p are arbitrary parameters subject to the constraint that $r + p = 1$, as allowed by gauge freedom.

Combining the electric and vector potentials gives us the full Lagrangian for our system:

$$\mathcal{L} = \frac{1}{2}m(\dot{x}^2 + \dot{y}^2 + \dot{z}^2) - q\frac{V_0}{h}x + q(-rB_oy\dot{x} + pB_0x\dot{y}) \tag{3}$$

From here we can proceed with the usual Lagrangian formalism. Using the coordinate system described in the schematic drawing above, the kinematic equations in the $\hat{z}$ direction are:

$$\frac{\partial \mathcal{L}}{\partial z} = 0 \tag{4}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\frac{\partial \mathcal{L}}{\partial \dot{z}} = m\ddot{z} \tag{5}$$

So the electrons experience no net force in the $\hat{z}$ direction—the only contribution to $\hat{z}$ motion will be the electrons' initial velocities in that direction. The $\hat{x}$ direction tells a different story:

$$\frac{\partial \mathcal{L}}{\partial x} = q(-\frac{V_0}{h} + pB_0\dot{y}) \tag{6}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\frac{\partial \mathcal{L}}{\partial \dot{x}} = m\ddot{x} - qrB_0\dot{y} \tag{7}$$

Using $r+p = 1$, we arrive at the following differential equation:

$$\ddot{x} - \frac{q}{m}B_0\dot{y} + \frac{q}{m}\frac{V_0}{h} = 0 \tag{8}$$

Similarly, for the y derivatives:

$$\frac{\partial \mathcal{L}}{\partial y} = -qrB_0\dot{x} \tag{9}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\frac{\partial \mathcal{L}}{\partial \dot{y}} = m\ddot{y} + qpB_0\dot{x} \tag{10}$$

Thus:

$$\ddot{y} + \frac{q}{m}B_0\dot{x} = 0 \tag{11}$$

We can now solve the system of differential equations defined by(8) and (11) to find time dependent equations for the vertical (x) and horizontal (y) position of the particle. Since we are primarily interested in finding the displacement in the y direction when the electron strikes the MCP surface, we will consider an electron which is at the origin at t=0; in this case y(t) will be equal to the displacement. Our assumption of uniformity in the electric and magnetic fields warrants the assumption that electrons will be displaced by roughly this amount regardless of where they are released on the nichrome layer.

The only two other initial conditions are the starting velocities in the x and y directions, which we label as v_{x0} and v_{y0}, respectively. These are determined by the residual energy of the electron as it exits the MCP; we will show later that typical initial energies have a comparatively small effect on the electron trajectories

If we let $E_0 = \frac{V_0}{h}$ and $R = \frac{e}{m}$ (e is the absolute value of the charge of the electron), the complete solution to the system of equations is:

$$x(t) = \frac{v_{x0}\sin(RB_0t)}{RB_0} + \frac{(\Gamma)\big(\cos(RB_0t) - 1\big)}{RB_0} \tag{12}$$

$$y(t) = \frac{v_{x0}\big(1 - \cos(RB_0t)\big)}{RB_0} + \frac{(\Gamma)\sin(RB_0t)}{RB_0} + \frac{E_0}{B_0}t \tag{13}$$

where

$$\Gamma = v_{y0} - \frac{E_0}{B_0} \tag{14}$$

3 Analysis

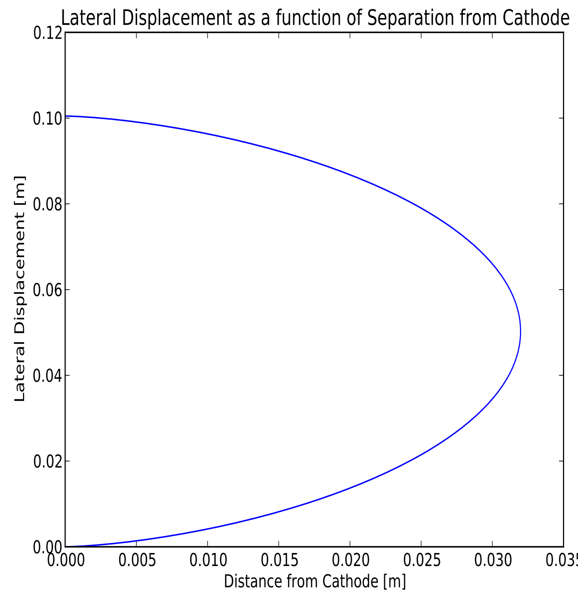
3.1 Initially Stationary Electrons

We begin by considering the case where the initial electron velocities are negligible—that is, we set v_{x0} and v_{y0} in both (12) and (13) equal to zero. This simplifies things considerably:

$$x(t) = \frac{-E_0\big(\cos(RB_0t) - 1\big)}{RB_0^2} \tag{15}$$

$$y(t) = \frac{-E_0\sin(RB_0t)}{RB_0^2} + \frac{E_0}{B_0}t \tag{16}$$

This corresponds to an epicycloidal trajectory; the following plot shows the path of an electron which starts at the origin and travels from the emitting source layer at x=0 towards the MCP in the positive x direction.



The electron reaches a maximum displacement in the vertical direction before curving back towards the nichrome. At $t = \frac{\pi}{RB_0}$, the electron attains its apogee in the $\hat{x}$ direction:

$$x_{max} = \frac{2E_0}{RB_0^2} \tag{17}$$

The maximum displacement, d, in the $\hat{y}$ direction before the electron curls back towards the cathode is simply $y(\frac{\pi}{RB_0})$, or:

$$d = \frac{\pi E_0}{RB_0^2} \tag{18}$$

We know R to be 1.759×10^{11}C/kg, and we will be working in a voltage range from 200V to a few kV; we can thus simply input a desired value for d to determine B_0 and hence the necessary MCP-to-source separation. Our MCP is 20cm x 20cm, so d will be on the order of about 5cm. We will arrange the MCP's and anode such that there is 600V potential difference between the electron source and the target MCP (of course, this implies a higher overall voltage difference between the nichrome and the anode–the exact value of this higher voltage is determined by the distance between the nichrome and the anode).

Plugging these values in to (18) and (17) gives us a separation of the MCP from the nichrome of 3.18 cm and a maximum B_0 of 0.00259 T (less deflection will be seen as the magnetic field shrinks from this value). Of course, we could bring the MCP closer to the electron source and use a higher magnetic field to compensate for it in order to still achieve a deflection of 5cm. Alternatively, we could pull it farther away from the nichrome layer and use a lower magnetic field. The calculation is the same in both cases—once we've specified the later displacement d and the nichrome-to-target MCP separation x_{max}, we can solve for B_0 and V_0, which we can adjust as necessary.

3.2 Accounting for Initial Velocities

Our goal here is to smear out the electrons across the MCP without losing too many of them—electrons which miss the MCP surface altogether or curl back to the cathode do not contribute to the scrubbing. The results of the preceding section apply to the case where the photoelectron has given up all of its energy in the process of escaping and, importantly, are also valid for electrons with initial velocities strictly in the $\hat{z}$ direction. We need to consider however three additional extreme cases: initial velocity in the positive and negative $\hat{y}$ directions as well as initial velocity in the $\hat{x}$ direction (we assume that electrons with initial velocities purely in the negative $\hat{x}$ direction are immediately reabsorbed by the nichrome).

Our first task is to determine the range of speeds we can reasonably expect the electrons to have. For the purpose of finding a reasonable estimate, let's assume that there is no fixed MCP present and pretend that the electrons released from the nichrome are the ones accelerated to the target MCP's. Depending on the cleanliness of the surface of the nichrome, work functions range from 5 to 8 eV. If we use a mercury-vapor bulb to illuminate the nichrome, the main source of photons capable of kicking electrons off the surface of the nichrome will be photons at a wavelength of 185nm. The maximum residual energy we can expect will thus be the energy of the 185nm photons minus a 5.1 eV workfunction—an electron with this residual energy (around 1.6 eV) will have a velocity of 7.5×10^5m/s. Of course, this initial velocity can be oriented in any direction, but we will only consider here the limiting cases of purely axial motion. For purposes of comparison, note that the electron released from rest will have an energy of 600 eV by the time it reaches the MCP; heuristically, an initial excess energy of 1.6 eV (or even 5eV, which is typical for secondary electrons in general) should have little effect on the final displacement values—let's check this hypothesis.

Our primary concern is to ensure that electrons with initial velocities in the xy plane can still contribute to scrubbing; of the four cases considered in this paper (no x or y momentum and purely axial motion in the xy plane), we should pick parameters for which even the initial conditions which lead to the lowest maximum x displacement still hit the MCP.

The electron's maximum displacement in the *hatx* direction as a function of the angle, α, of the initial velocity in the xy plane is given by:

$$x_{max}(\alpha) = v_0 \frac{\cos^2(\alpha) + P^2 - P\sqrt{Q}}{RB_0\sqrt{Q}} \tag{19}$$

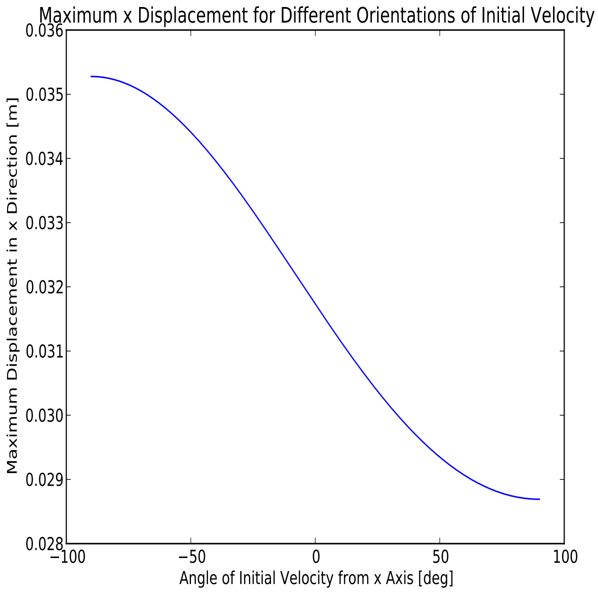
where:

$$P = \sin\alpha - \frac{E_0}{B_0 v_0} \tag{20}$$

and

$$Q = \cos^2(\alpha) + P^2 \tag{21}$$

For the parameters we specified above and using an initial velocity of 7.5×10^5m/s, we get the following plot of maximum displacement on x axis as a function of the angle of the initial velocity in the xy plane from the x axis:



The electrons travel the farthest in the $\hat{x}$ direction if their initial velocities are oriented in the negative $\hat{y}$ direction, and the least if their initial velocities are in the positive $\hat{y}$ direction—the plot above indicates a 20% difference between the two.

We would like no electrons to curl back to the nichrome—we'll thus redo the calculations in section 3.1 for the separation of the scrubees from the electron source and B_0 using an initial velocity entirely in the positive $\hat{y}$ direction. Luckily this only requires a few minor adjustments:

$$x_{max} = \frac{2(E_0 - B_0 v_{y0})}{RB_0^2} \tag{22}$$

We do not need to be quite as meticulous in calculating d because the desired lateral displacement will be a loose figure anyway—we are safe using (18). If we wanted to be fully rigorous, d can be calculated by inserting the time of the x apogee back in to the equation for y:

$$d = y(t_{xmax}) = y\left(\frac{\arctan\left(\frac{v_{x0}}{v_{y0} - \frac{E_0}{B_0}}\right)}{RB_0}\right) \tag{23}$$

The protocol for addressing potentially nonzero velocities should be the following—first compute everything assuming no initial velocity, then use (22) to ensure than even the electrons which stay closest to the emitter still hit the scrubee MCP; if they don't, adjust the separation between the target and source accordingly to ensure that we catch even the electrons most eager to return to the nichrome.

3.3 Frequency of Oscillating Magnetic Field

Scrubbing times generally run on the order of hours—we thus have no reason to oscillate the magnetic field particularly quickly. We hence have the freedom to select a period of oscillation significantly larger than the time required for an electron to travel from the nichrome to the MCP surface—the electron will then see a roughly constant magnetic field. We saw above that electrons require no more than around $\frac{\pi}{RB_0}$seconds, or about 6×10^{-9} seconds to travel from the nichrome to the MCP (supposing that the MCP is placed at the apogee of the electron arcs). The results derived in the previous two sections remain valid so long as this time is much smaller than the period of oscillation of the magnetic field—specifically, if we want the period of oscillation to be a factor of 10^4 larger than the electron travel time, we have an effective upper limit on the frequency of the oscillation in the magnetic field of around 20,000 Hz.

4 Uniformity of Magnetic Field

We can tolerate some lack of uniformity in the magnetic field since it will effectively counteract some of the irregularities in the electron shower: both the incoming light and the magnetic field will have maximum magnitude near the center of the MCP, and lowest magnitude near the fringes. Hot spots are thus more likely to develop in the center of the MCP, but are likewise more likely to be washed away by the stronger magnetic fields there. We would like to determine the dimensions of the Helmholtz coils necessary to achieve a magnetic field which varies no more than 20% throughout the area between the fixed MCP and the target MCP's.

The magnetic field produced by a length of wire can be found using the Biot-Savart law, given by:

$$B(\mathbf{r}) = \frac{I\mu_o}{4\pi}\int \frac{d\mathbf{r'} \times (\mathbf{r} - \mathbf{r'})}{|\mathbf{r} - \mathbf{r'}|^3} \tag{24}$$

We'll focus on integrating over one loop at a time, and then add the results together at the end. If the radius of the wire loop is a, the loop is defined in cylindrical coordinates with the origin at the center of the loop by $\mathbf{r'} = a\hat{\boldsymbol{\rho}}$, so we have $d\mathbf{r'} = a\hat{\boldsymbol{\varphi}}d\varphi$. For the numerator of the integrand, we have:

$$d\mathbf{r'} \times (\mathbf{r} - \mathbf{r'}) = a\hat{\boldsymbol{\varphi}}d\varphi \times (z\hat{\boldsymbol{z}} + \rho\hat{\boldsymbol{\rho}} - a\hat{\boldsymbol{\rho}}) \tag{25}$$

Here z and ρ refer to the position between the coils where we would like to determine the magnetic field. We can ignore the angular position because we have the freedom to redefine the coordinate system so that φ, the angular position of the point we are evaluating, is zero.

Simple geometry gives us the denominator. The full integral we need to investigate is:

$$B(\mathbf{r}) = \frac{I\mu_o}{4\pi}\int_0^{2\pi} \frac{(a^2 - \rho a)\hat{\boldsymbol{z}} + az\hat{\boldsymbol{\rho}}}{\left(z^2 + \rho^2 + a^2 - 2\rho a\cos(\theta)\right)^{\frac{3}{2}}}d\varphi \tag{26}$$

Solving this abstractly is not necessary: it suffices to vary the inputs and see what outputs they generate. We desire Helmholtz coils capable of creating a magnetic field which varies by less than 20% in the region between the fixed MCP and the first target MCP. Since we can expect the widest variation in magnetic field strength to be between the center of the region and the corner, we can simply calculate the magnetic fields in these two points and search for suitable parameters for the Helmholtz coil which give us the desired 20% variance.

Four integrals must be computed for each set of parameters: two possible directions of magnetic field within the plane of the MCP (we ignore any vertical components of the magnetic field since they are parallel to the motion of the electrons and hence do not deflect them) need to be computed for both sides of the Helmholtz coil pair. We add the components of the magnetic field in each of the planar directions from the two coils individually, then find the total magnitude of the field in the plane of the MCP by squaring, adding, and taking the square root of the planar components. Mathematically, the total field in the plane is:

$$\sqrt{(B_{y,leftcoil} + B_{y,rightcoil})^2 + (B_{z,leftcoil} + B_{z,rightcoil})^2} \tag{27}$$

Recall that the z and y directions are in the plane of the MCP surface—the vertical x components are ignored since they are effectively parallel to the motion of the electrons. Letting rho=10cm (the axial distance from the center axis of the coil to the corner of the plate), z=5cm (the distance of the side edge of the plate to the plane defined by the coil) and a=30cm (the radius of the coil) gives us a twenty percent reduction in the magnetic field at the corner relative to the center of the MCP—the magnetic field at the corner of the MCP is 80.28% of the magnitude of the field at the center of the MCP.

5 Conclusion

Given a desired lateral electron displacement distance d, we have generated a means of determining the necessary magnetic field and source to MCP distance. If we have 600V between the fixed MCP and the target MCP, we should separate the fixed MCP from the target MCP by about 1.5", and use a magnetic field of 0.002T. To maximize the uniformity of the magnetic field, we propose using Helmholtz coils with a radius and separation of 30cm. Our results are valid for slowly oscillating magnetic fields, with frequencies lower than 20,000Hz; in practice, we will be using frequencies on the order of a Hertz or less.

MCP Scrubber Vacuum Chamber and Penthouse Design Details

Tyler Lutz

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1 Light Source

1.1 Bulb

Light is supplied by a mercury vapor bulb. Most of the light is of too low of an energy to liberate photoelectrons in the nichrome layer, but mercury has a large flux peak of photons at 184nm, which indeed provides sufficient energy to kick electrons out of the metal.
We currently possess a mercury vapor bulb that runs on 175 watts (Philips

ED28 clear), including the necessary Mogul base adapter. We have as well a Pen-Ray mercury vapor bulb (including dedicated power source), which is the industrial standard for scrubbers.
Appendix D details the intensity profile of the Pen-Ray lamp; happily, the lamp can be arranged so that the light is very nearly uniform over a plane (the intensity profile is rectangular, so the lamp could be arranged so that the intensity increases as one moves away from the midpoint of the MCP).

1.2 Light Housing (Penthouse)

UV light of the wavelength range necessary to excite photoelectrons from the nichrome is strongly attenuated by oxygen but not by nitrogen. We thus flood the space around the light bulb with nitrogen gas. In order to utilize as much light from the bulb as possible, we shape highly reflective aluminium into a parabola and fit it around the bulb. Sheets of cost-effective reflective aluminium sheets are available from http://www.anomet.com/ (we haven't ordered any as of 16. August 2013)
The penthouse itself is a 5" high cylindrical chamber with an inner diameter of 7.5". Two swageloks are installed on opposite sides of the cylinder to allow inflow and outflow of nitrogen gas, respectively, and one port for each of the light sources is welded on the cylinder as well. We plan to only have one light source (Hg lamp or Pen-Ray) installed at a time. The electrical feedthrough for the Pen-Ray is selected to have extra pins for a thermocouple (see pin-out list in separate document for details).
Since the penthouse is never subjected to a vacuum, we use KF (we have KF40 and KF50 aluminium half nipples) flanges for the ports, and bolt it to the top of the main vacuum chamber using a rubber flat gasket. The penthouse and its associated ports is constructed out of aluminium.

2 Vacuum Chamber

2.1 Outer Housing

For simplicity, we opt for a cylindrical outer housing for the vacuum chamber. In the present design, the chamber, including all flanges (but not the bolts), will be 11.28 inches high and have an 8" inner diameter. The chamber is constructed entirely out of stainless steel, and uses CF flanges so that we can subject it to a high vacuum.
Copper gaskets for the CF flanges have been ordered, but an order for the bolts, the cylindrical component, and the ports still needs to be placed. We currently possess two 16.5" OD CF blank flanges and four 16.5"OD CF flange rings (MDC part numbers 110040 and 110039, respectively).

2.2 Quartz Viewport

A quartz viewport separates the vacuum chamber from the light source. The window itself is circular, with a diameter of 4” and a thickness of 1/4”, and it is mounted on a CF flange with a 6” outer diameter. The flange is bolted onto the vacuum chamber so that it extends over a circular hole in the upper flange of the vacuum chamber. An opaque metal screen with a square hole cut into can be placed on top of the window to ensure that the light passing through the window lands only on the fixed MCP. The Quartz Viewport has been ordered from MDC (p/n 1001801) and is on its way as of 16. August 2013. Any opaque screens will be designed and constructed once the dimensions of the vacuum chamber have been finalized.

2.3 Snout

A snout is installed in the side of the cylinder to allow for the easy insertion and removal of the target MCP’s. Since the door of the snout is opened and closed frequently, it is sealed with an o-ring. A vacuum is established in the main chamber by pumping though a port in the snout as well as through a vacuum port in the main chamber. In the present design, the snout opening is is 10” wide, and 4” tall. It extents 11.53” out from the central axis of the vacuum chamber.

2.4 Flanges and Feedthroughs

In addition to the flanges necessary to establish a vacuum, the vacuum chamber has ports for electrical feedthroughs for the components described below. A full list of ports and feedthroughs is compiled in a separate document.

3 Anode

An 8”x8” anode is placed inside the vacuum chamber, on top of the bottom blank flange.

3.1 Voltage

A voltage between 200V and a few kV is established between the fixed MCP and the anode by a voltage source located outside the vacuum chamber. The voltage source is connected to the components inside the vacuum chamber via the vacuum feedthroughs (see separate pin-out list).

3.2 Readout

One ammeter is attached to each of the anode strips to allow us to monitor the electron shower on the anode and hence probe the uniformity of the scrubbing. The ammeters are placed outside of the vacuum chamber between the vacuum

feedthrough and the voltage source. We haven't yet ordered any ammeters, but they are easy to come by.
Our current design for the vacuum chamber includes an extra port for the anode readouts, in case we should desire to read both sided of the anode strips simultaneously.

4 Internal Structure

An internal metal scaffold holds the target MCP's in place between the fixed MCP and the anode. The details of the metal structure still need to be fleshed out, but my proposal is the following: we could have an open metal frame (cassette) into which the target MCP can be installed, consisting of four L-shaped metal rods welded into a square (the MCP sits on the lower leg of the L). The wires supplying voltage to the MCP are attached to the MCP while it is sitting in the frame, and the frame itself is attached to rollers (like a drawer in a cabinet) which allow us to slide it out of the chamber through the snout to remove/install MCP's. Once the wires are attached to the target MCP, we simply slide it into place and close the snout door. Springs can be attached between the high voltage wires and the vacuum chamber walls to ensure that the wires don't get in the way of the electron shower on the target MCP.
Insulated pads between the metal structure and the target MCP's prevent anything from shorting. The fixed MCP is clamped to tabs welded into the inner surface of the vacuum chamber. In the current design, the target and fixed MCP's are separated by 2".

5 Fixed MCP

The fixed MCP is coated with a thin layer of nichrome (80% nickel, 20% chromium) in order to convert the incident photons into photoelectrons. The work function of nichrome is between 5.1 and 8 eV, depending on the cleanliness of the surface. The fixed MCP provides a gain of around 10^5, and the electrons exiting the MCP are then accelerated to the target MCP's along a uniform electric potential gradient.

6 Helmholtz Coils

The design of the coils is described in a separate document—we summarize here the highlights:

6.1 Dimensions

In order to achieve a magnetic field of 0.00259T which varies by no more than 80% over the surface of the target MCP, we construct Helmholtz coils with a radius of 12 inches and separated by 12 inches consisting of 43 loops of wire

with 20 amps of current passing through them. Using the equations derived in the attached document detailing the design of the Helmholtz coils, the voltage between the fixed MCP and the target MCP needs to be adjusted to ensure that the electrons from the fixed MCP don't curl back to their source—in practice a voltage in the range of 450V to 600V sill suffice for this purpose given the present configuration (fixed to target MCP separation of 2"). The Helmholtz coils will be placed outside the vacuum chamber but rigidly attached to it, potentially by wooden dowels.
The Helmholtz coils still need to be constructed as of today—We have a large plastic tube that we can use to provide a circular structure for the loops of wire. Coils of the dimensions needed are not widely available commercially, and custom-ordered coil pairs run in the vicinity of $5000.

6.2 Varying Intensity

The current in the Helmholtz coils is supplied by two triangular pulse generators, with one supplying the current to each pair. In order to evenly spread out the electrons over a square area, the frequencies of the two triangular pulse generators are set to be close to each other but not exactly equal. The frequencies of the pulses will be small, on the order of a Hertz or less.
Reasonably-priced triangular waveform generators can be purchased from:
http://www.karlssonrobotics.com/cart/frequency-generator-kit-fg085/

Appendix A: Desired MCP Scrubber Specifications

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1 Light Source

1.1 Bulb

The work function of Nichrome runs between 5.1 and 8 eV, depending on the cleanliness of the surface. We thus seek light with a wavelength lower than about 245nm. Mercury vapor bulbs offer a large flux of light at 185nm. A more expensive alternative would be to use Pen-Ray lamps, which is generally accepted as the industrial standard for scrubbers. The bulb we currently have runs on 175 Watts and requires a Mogul base.

Specifications:

1. The bulb needs to be able to run continuously for at least 5 hours at a time.

2. The bulb should have a reasonably long lifetime, ideally on the order of 10,000 hours or more.

3. The bulb must be able to emit UV light with wavelength below 245nm.

1.2 Light Housing

We would ideally like to flood the Nichrome surface with perfectly uniform UV light; though we will later be using Helmholtz coils to make the electron shower on the MCP's more uniform, we should strive to make the light incident on the nichrome as uniform as possible first. We would also like to maximize the flux of UV light into the vacuum chamber.

Specifications:

1. The light source(s) and housing should be arranged to transmit a sufficient quantity of UV light into the vacuum chamber so that the scrubbing can be effected in less than 10 hours.
2. The intensity of the light incident on the nichrome surface should vary by less than 10% across the surface.

Both items can be simultaneously accomplished using multiple light sources and a suitably designed reflective surface inside the light housing. An additional consideration is that UV light in the wavelengths we are considering is strongly attenuated by oxygen; a common industrial solution is to fill the space around the bulb with nitrogen, which is transparent to UV light in the range from 150 to 200nm.

2 Vacuum Chamber

2.1 Dimensions

1. The vacuum chamber can have either a rectangular or circular horizontal cross-section; in either case, it needs to be able to accommodate an 8×8 in. MCP lying flat inside it.
2. The vacuum chamber must be at least tall enough to accommodate:
   (a) a fixed MCP with a layer of Nichrome coating its upper surface
   (b) as many as three MCP's to be scrubbed
   (c) a space of around 2 inches between the fixed MCP and the scrubees to allow a dithering magnetic field created in this space to sufficiently spread out the electrons.

(d) an anode, placed beneath the lowest MCP in the vacuum chamber

(e) any housing necessary to keep the aforementioned items in place

(f) a space between the fixed MCP and the quartz window to allow the incoming light to spread out (and thereby better ensure uniformity of the light incident on the nichrome).

Item (f) above depends crucially both on the raw uniformity of light from the source and on the dimensions of the quartz window as detailed below.

2.2 Window

A window separates the inner vacuum chamber from the light.

Specifications:

1. The window be sufficiently thick to withstand atmospheric pressure on one side and a vacuum on the other.

2. The window should transmit more than 50% of the UV light from the light source into the vacuum chamber. These are the two driving constraints on the dimensions of the window: in practice, it would be possible to reinforce the window by installing a metal mesh or support directly beneath the window.

3. The window should be no larger than 8×8 in., and should ideally be smaller such that it only transmits a section of the full spatial intensity profile of the light source which is highly uniform in intensity.

A smaller and hence thinner window can be used if we are able to place the light source very close to it. Smaller windows, however, force us to place more distance between the window and the MCP in the vacuum chamber to allow the light to fan out to the full 8×8 area of the fixed MCP.

2.3 Flanges and Feedthroughs

1. We need to be able to easily insert and remove target MCP's into the vacuum chamber.

2. Wires need to pass through the walls of the vacuum chamber in order to establish a voltage between the fixed MCP and the anode, and to supply the Helmholtz coils with current.

The former can be accomplished by attaching a side chamber to the vacuum chamber ending in a removable blank rectangular flange. To satisfy the latter, vacuum feedthroughs can easily be built into the vacuum chamber walls.

3 Anode

3.1 Voltage

A voltage of between 200V and a few kV needs to be established between the fixed MCP and the anode lying beneath the target MCP's.

3.2 Readout

We would ideally like to be able to do a current reading over the strips of the anode in order to probe the uniformity of the electron stream on the target MCP's.

4 Helmholtz Coils

Need to be arranged to create a uniform magnetic field of around 0.002 Tesla in the space between the fixed MCP and the target MCP's. This will require a current of a few amps.

4.1 Varying Intensity

The magnetic fields need to smear out the incoming electrons over a large surface—we thus vary the magnetic fields by sending triangular pulses into the pairs of Helmholtz coils. The triangular waveforms will have frequencies that are slightly different from each other.

Appendix B: Electrical Feedthroughs and Pin-Out

	Feedthrough	Style	Pin #	Use
Penthouse				
	Penthouse 1	4 pin, ¾'' weldable feedthrough (MDC p/n 9131000)		
			1	Penray Lamp (300V)
			2	Penray Lamp return
			3	Thermocouple
			4	Thermocouple return
Scrubber				
	Test 1	20 pin, 2.73'' CF flange feedthrough (MDC 9132006)		
			1-20	Anode singles (low current)
	Test 2	20 pin, 2.73'' CF flange feedthrough (MDC 9132006)		
			1-10	Anode singles (ctd.)
			11	Ground for Anode
			12,13	In/out voltages for target MCP
			14, 15	In/out voltage for fixed MCP

Appendix C: Ports

Port #	Port Style	Use
Penthouse		
1	Aluminum KF40 (from Lesker)	Penthouse 1 electrical feedthrough
2	Aluminum KF50 (Lesker)	175W Hg lamp (lamp's Mugal base adapter cemented into port)
3	Swagelok	Nitrogen in port (Swagelok)
4	Swagelok (+relief valve?)	Nitrogen out port (Swagelok + valve)
Scrubber		
1	2-3/4'' CF half nipple (MDC 401028)	Vacuum pump and RGA attached to Tee (MDC p/n 404003))
2	2-3/4'' CF half nipple (MDC 401028)	Test 1 electrical feedthrough
3	2-3/4'' CF half nipple (MDC 401028)	Test 2 electrical feedthrough
4	2-3/4'' CF half nipple (MDC 401028)	(snout) Vacuum pump

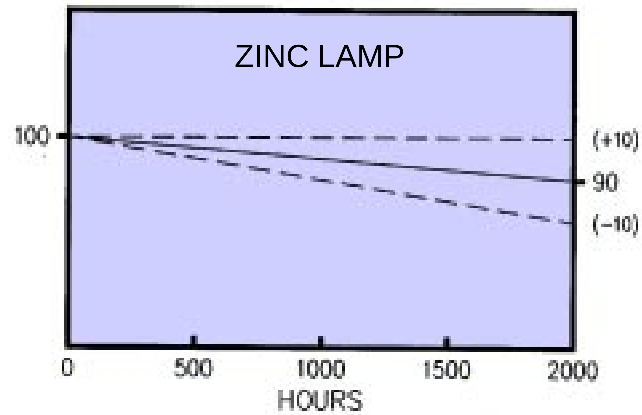
Additional Information

- Both the RGA and the vacuum pump are attached to scrubber port 1 using a 2-3/4'' CF flanged tee, MDC part number 404002. The RGA can be mounted directly on the 2-3/4'' CF flange of the tee.
- If we wanted to read the anode from both ends, we could add another pair of ports and feedthroughs—Test3 and Test4—using the same parts as Test1 and Test2. It's not clear, however, whether this extra information is worth the cost (using MDC parts, it would require over $1000 in extra parts, not to mention machining costs). We've left this option out of the design, but mention that it could possibly be added to the vacuum chamber at a later time if desired.
- Single ended feedthroughs are about a quarter of the price of double ended feedthroughs, but the maximum number of pins for the feedthroughs that MDC sells are 20 for the single ended and 35 for the double ended. We would thus need two 20-pin feedthoughs to accommodate the 30 anode strips. A more expensive (and larger) alternative to the two ports would be to purchase a single 35 pin, 5.97'' CF flanged feedthrough (MDC 9132014) and attach it to a 6'' CF Half nipple (MDC 401006)—this would also provide enough pins to supply the MCP high voltages (4 pins total) and the anode ground (1 pin).
- The 175W HG lamp (with outer shell removed) requires a Mogul base adapter, which we currently have; I was thinking about simply cementing the base adapter into the QF50 port directly without using any additional feedthroughs. The base adapter would then function as our "feedthrough" since both the lamp and power source can be removed while leaving the adapter in place. Care must be taken to ensure that the adaptor is reasonably air-tight (we don't want oxygen sneaking in through it).

PEN-RAY LAMPS

Pen-Ray Lamp Profiles

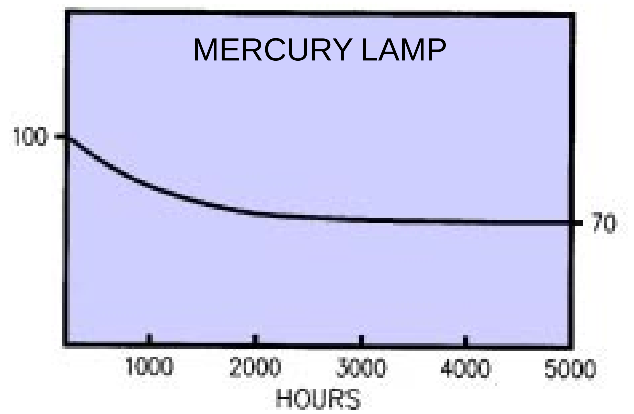
Zinc and Mercury typical life profiles are based on established history of average life studies performed by UVP. While not a guarantee of individual performance, we believe that it reflects a typical lamp.



Pen-Ray Lamp Polarity Plot

The graph shown below illustrates relative 254nm output intensities versus the orientation of the double bore tube. This may be used to determine placement of the lamp for optimum efficiency. The concentric rings represent measurements at different distances from the lamp.

Orientation collars are available for most Pen-Ray Lamps. Refer to Stock Designs for standard model configurations offering orientation collars. Options for customizing Pen-Ray Lamps, page 8, further discusses this orientation.



Polar Intensity Plot

Relative 254nm output from Mercury Pen-Ray Lamp using an untreated fused quartz envelop.

Greater distance from center indicates high intensity. The * indicates lamp to sensor distance.