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VUV-soft x-ray beamline for spectroscopy and calibration

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Abstract

We describe the design and performance of the Los Alamos VUV synchrotron radiation beamline, U3C, on the VUV ring of the National Synchrotron Light Source at Brookhaven National Laboratory. The beamline uses separate function optics to collect and focus the horizontally and vertically diverging beam. The monochromator is a grazing incidence Roland circle instrument of the extended grasshopper design (ERG). A post monochromator refocusing mirror is used to focus or collimate the diverging beam from the monochromator. The beamline control and diagnostics systems are also discussed.

Introduction

Los Alamos is building four synchrotron radiation (SR) beamlines at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. Two of these lines will be on the 2.5 GeV (stored electron energy) x-ray ring, and the other two are on the 0.75 GeV VUV ring. The x-ray lines are designed to have a combined energy range from approximately 1 KeV to 25 KeV. The VUV lines will cover the range from approximately 10 eV to 1200 eV. Because the large number of potential users and the variety of the science that will be performed on these lines, the lines have been designed to be as versatile as possible.

The first of these lines, designated U3C, is now in its final commissioning stage. This line is on the VUV ring and will have an energy coverage of approximately 30 eV to 1200 eV. It is being developed for spectroscopy experiments and x-ray calibration measurements. With this in mind, we have tried to produce a photon source with minimum stray and harmonic light, a high degree of polarization, accurate energy calibration, a variable degree of beam divergence, variable energy resolution, and a built-in diagnostic system that can be used to verify the line performance. The line will be used for x-ray diode calibration, spectrometer development and evaluation, x-ray optics characterization, as well as photoelectron spectroscopy of solids, gases and ions.

Beamline design

The VUV ring at the NSLS provides a continuous energy spectrum from the infrared through the soft x-ray range with a critical energy (Ec) of 486 eV. This radiation is produced in a horizontal fan with a vertical opening angle of approximately 1.5 mRadian at Ec. The vertical source size is on the order of 0.1 mm (1σ value). The beamline optics and monochromator, shown schematically in Figure 1, collect, focus, and monochromatize the beam.

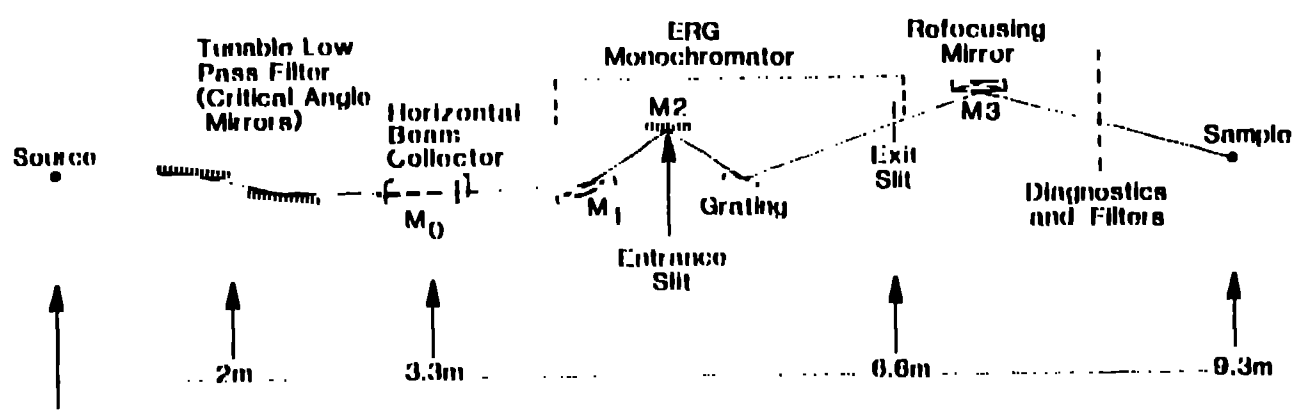

Figure 1. Optical elements and basic arrangement of the VUV beamline and ERG monochromator.

The first optical element in the line is a low pass filter system consisting of parallel mirror pairs.[1] The filter system is used to reduce the higher order light. Thus the cut off energies of the critical angle mirror sets are adjusted to be approximately an overtone apart in energy. The mirror sets reduce the light intensity by approximately 50%. If higher order rejection is not needed, the filter system can be removed from the beam.

The next optical element in the beamline is the horizontal collection mirror, M_0. The mirror is a platium coated 1 m long piece of float glass that is bent to approximate an ellipse. At a grazing angle of incidence of 2°, the mirror collects approximately 10 mRad of horizontal angle and focuses it onto the exit slit of the monochromator with unity magnification. The mirror position, angle of incidence, and the curvature can be externally adjusted while the system is under vacuum.

The next set of optical elements are in the Extended Range Grasshopper (ERG) monochromator.[2] The monochromator is a grazing incidence Rawland circle instrument with fixed output beam. The motions of the internal elements are controlled by stepping motors. A computer program then coordinates the stepping motor drives in order to scan the photon energy.

The first optical element in the ERG is a 30 cm long gold-coated elliptical mirror (M1) 52 cm from the entrance slit that vertically focuses the beam with a 10:1 demagnification onto the slit. Then the Codling mirror (M2) entrance slit[3] directs the light onto one of three spherical gratings (2 m, 3.71 m, or 5 m radius of curvature). The grating in turn vertically dispenses the radiation and focuses it onto the exit slit.

At the exit slit of the monochromator the beam is diverging at approximately 10 mRad in both the horizontal and vertical directions. A refocusing mirror is used to focus the beam at a sample or to collimate it.

With the above described arrangement, the line accepts 10 mRad of the beam in the horizontal plane and an energy dependent fraction of the beam in the vertical plane. The vertical acceptance of the line is shown in Figure 2. This acceptance is based on 10 μm slits and a source size of 0.1 mm (1σ value). With the 10:1 demagnification of M1 the 1σ source size is fully accepted, i.e., 30% of the total source. However, M1 only accepts 1 mRad of the vertically diverging beam. The opening angle of the SR is increasing with decreasing photon energy thus the reduced acceptance at lower energies. This effect reduces the accepted flux by approximately 4.25 from 1200 eV to 12.5 eV.

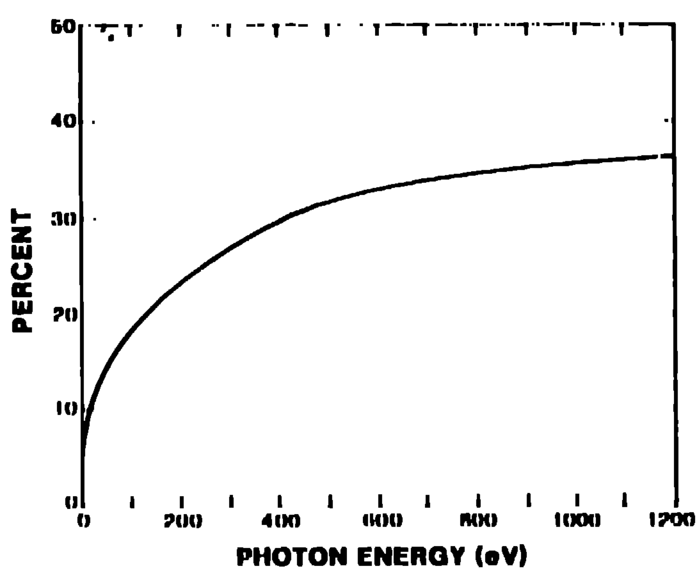

Figure 2. The percentage of flux accepted by the ERG as a function of photon energy. The calculation is based on a source size of 0.1 mm (1σ value) and 10 μm slits.

Beamline diagnostics

In order to monitor the performance of the beamline and, in some cases, change the characteristics of the line, a number of diagnostic and beam shaping elements have been installed or are planned for the beamline. The general position of these elements is shown in the beamline assembly drawing (Figure 3). The first element downstream from the source is a water cooled mask that divides the horizontal fan of radiation into three 12 mrad wide beams. The beam closest to the electron storage ring is U3C. This beam is then further defined by a water cooled aperture/shutter mechanism located at the upstream end of the M_0 mirror chamber. Also attached to the movable shutter is a horizontal wire which can be used to map out the vertical beam profile and to locate the vertical beam center. This is done by moving the wire through the beam using a stepping motor drive system and recording the photocurrent emitted from the wire. The maximum photocurrent corresponds to the beam center. Once positioned in the beam center, the shadow of the wire can be used to align other downstream elements.

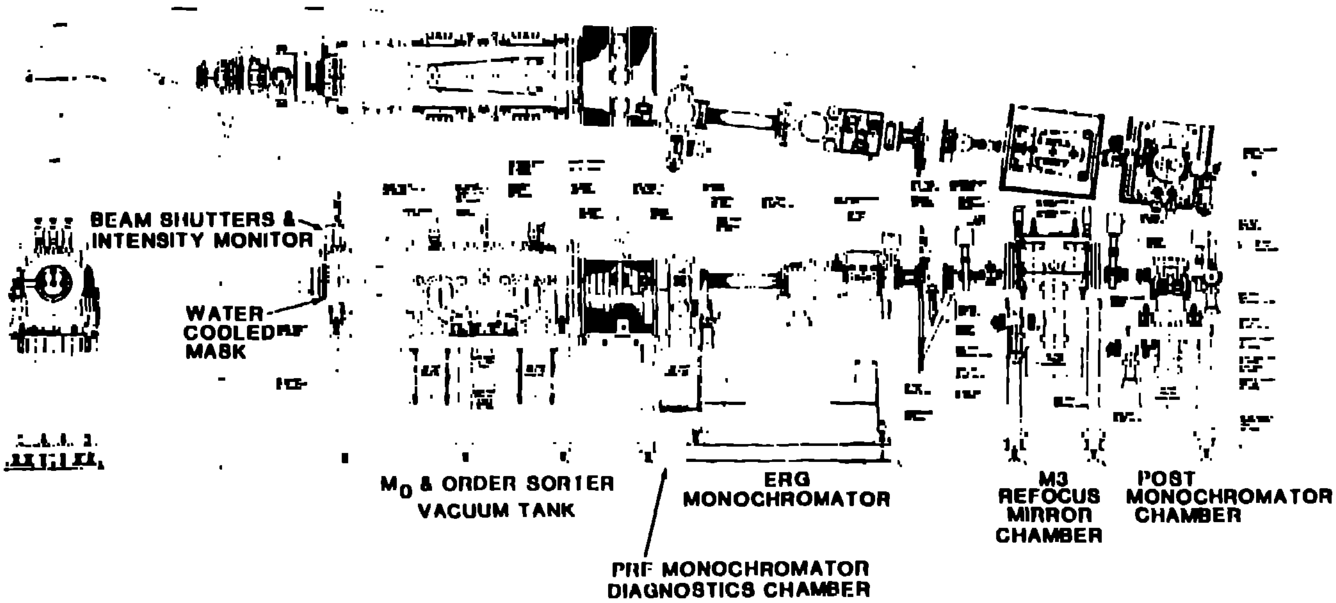

Figure 3. Beamline assembly drawing showing both an electron and plan view of the line.

The photocurrent from the wire can also be used to monitor the photon intensity. This system has worked well and has been used to diagnose beam position problems, beam movement, and to test for occlusion of the beam.

In between the M_0 mirror chamber and the monochromator is the premonochromator diagnostics chamber. The chamber contains a four-way adjustable aperture, two prisms, and a set of horizontal wires. The adjustable aperture is used to reduce the beam size to the minimum required and to block any sperious light that may be scattered from upstream components. Early measurements indicate that the aperture is useful in eliminating stray light from the beam.

One of the prisms is used to bring the visible portion of the SR spectrum out through a window in the top of the chamber. This feature is used to check the quality and position of the focus of the M_0 mirror. The other prism is arranged so that laser light can be introduced into the monochromator collinearly with the SR beam. This is useful for alignment of the optical elements in the monochromator and other downstream elements including the sample.

The two parallel horizontal wires are used to monitor the position and to detect any beam movement. They can also be used to measure the beam intensity.

A second diagnostic system is located downstream from the refocusing mirror. This system is used to measure and monitor the characteristics of the monochromatic beam. The system is used to measure the absolute beam intensity, to check the photon energy calibration, to measure the amount of higher order light, to monitor the relative beam intensity, and to visually observe the beam profile. To accomplish these tasks the post monochromator diagnostics chamber is equipped with a NBS calibrated aluminum diode, a set of thin film filters, an electron energy analyzer, a nickel mesh, and a phosphor coated plate.

Other diagnostics that can be coupled to the beamline include an ionization chamber to measure the absolute photon intensity and a multilayer polarimeter to measure the polarization of the beam. A prism will also be included in the diagnostics chamber so that laser light can be introduced into the system for alignment. Also, the prism can be used to visually align elements in the line and sample chamber.

Beamline control, safety, and vacuum systems

There are three general areas in the operation of the beamline that either for safety (personnel and equipment) or convenience are best handled by automated control. These are the vacuum system and valve control, photon and bremsstrahlung radiation protection, and monochromator control and data acquisition. The philosophy taken has been to separate safety and beamline control functions from the data acquisition system including the monochromator.

The safety system is controlled by a microprocessor based system that is "hard wired" and cannot be overridden without a key access. This system monitors and protects the vacuum

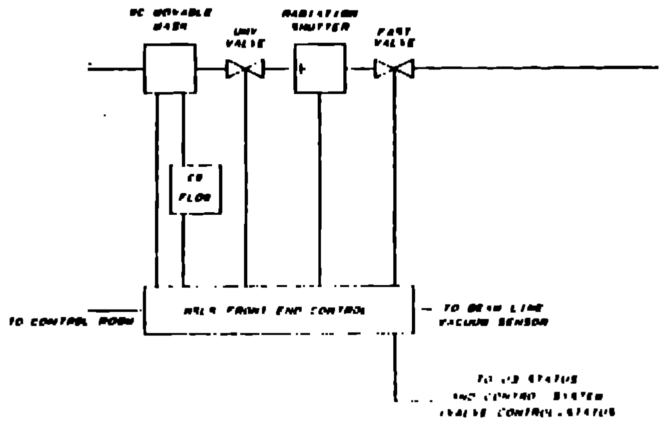

Figure 4. (a) NSLS front end assembly.

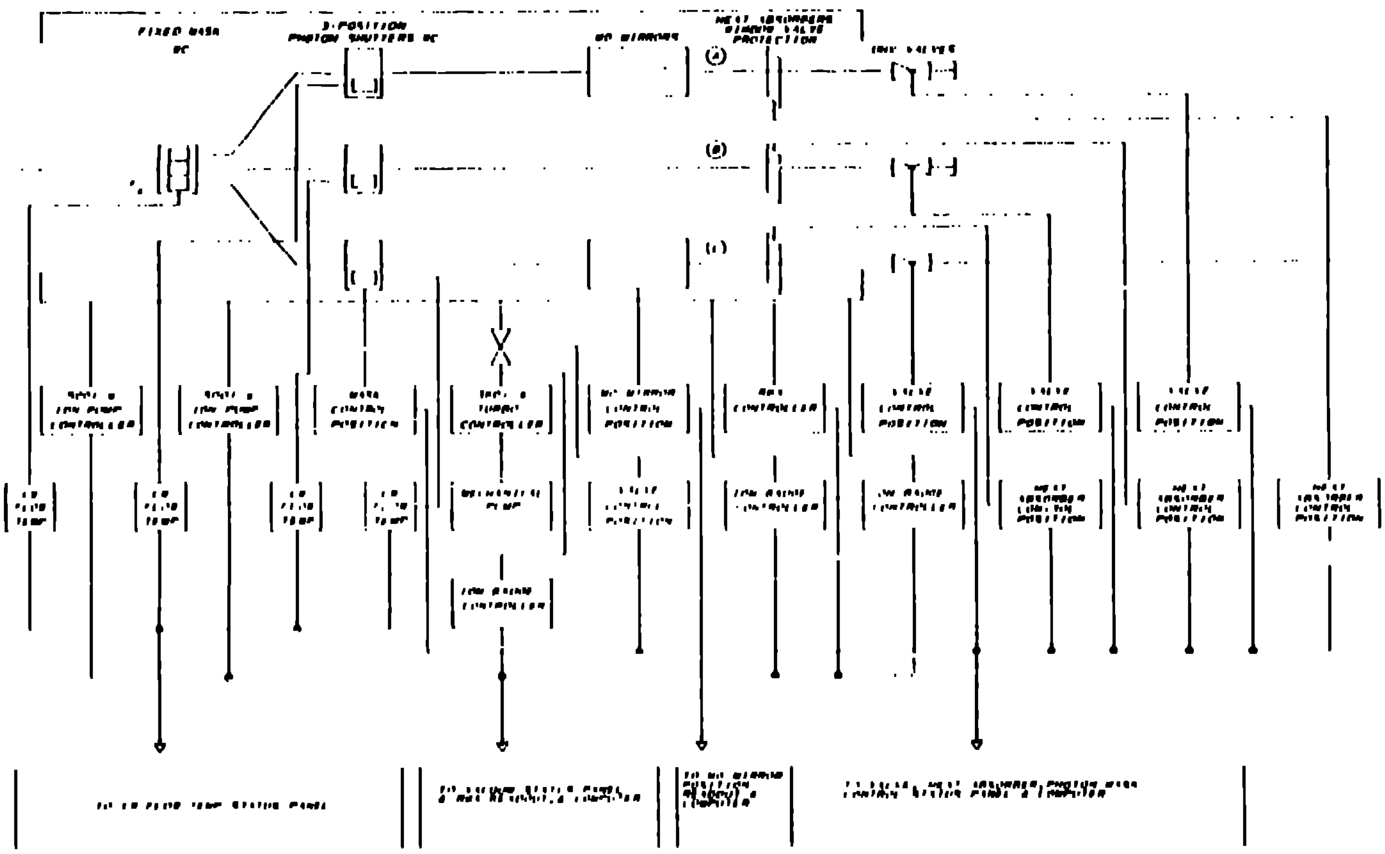

Figure 4. (b) Front end mirror tank assembly.

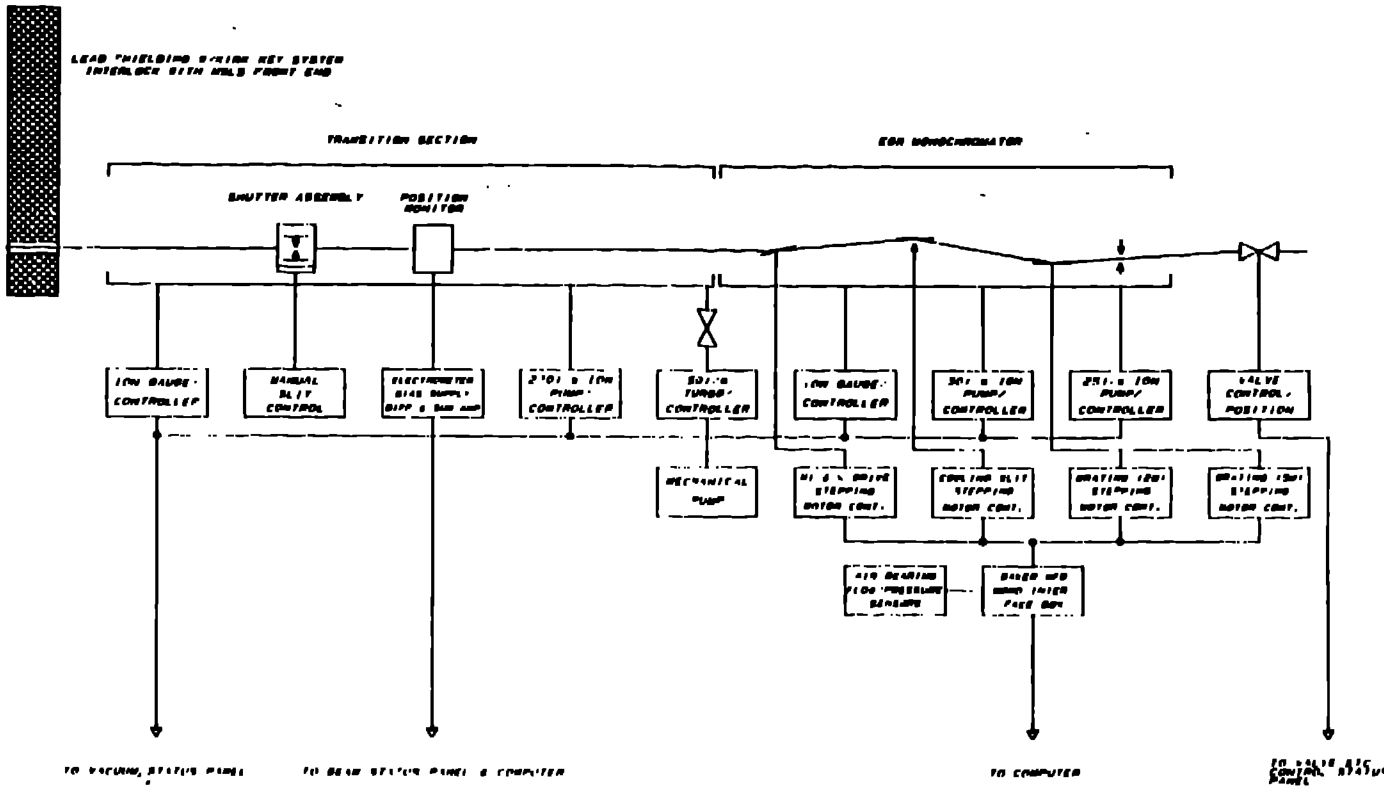

Figure 4. (c) Transition section and ERG monochromator.

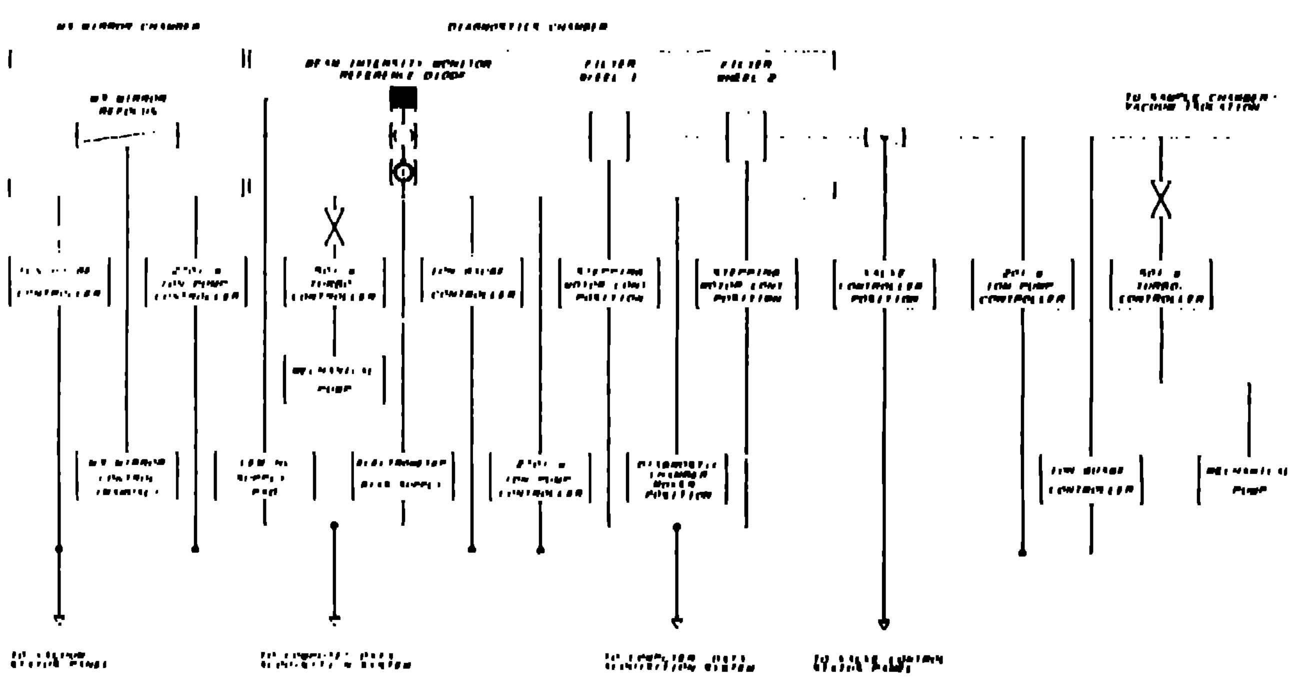

Figure 4. (d) M3 mirror chamber and diagnostics chamber.

integrity of the line preventing valve opening or closing without the proper vacuum conditions existing and warning of improper vacuum conditions. A similar system exists for radiation protection. Here the problem involves preventing damage to optical components including vacuum chamber windows due to heating from the photon beam or preventing the possible exposure to hard bremsstrahlung radiation that would be produced by a sudden stopping of the electron beam.

The data acquisition and monochromator control as well as some data reduction and analysis will be handled by a DEC Microvax II. At the present time this task is being performed by a DEC LSI 11/73 computer. The computer system can access information about valve and radiation shutter status and request changes in the status, but it cannot override the safety system control. The vacuum status of the line can be monitored by the computer and the information incorporated into the data files.

A block diagram of the beamline control system is shown in Figure 4 (see next two pages). Also shown on the diagram is the beamline pumping system. It consists of ion pumps for all vacuum chambers with turbomolecular pumps used to "rough out" the system. The entire line has an operating pressure in the mid 10^{-10} torr range.

Performance

At this time we have preliminary data on the performance of the beamline. Intensity measurements over the complete energy range have been taken as well as zero order scans to test the resolution of the ERG. Qualitative measurements of the stray light and higher order light have also been made.

The measurements were made with a small test chamber attached directly to the exit housing of the monochromator. The test chamber contained an aluminum overcoated nickel mesh, a phosphor coated glass disk, and an aluminum oxide x-ray diode. Figure 5 shows the yeild from the x-ray diode over the energy range from 30 eV to 1350 eV.

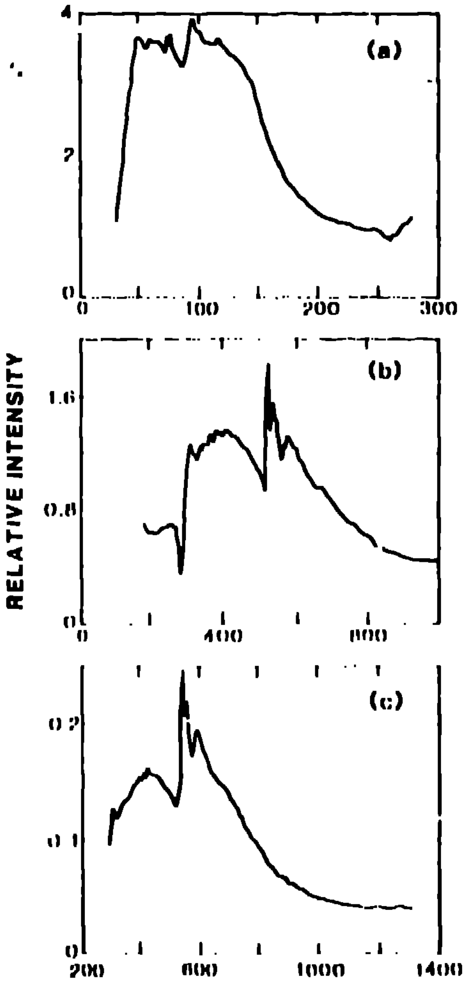

Figure 5. Aluminum diode photocathode relative yield as function of photon energy for the (a) 2 m, (b) 3.71 m, and (c) 5 m radius of curvature gratings.

The 2 m and 5 m gratings are ruled and have a 2° blaze angle. The ruling density is 900 l/mm for the 2 m grating and 1200 l/mm for the 5 m grating. The 3.71 m grating is a ion etched holographic type with 1200 l/mm.

The low energy range of the scan is covered by a 2 m radius of curvature 900 l/mm ruled grating. The grating is blazed at 2°. The midrange uses a holographic ion etched grating with a 3.71 m radius of curvature and 1200 l/mm. The high energy range is covered by a 5 mm radius, ruled grating with 1200 l/mm that is also blazed at 2°. A smaller blaze angle of approximately 1.5° would be more appropriate for this range and would increase the output. These scans were taken with 35 μm slits. Based on literature values[4] for the response of the aluminum diode, the flux from the monochromator is as high as 10^9 photons per second per milliamp of beam current for energies as high as 900 eV. This agrees with estimates of the flux based on the output from the storage ring, the acceptance of the monochromator, and calculated values of the mirror reflectivities.

Calculated values of the resolving power of the ERG with 10 μm slits for several gratings are shown in Figure 6. As can be seen, it is possible to have a resolving power of greater than 1100 for energies from 30 eV to over 1000 eV. With the three gratings currently installed in the ERG the resolving power of the higher energies is that of the 5 m, 1200 l/mm grating.

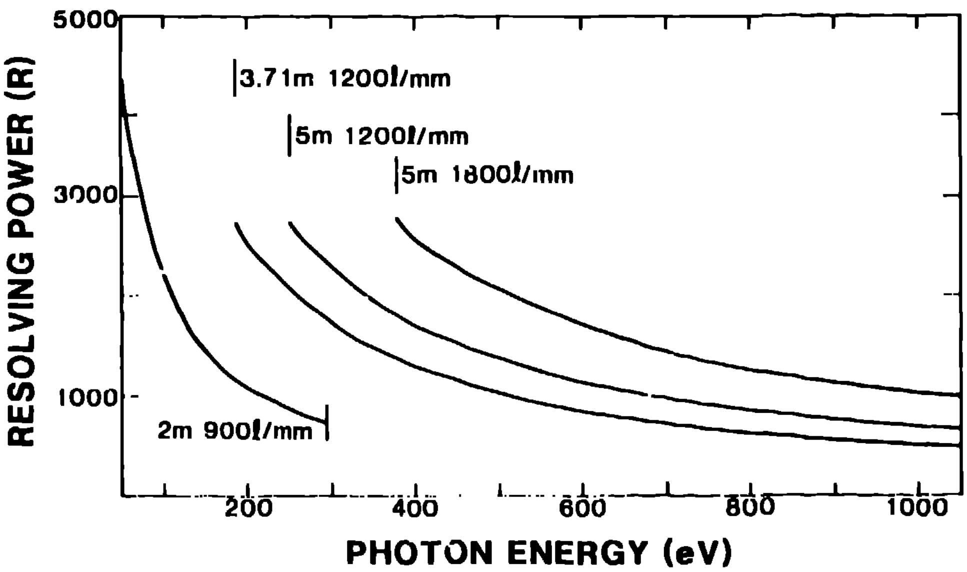

Figure 6. Calculated resolving power of the ERG monochromator with 10 μm slits for several gratings.

The actual resolution of the monochromator is also dependent on how well the instrument is aligned. Scans of the zero order line width for the gratings indicate that the resolution of the 3.71 m grating is within approximately 30% of the theoretical value. At the present time the 5 m grating is approximately three times worse than the calculated value. Further alignment of this grating is currently under way. Because the monochromator scan range does not extend to zero order for the 2 m grating, no estimate of its resolving power is available at this time.

The best indication that stray light is not a major problem is the continued decrease in the light intensity at energies above 1100 eV. A slight increase was observed above ~ 1200 eV. Some of this signal was eliminated by adjusting the variable aperture at the entrance to the monochromator. It is anticipated that baffles in the ERG will be necessary to reduce the stray light at the higher energies.

The higher order light seems to be mostly evident below 150 eV. The oxygen edge structure in fifth and seventh order can be seen. Quantitative measurements of the higher orders have not been made at this time.

The first measurement using the beam line was the calibration of a multilayer spectrometer. The energy of the Bragg reflection and the resolution of the instrument was determined. The response of one of the multilayers is shown in Figure 7.

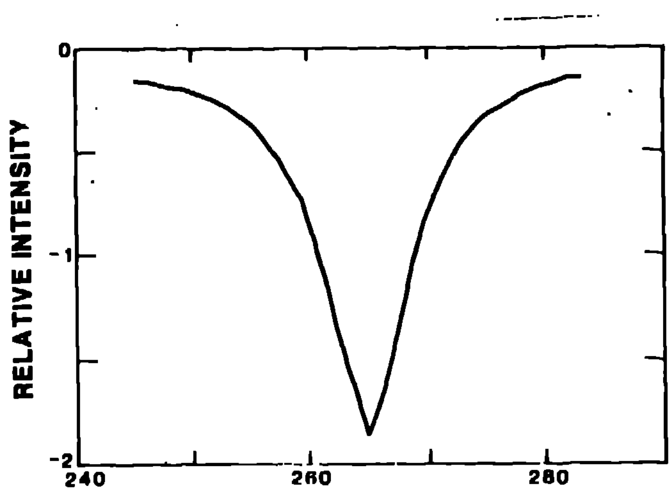

Figure 7. Measured response of a multilayer mirror.

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