X-Ray Synchrotron Radiation Diagnostic Beamline Manual

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TABLE OF CONTENTS

1.0 Introduction 1
1.1 Purpose and Scope 1
1.2 Background 1
1.3 Definitions and Abbreviations 1
2.0 Description 2
2.1 Front End and Transfer Line 2
2.2 Optical Table 3
2.2.1 Pinhole Camera Instrumentation 3
2.2.1.1 Optical Relay Line 3
2.2.1.2 CCD Camera 4
2.2.1.3 Firewire Camera 4
2.2.2 Position Sensitive Detector 4
2.2.2.1 Optical Relay Line 4
2.2.2.2 Detector 5
2.2.2.3 Readout 5
2.2.3 Fill Pattern Monitor 5
2.2.3.1 Detector 5
2.2.3.2 Readout 5
2.3 Control Hardware 5
2.4 Local Monitors and Displays 6
2.5 Test Equipment 6
3.0 User's Guide 7
3.1 How to Set up the XSR Front End 7
3.2 How to Operate the Detectors on the XSR Table 8
3.2.1 Setup of the Optical Table 8
3.2.2 Running the CCD Camera Using Spiricon 10
3.2.3 Running the Firewire Camera 15
3.2.4 Running the Position Sensitive Detector 15
3.2.5 Sensitivity in Y to Beam Angle and Position at the Source Point 16
3.2.6 Sensitivity in X to Beam Angle and Position at the Source Point 17
3.2.7 Running the Fill Pattern Monitor 18
References 20

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

This manual describes the design and operation of the Canadian Light Source X-ray Synchrotron Radiation (XSR) Diagnostic Beamline. It describes the procedure for setting up the front end and it summarizes the parameters for setting up the instruments on the optical table for the various measurements that can be made on the beamline. These parameters are intended to provide a reasonable starting point for any of the measurements, not a complete list of all possible settings. Also, the interpretation of the data is beyond the scope of this manual.

1.2 BACKGROUND

The X-ray Synchrotron Radiation beamline is located on port 02B2-2. This beamline is used to monitor Storage Ring characteristics using X-rays. The readout instrumentation is located in the OSR hutch and is accessed from the control room in normal operation. Users have remote access to the fill pattern monitor data and to the image captured by the CCD camera.

1.3 DEFINITIONS AND ABBREVIATIONS

APD: Avalanche Photo Diode

BPM: Beam Position Monitor

CCD: Charge-coupled Device

KVM: Keyboard/Video/Mouse

OSR: Optical Synchrotron Radiation

PSD: Position Sensitive Detector

TDC: Time-to-digital converter

XSR: X-ray Synchrotron Radiation

X,Y,Z: A right-handed system of coordinates defined such that Y is up and the beam travels in the Z direction. Therefore X is left when looking downstream, i.e. in the XSR hutch the Storage Ring is in the -X direction and the elevator is in the +X direction.

YAG: Yttrium Aluminum Garnet

2.0 DESCRIPTION

2.1 FRONT END AND TRANSFER LINE

Fig. 1 shows the XSR transfer line. The source point is at an angle of 4° into dipole 02B2. The front end is based on the standard CLS design for bend magnet beamline front ends [1]. Those components, that are specific to the XSR front end, are described below.

There are 3 fixed-aperture masks with the following parameters:

Mask #	To source-point (mm)	Aperture H × V (mm)	Acceptance (mrad)
1	2780	21.3 × 11.9	7.7 × 4.3
2	5601	34.3 × 15.0	6.1 × 2.7
3	6900	2.0 × 2.0	0.29 × 0.29

Masks #1 and #2 are fixed, mask #3 can be moved in X and Y.

A vacuum-isolation cell immediately follows mask #3, and serves to segregate the upstream and downstream vacuums. The cell is maintained under vacuum and is designed to protect the synchrotron vacuum in the event of a catastrophic failure of the final beryllium window. The cell consists of two beryllium windows, each 0.25 mm thick and separated by about 145 mm. The maximum heat load on each window is estimated to be about 0.40 W. All beryllium windows are high-grade material with a maximum r.m.s. surface roughness of about 1 μm in order to minimize the selective absorption of x-rays across the beam profile.

The pinhole assembly is downstream of the vacuum-isolation cell, 7965 mm from the source-point. The in-vacuum slit system consists of four independently-driven motorized blades, each water-cooled and temperature-stabilized to ± 0.1°C. The blades are 5 mm thick and fabricated from tungsten. The active edges are chamfered at an angle of 2° and oriented such that the slit aperture widens in the beam direction, thus minimizing halo formation due to slit-edge scattering. The blade positions are read by optical encoders with a position resolution of ± 0.5 μm.

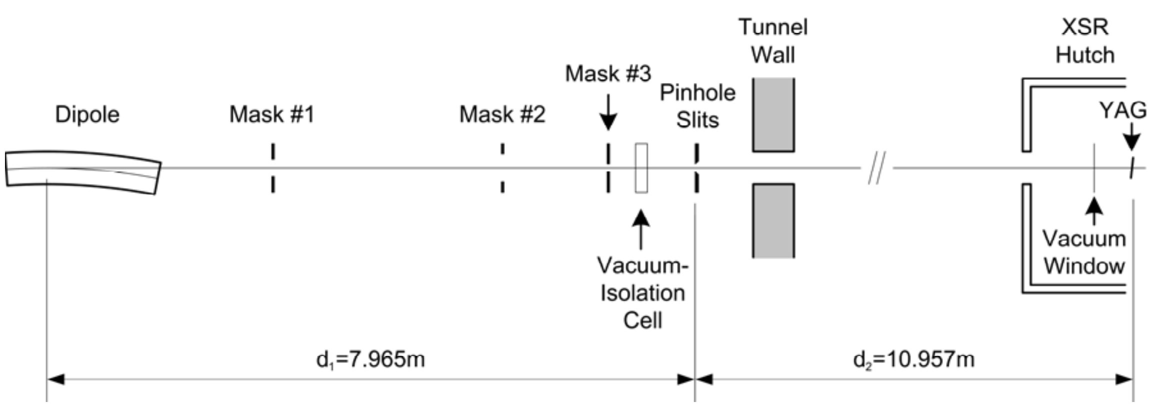


Fig. 1: Schematic of the XSR transfer line. The X-ray source-point is 4° inside the entrance of a Storage Ring dipole (the bend-angle is 15°). The source, pinhole aperture, and YAG crystal define the pinhole camera. The pinhole aperture is typically set to 25-30 μm in both planes. The geometric magnification is M = 1.376.

2.2 OPTICAL TABLE

The layout of the instrumentation on the optical table is shown in Fig. 2. The optical table is a metric table, 900 × 1800 mm, with M6 holes on a 25 mm grid. The beam centreline is 200 mm above the surface. The layout is divided into two sectors as far as function is concerned. The upstream sector consists of the YAG converter and the associated devices for capturing the beam profile. The downstream sector consists of the PSD, the APD, and the related optical hardware.

The two sectors can not operate simultaneously, since the YAG crystal must be moved off the beam path to allow the PSD and the APD full access to the beam. Since these devices require a higher X-ray flux than available during routine pinhole-camera operation, the pinhole aperture is opened to provide the optimal intensity.

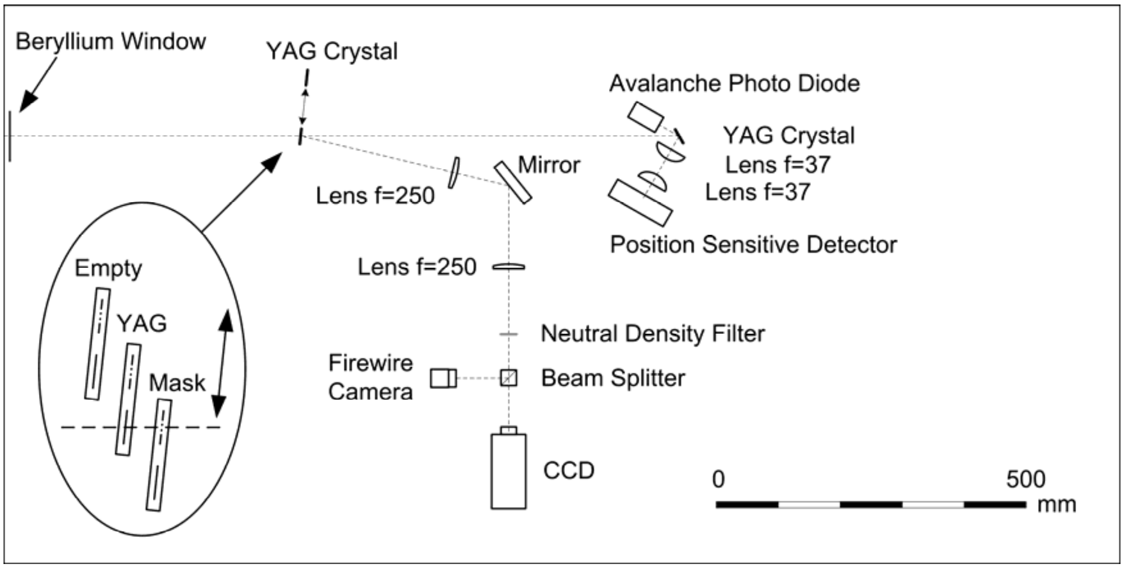


Fig. 2: Layout of instrumentation on the XSR optical table. The beam enters from the left through a 0.50 mm thick beryllium vacuum window. The upstream components, including the YAG wafer, optical relay line, and the CCD cameras, are associated with the pinhole camera. The downstream components include the APD for fill-pattern measurements, and a PSD for monitoring the beam position. The optical table is installed inside a lead-lined hutch.

2.2.1 Pinhole Camera Instrumentation

2.2.1.1 Optical Relay Line

The X-ray image projected by the pinhole is converted to visible light ($\lambda \approx 540$ nm) by a thin self-supporting circular wafer of YAG:Ce, 100 μm thick and 25 mm in diameter. The wafer is mounted on a small manual x-y-z stage for making fine position adjustments, and this stage in turn is mounted on a motorized linear-stage for remote translational control. Mounted adjacent to, and coplanar with the YAG wafer is a thin metal disk, 12.7 μm thick and 10 mm in diameter, and perforated by a rectangular grid of holes. The holes are 50 ± 3 μm in diameter and are separated by 1.0 mm. The hole-pattern has been mapped to a tolerance of ~ 2 μm. The metal disk can be moved into the position normally occupied by the YAG in order to fine-tune the focusing of the optical relay line and to calibrate the system magnification. The disk is illuminated from behind by a diffuse light source, and the hole-pattern as captured by the camera is analyzed by the image-processing software to give the centroid coordinates of each hole. From such measurements, the magnification of the entire optical system following the YAG crystal is M = 1.00.

The beam image is directed to a CCD camera and a Firewire camera by an optical relay line consisting of two lenses (Newport PAC088, f = 250 mm), a mirror (Newport 30D20BD.1), and a beam splitter. The optic axis of this line is downstream from the YAG crystal, and is rotated about 12° from the X-ray path to prevent hard X-rays from impinging on any of the components. Image blurring due to the depth-of-focus within the YAG crystal is minimized by rotating the symmetry axis of the crystal 6° to the beam path. The cameras are mounted on small manual x-y-z stages for fine adjustments.

Provision has been made to insert an OD-1 neutral-density filter into the light path when necessary to prevent saturation of the cameras. The filter is a Melles Griot absorptive neutral-density filter with a diameter of 25 mm. It is driven into the light path by a 2-position pneumatic lifter of the type used extensively in the OSR.

Initially, the images captured by the CCD camera displayed a halo-like feature surrounding the beam profile, which was likely caused by light from the converted image reflecting off the entrance face of the YAG wafer after one (or more) internal reflections. The net effect was to exaggerate the profile dimensions. The problem was remedied by locating an aperture-stop in front of the first lens. It was observed that the image size stabilized once the aperture dropped below a critical size. A circular aperture 15 mm in diameter was finally chosen, which still leaves ample light for the camera.

2.2.1.2 CCD Camera

The CCD camera is a COHU Model 6612-3000, configured for interlaced mode with a shutter speed of 1/60 s. The video signal is distributed to:

- A video monitor located in the OSR hutch,
- A video to Ethernet adapter, which is used to make the image available on a web page,
- A fibre link connected to a video monitor in the control room,
- A frame grabber in the OSR hutch.

The digitized images from the frame grabber are analyzed by a software package called “Spiricon”. Although the computer running Spiricon is located in the OSR hutch, it can be accessed from the Control Room via a KVM extender.

The wiring of the CCD camera is shown in O2B2-2/EE/WIR/0108213.

2.2.1.3 Firewire Camera

Readout and image analysis for a Firewire camera are under development.

2.2.2 Position Sensitive Detector

The position sensitive detector, the optical relay line and the YAG:Ce are mounted on a Parker stage. The YAG:Ce is normally parked out of the beam.

2.2.2.1 Optical Relay Line

The optical relay line consists of 2 Newport KPA046-C lenses (50mm diameter, 37mm focal length) in a point to parallel to point setup. The magnification of the relay line is 1 and the numeric aperture is 1:0.74.

2.2.2.2 Detector

The detector is a Hamamatsu Model S1300 Duo-Lateral, Super Linear Position Sensing Detector mounted on a C4757 signal processing board.

The Position Sensitive Detector can monitor the stability of the beam position in X and Y with a resolution of better than 1 μm and with a bandwidth of more than 10 kHz.

2.2.2.3 Readout

The detector output is read by a Hytec MADC2508 16-bit VME ADC. Three ADC channels are used for X (channel 0), Y (channel 1), and intensity (channel 2). The ADC is located in the OSR hutch.

2.2.3 Fill Pattern Monitor

2.2.3.1 Detector

The detector is a Hamamatsu C5658 module consisting of an Avalanche Photodiode, a bias supply and an amplifier. The detector has a bandwidth of 1 GHz and an active area 0.5 mm in diameter. The spectral response range is 400-1000 nm, but the module works well as a single-photon X-ray detector. Because of the small active area, it would be difficult to align the detector in the X-ray beam. The module is therefore mounted on the same motorized stage as the PSD and detects X-rays scattered by the same YAG:Ce crystal observed by the PSD.

2.2.3.2 Readout

The readout system consists of a constant fraction discriminator and a time-to-digital converter.

The constant fraction discriminator is a custom designed NIM module with a fixed constant fraction delay matched to the rise time of the APD, a fixed fraction of 0.25, and a fixed output pulse width of 5 ns. The deadtime of the CFD is just under 10 ns. Therefore, after an X-ray is detected, the system is blind to photons from the following 4 bunches, but is able to detect an X-ray from the fifth bunch.

The time-to-digital converter is a CAEN V1290N multi-hit VME TDC with a resolution of 25 ps. It measures the arrival time of an X-ray relative to the orbit clock of the Storage Ring.

2.3 CONTROL HARDWARE

The control hardware for XSR is located on top of the Storage Ring:

Rack R2405.1-04	Optical table motor controllers
Rack R2406.9-01	Front end vacuum controllers
Rack R2406.9-02	Front end PLC
Rack R2406.1-09	Front end motor controllers

2.4 LOCAL MONITORS AND DISPLAYS

The following monitors and displays, which are permanently installed in the OSR hutch, are used for the XSR beamline:

- A rack-mounted computer monitor and keyboard tray, switched between the CCD/ICCD and Streak Camera data acquisition computers,
- A rack-mounted control computer for beamline control and other diagnostics,
- A rack-mounted video monitor, which is connected to the CCD in the XSR hutch.
- 2 Keithley 6485 Picoammeters, which are connected to the XSR X-ray BPM.

2.5 TEST EQUIPMENT

The OSR test equipment is used for work on the XSR beamline.

3.0 USER'S GUIDE

3.1 HOW TO SET UP THE XSR FRONT END

On the control screen, select **CLS Logo** → **Storage Ring** → **XSR Diagnostic Beamline** and click on the **XSR Front End** tab (see Fig. 3).

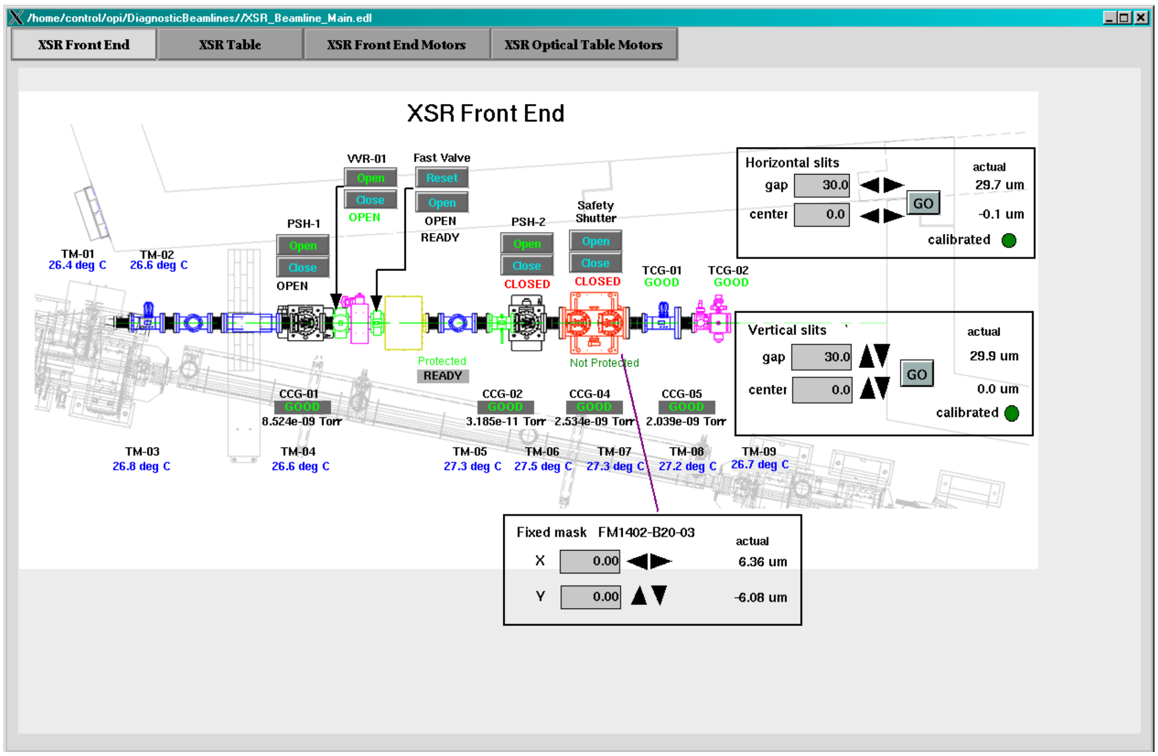


Fig. 3: The XSR Front End control window showing the typical slit settings for the pinhole camera.

Verify that the slits are calibrated. This is indicated by green dots in the "calibrated" columns of the settings. There have to be 2 green dots as indicated in Fig. 3. The fixed mask has absolute feedback and does not need to be calibrated.

If any of the slits is not calibrated, **make sure photon shutter 2 is closed** and click on the **XSR Front End Motors** tab (see Fig. 4). Click **RUN** for any motor that does not indicate **CALIBRATED**. Wait until the motors finish their position calibration. Return to the **XSR Front End** screen.

Verify that the vacuum valve VVR-01 and photon shutter PSH-1 are open. PSH-1 protects VVR-1 and can only be opened when the vacuum valve is open. Verify that the safety shutter and PSH-2 are open. The safety shutter can only be opened when the hutch is locked up and the beamline is enabled. PSH-2 protects the safety shutter and can only be opened when the safety shutter is open. PSH-1 would normally be left open. PSH-2 is used to turn the X-ray beam on and off.

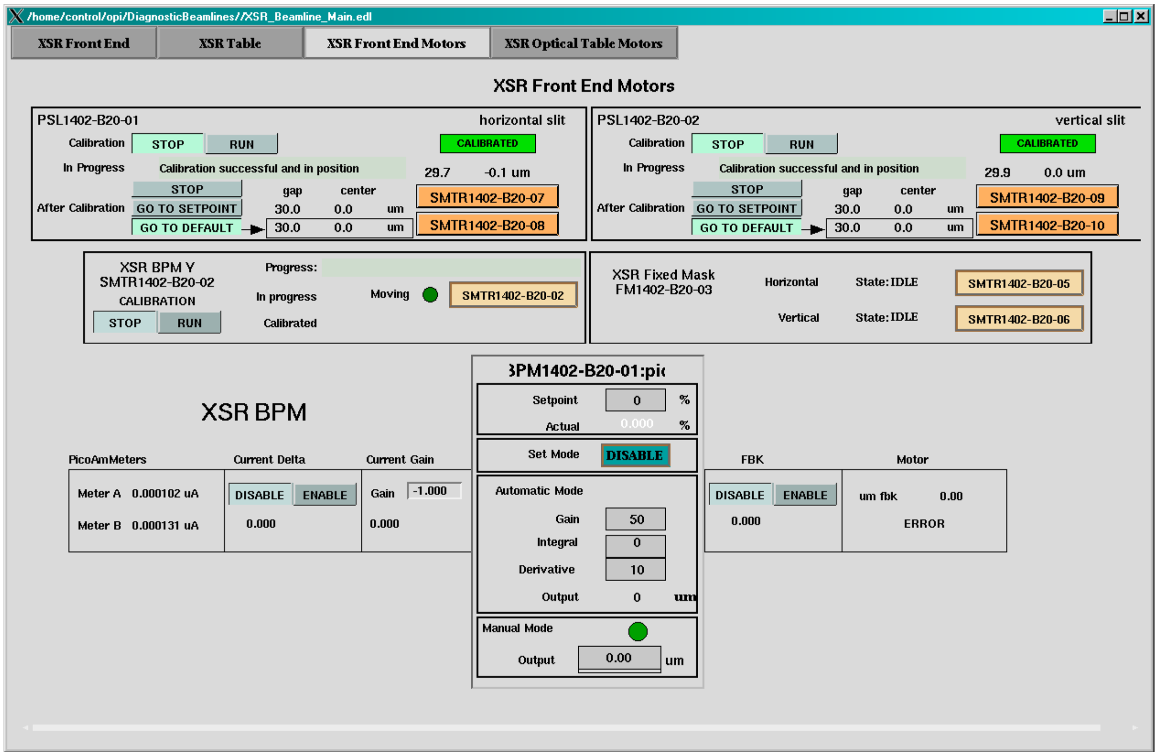


Fig. 4: XSR Front End Motors screen. Both motors of the slits are calibrated. The XSR Fixed Mask box is for debugging purposes and is not normally used. The XSR BPM controls are under development.

3.2 HOW TO OPERATE THE DETECTORS ON THE XSR TABLE

3.2.1 Setup of the Optical Table

In the XSR Control Window, click on the **XSR Table** tab. Verify that both stages are calibrated as indicated by the **CALIBRATED** flag (see Fig. 5). If any of the stages is not calibrated, click on the **XSR Optical Table Motors** tab (see Fig. 6). Click **RUN** for any motor that does not indicate **CALIBRATED**. Wait until the motors finish their position calibration. Return to the **XSR Table** screen.

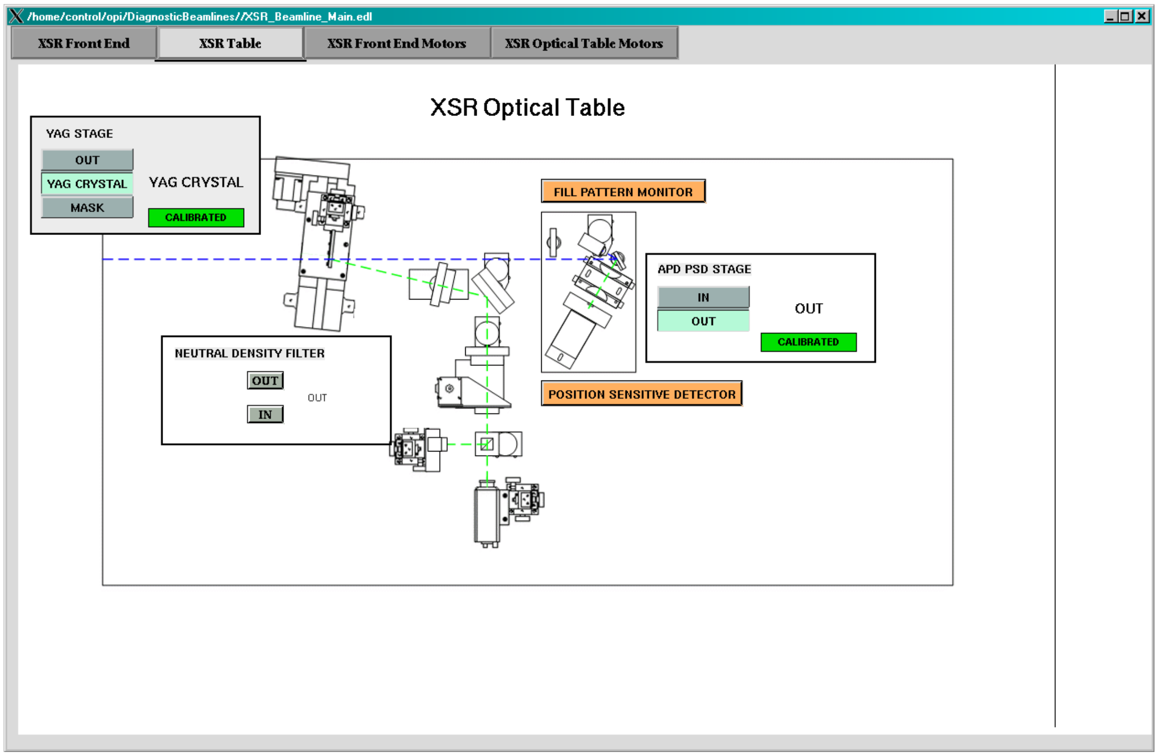


Fig. 5: XSR Table screen. The configuration shown is for use of the CCD camera. The neutral density filter is normally out. If the Fill Pattern Monitor or the Position Sensitive Detector is to be used, the **YAG STAGE** needs to be moved out and the **APD PSD Stage** needs to be moved in.

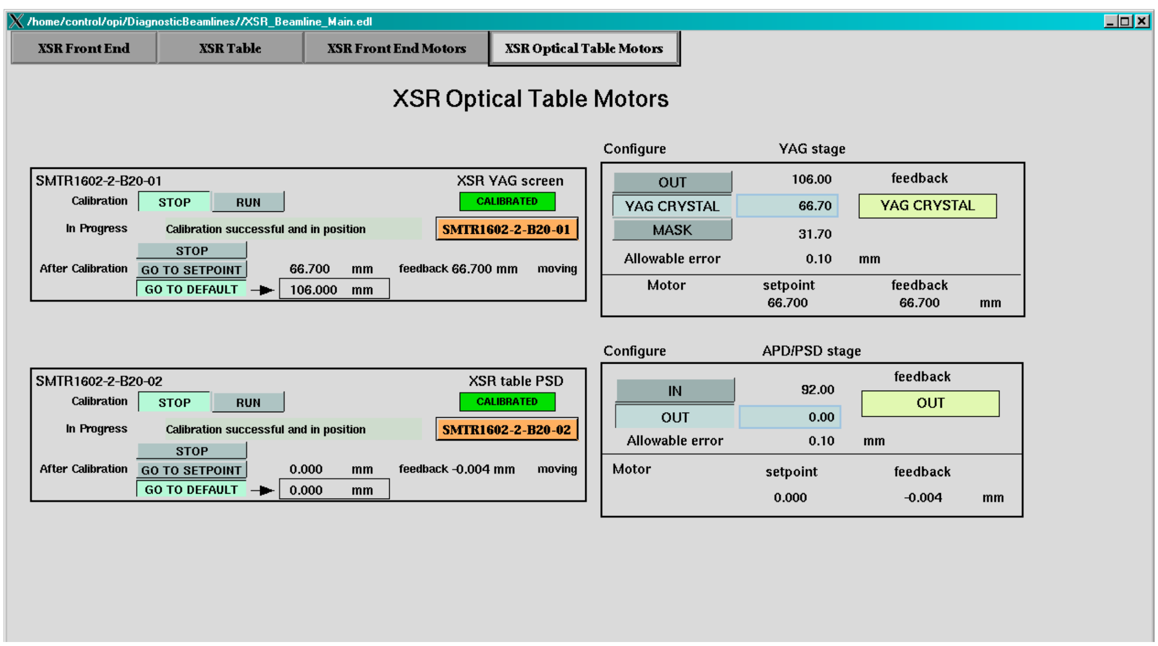


Fig. 6: The XSR Optical Table Motors screen. Both stages are calibrated and the settings of the various positions are shown.

3.2.2 Running the CCD Camera Using Spiricon

In the **XSR Front End** screen, set the horizontal and vertical slits to an aperture of 25-30 μm.

In the **XSR Table** screen, move the **YAG STAGE** in and the **APD PSD STAGE** out.

Spiricon is installed on a dedicated computer in the OSR hutch, but it can be accessed from the control room via a KVM extender.

To start up Spiricon, click on the icon

Spiricon has a large number of features and options. Some have not been explored yet, and some are not applicable to the CCD camera. The following configuration is suggested as a starting point. A detailed description of the Spiricon software can be found in Ref. [2].

Select **Options** → **Camera** and set the configuration shown in Fig. 7. "Frames" may be set as desired.

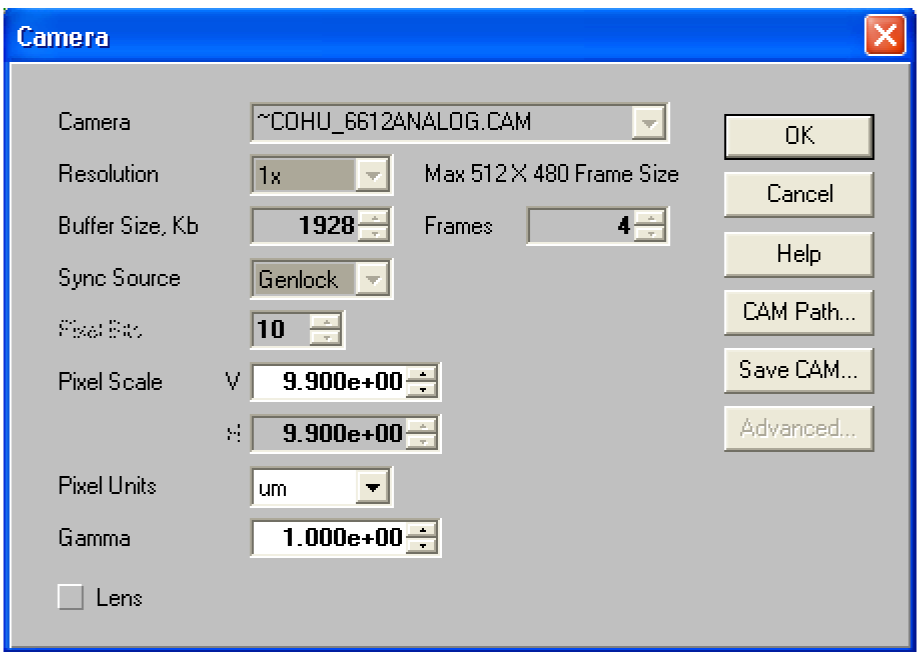


Fig. 7: Configuration of the "**Camera**" window for the CCD camera.

Select **Options** → **Capture** and set the configuration shown in Fig. 8:

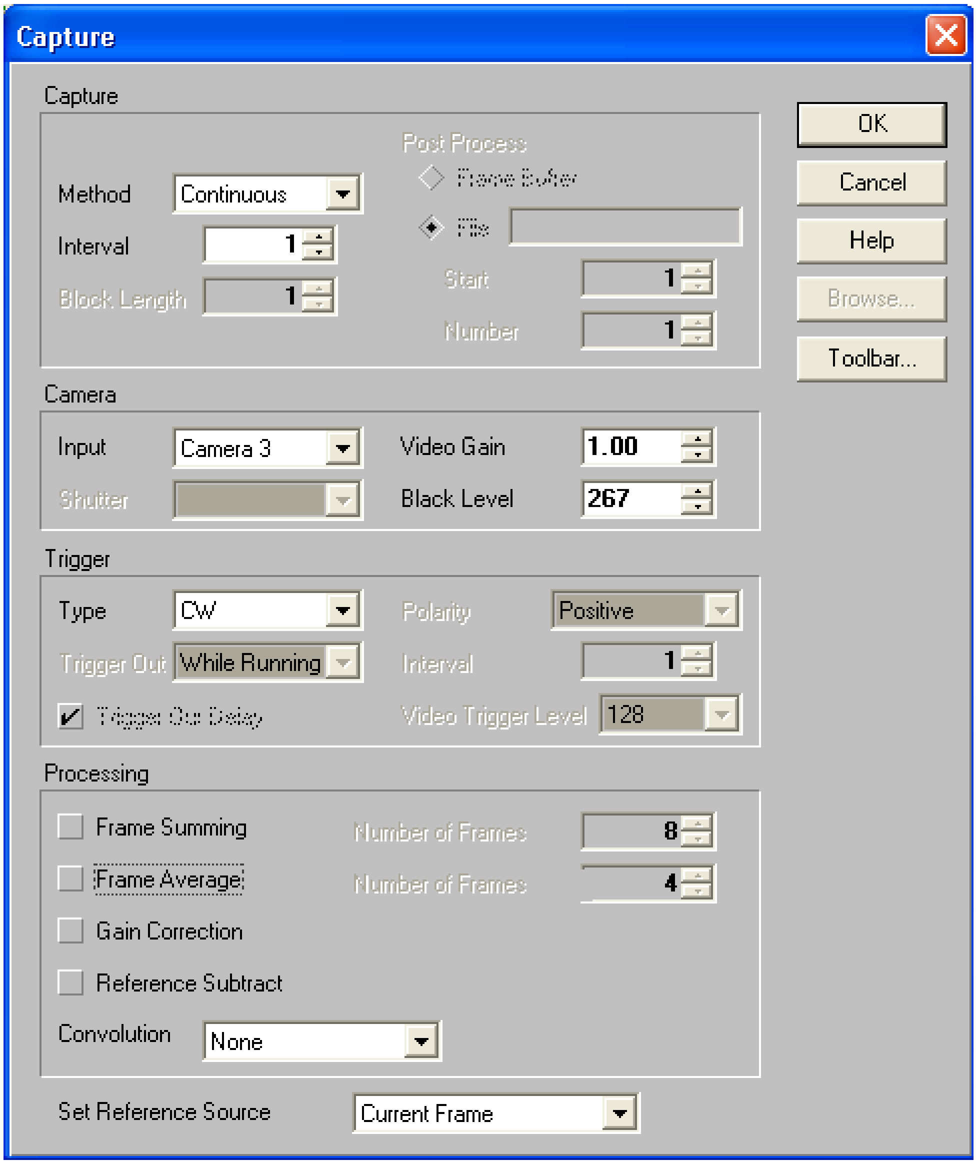


Fig. 8: Configuration of the “**Capture**” window for the CCD camera.

The CCD camera can be used to capture an image of the beam at its "moment of death", as the Storage Ring trips. In this case the "**Capture**" window needs to be set up as shown in Fig. 9.

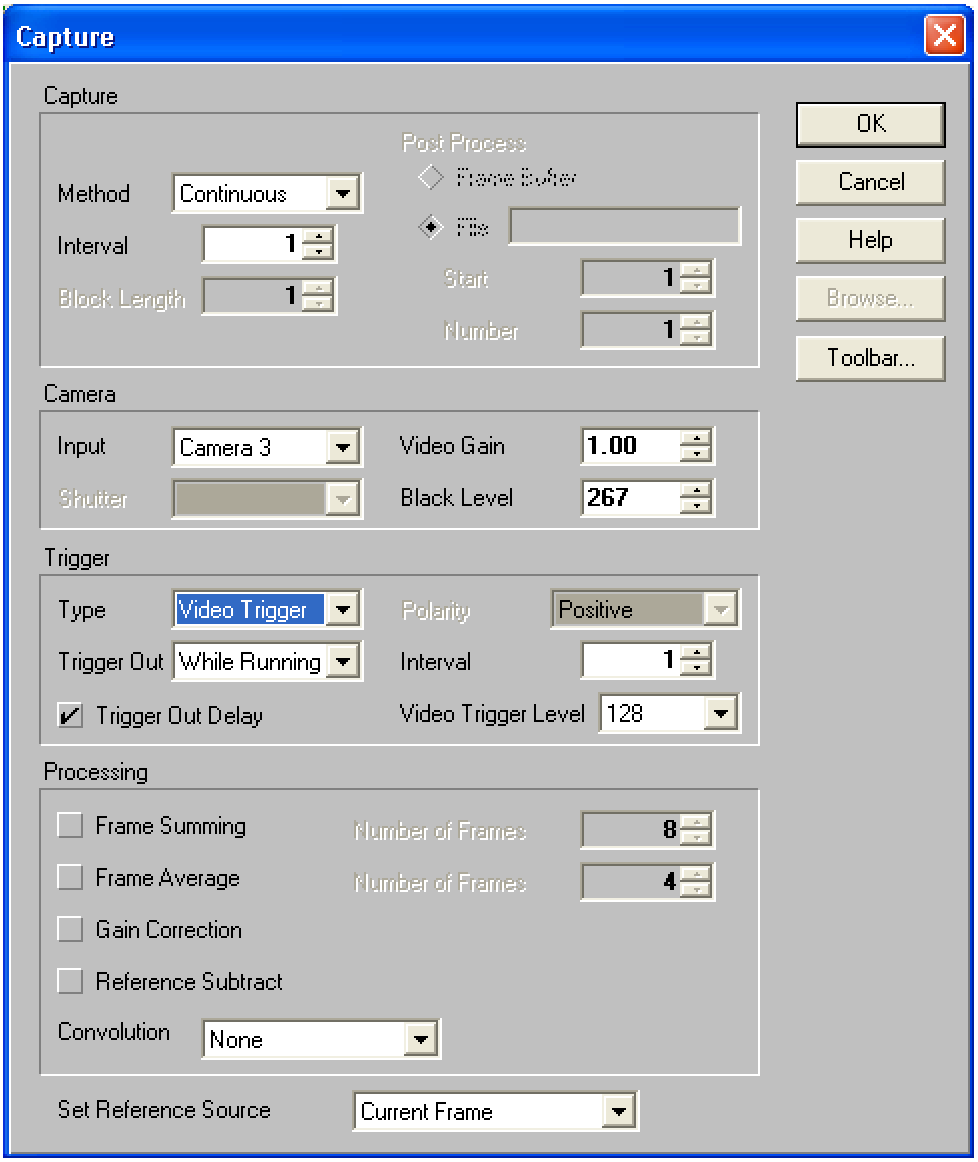


Fig. 9: Configuration of the "**Capture**" window for capturing the beam at its "moment of death" using the CCD camera.

Select **Options** → **Computations** and set the configuration shown in Fig. 10:

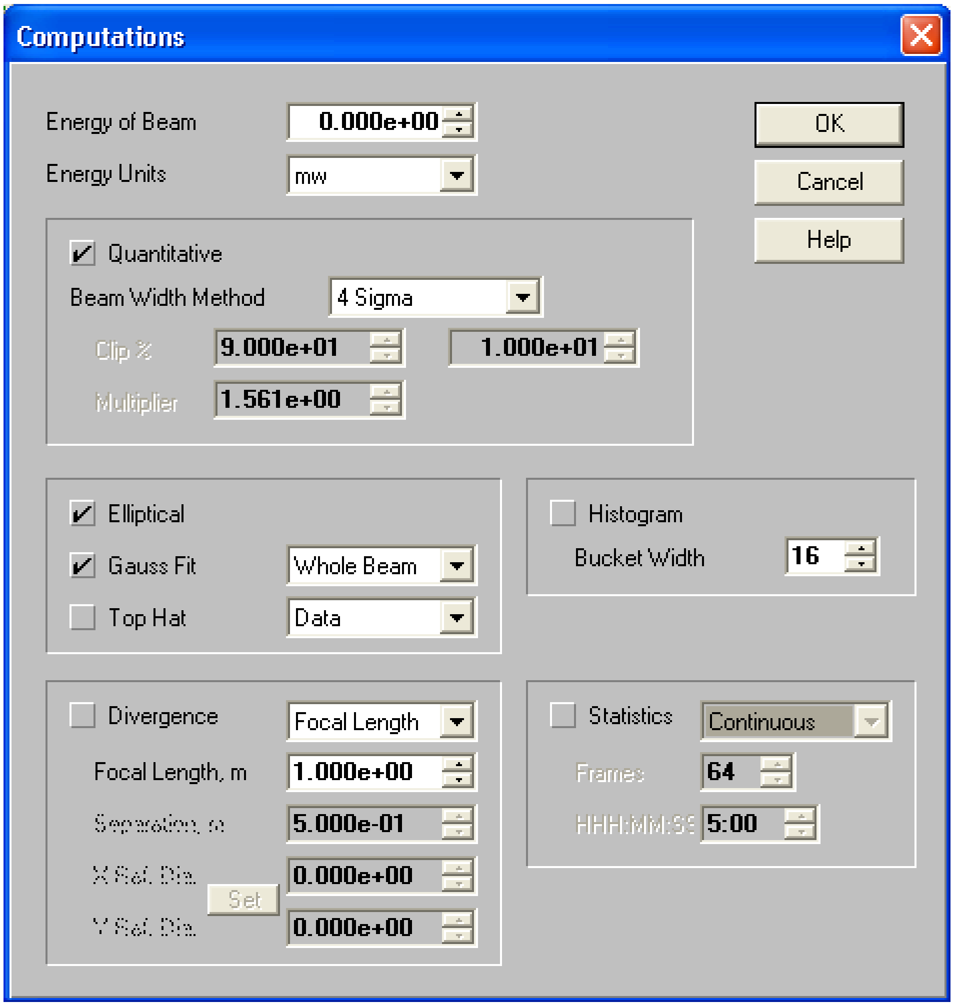


Fig. 10: Configuration of the "**Computations**" window for the CCD camera.

Select **Options** → **Beam Display** and set the configuration shown in Fig. 11. “Curser Orientation” may be set as desired.

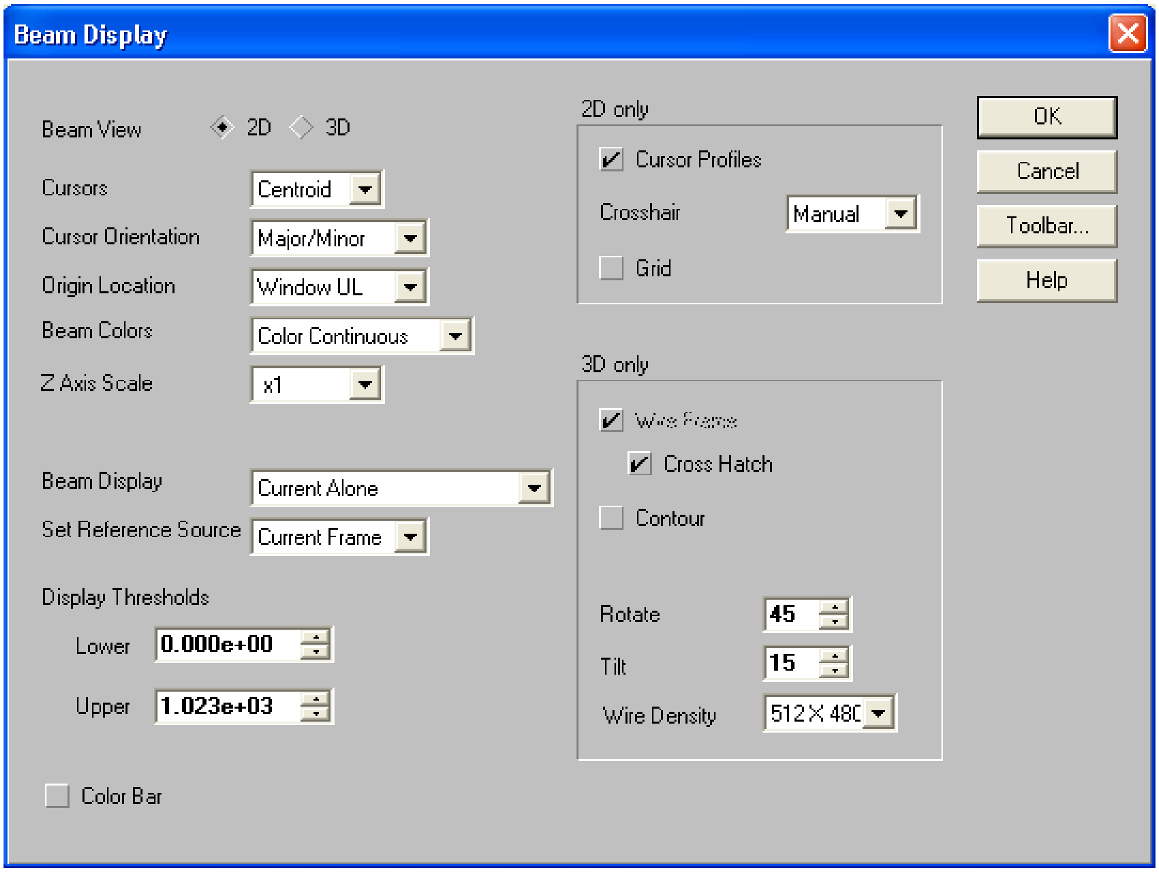
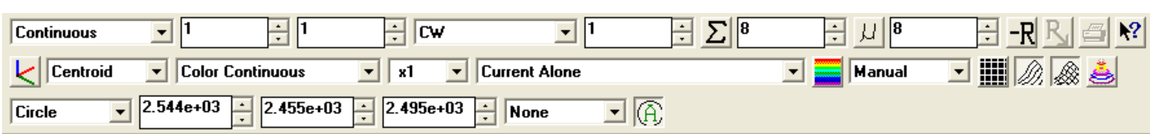


Fig. 11: Configuration of the “**Beam Display**” window for the CCD camera.

For a proper measurement of the beam size and position, it is important to subtract the background light. To start this background subtraction, close photon shutter 2 (see Fig. 3) and click “**Ultracal**” in the Spiricon window. Open the photon shutter again when the background measurement is finished (after a few seconds).

Spiricon has 3 toolbars:



The top toolbar is for triggering and sampling. It should be set as shown, with Σ and μ not pressed. The numbers to the right of Σ and μ are then meaningless.

The middle toolbar defines the crosshairs and should be set as shown.

The bottom toolbar describes the region of interest. The region of interest can be defined by entering coordinates or by dragging and resizing. The Ⓐ-button needs to be pressed to read meaningful values for the beam position or the beam size.

3.2.3 Running the Firewire Camera

Not yet implemented.

3.2.4 Running the Position Sensitive Detector

In the **XSR Table** screen, move the **YAG STAGE** out and the **APD PSD STAGE** in. Click on **POSITION SENSITIVE DETECTOR.** The window in Fig. 12 will open.

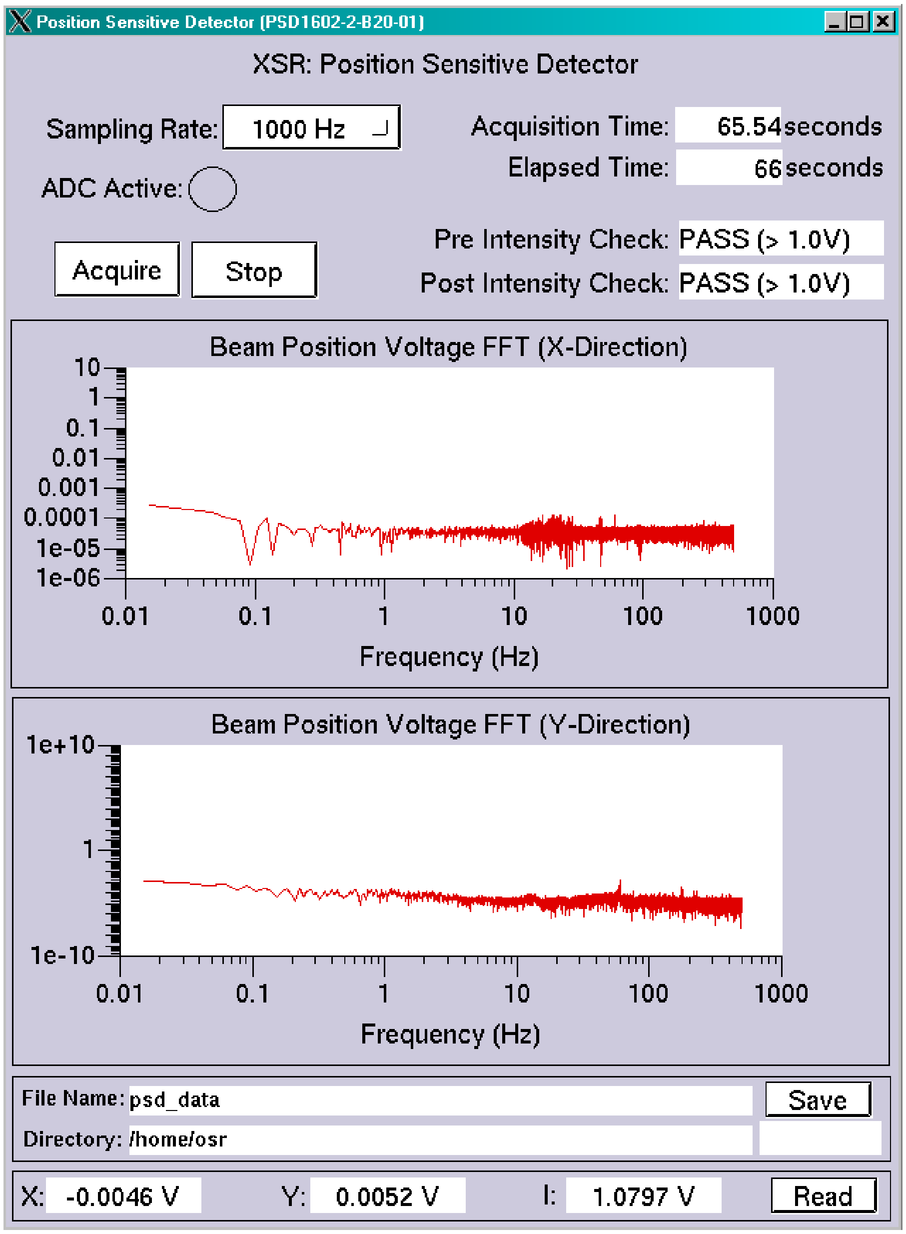


Fig. 12: Position Sensitive Detector control window. Manual readout for setting up the detector can be initiated by pressing **Read** at the bottom. Data acquisition cycles are controlled and monitored at the top of the window. The Fourier transform of the position data is displayed in X and Y. The Fourier spectra can be saved at the end of a run.

To set up the detector and the XSR slits, click **Read**. According to the detector manual, the intensity **I** should be between 1V and 10V. However, experience shows that there is an increased noise floor if **I** > 2V or so, whereas a voltage slightly below 1V does not increase the noise much. It seems best to keep **I** near 1V. Adjust the slits in the XSR front end, considering the effect on the angular and positional sensitivities explained in 3.2.5.

The beam position on the detector, **X** and **Y**, should not read more than ± a few mV. If the magnitude of the reading is higher, either the beam or the detector is misaligned or, if the problem is in **X**, the calibration of the stage may be wrong. The sensitivity of the detector is 1V/mm.

To start an acquisition cycle, select the sampling rate as implied by your frequency range of interest and click **Acquire**. At the beginning of the acquisition cycle, the intensity is checked and the run is aborted if **I** < 0.1V or **I** > 9.9V. If the test is passed, the software acquires 64Ksamples each of X and Y at the selected sampling frequency. Another intensity check is done at the end and if it is passed, the Fourier transforms of the X and Y voltages are displayed.

3.2.5 Sensitivity in Y to Beam Angle and Position at the Source Point

The image of the beam at the source point, generated by the slits, depends on the size of the slits. Since the Position Sensitive Detector is sensitive to the centroid of the beam, what matters is the location of the centroid as a function of the slit setting. This correlation has been studied for the vertical direction [3] with the results shown in Figs. 13 and 14.

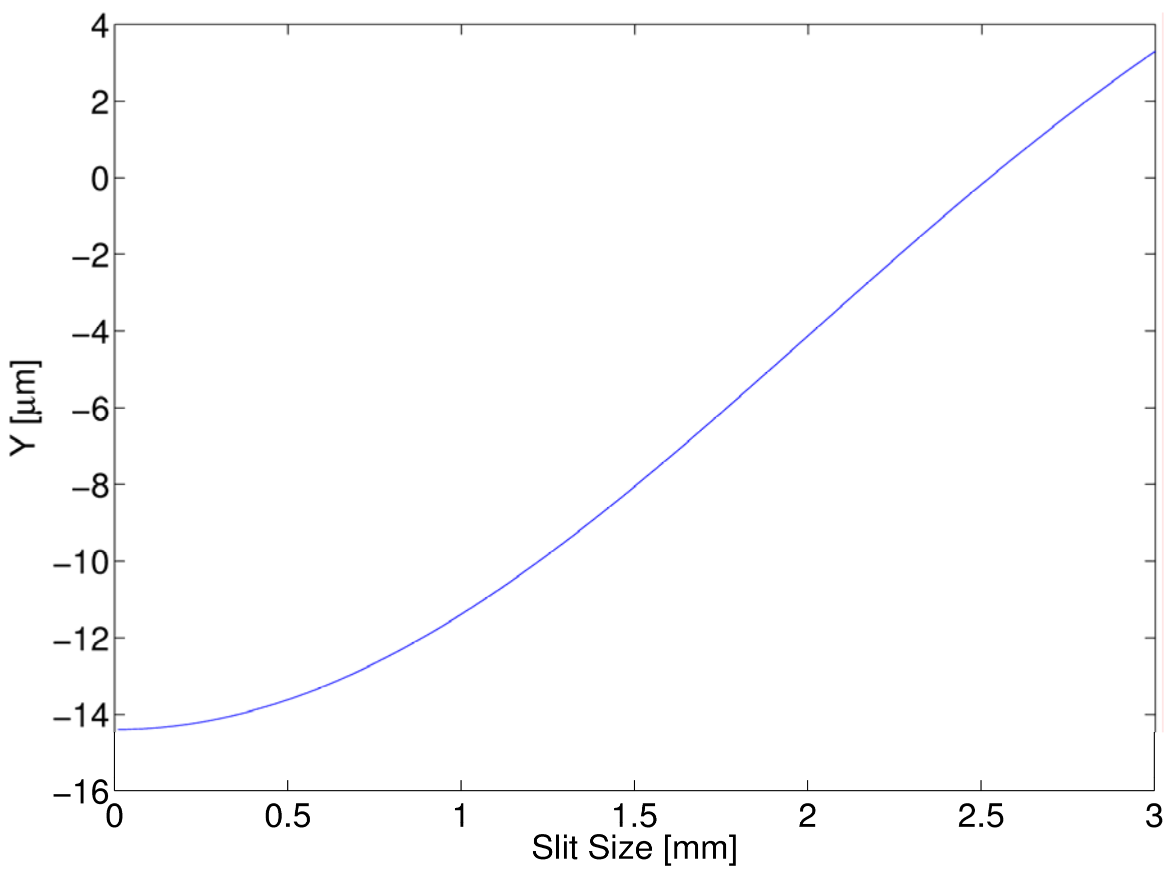


Fig. 13: The vertical position of the centroid of the image at the PSD YAG as a function of the vertical slit size. The beam offset at the source point is +10 μm in Y, the angle is 0. According to this simulation, the PSD is not sensitive to a shift of the beam position at a slit size of 2.52 mm. In reality, however, the fixed mask cuts into the beam at slit settings > 2.3 mm.

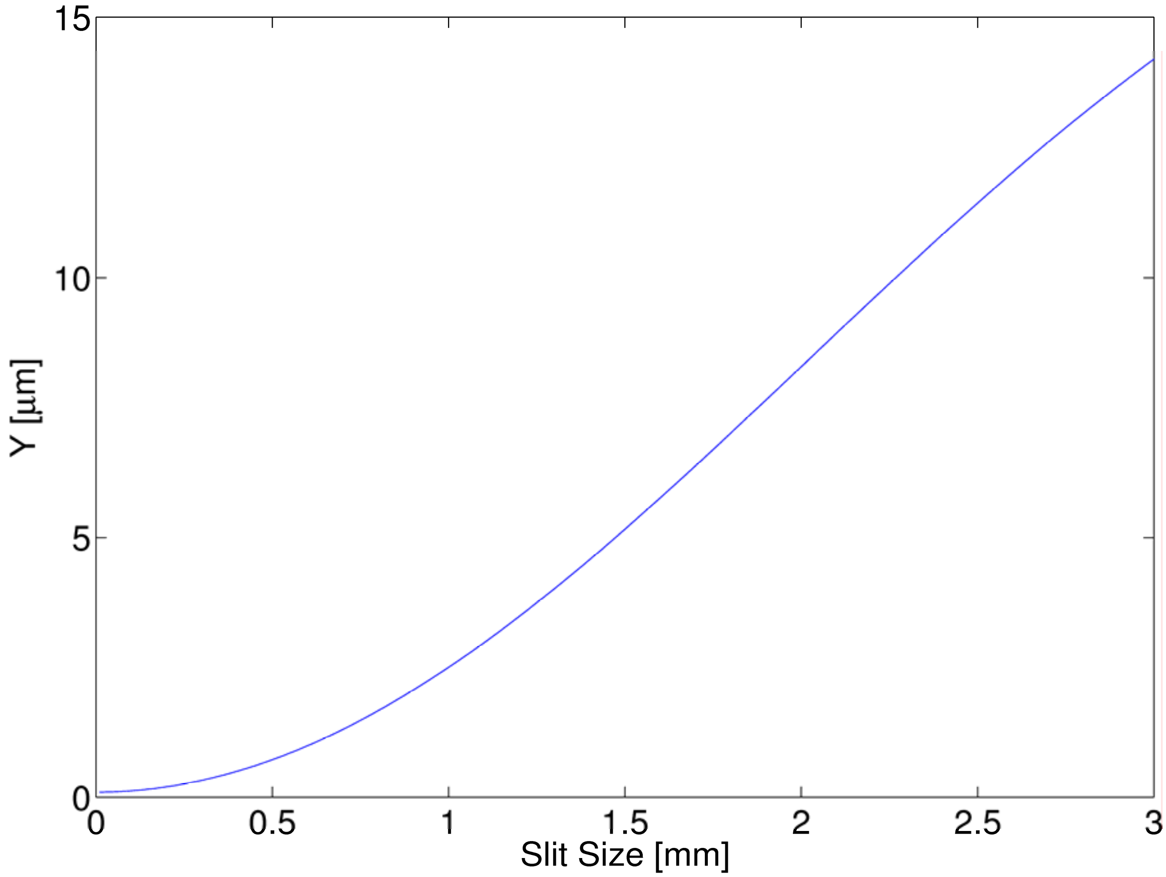


Fig. 14: The vertical position of the centroid of the image at the PSD YAG as a function of the vertical slit size. The beam angle at the source point is +1 µrad in Y, the offset is 0. At small slit settings the PSD is not sensitive to the beam angle.

As indicated by the graphs, small slit settings make the detector sensitive only to the beam position at the source point. At a slit setting of 2.3 mm, the fixed mask starts determining the aperture. Thus a gap of 2.52 mm, at which the detector is sensitive only to the angle of the beam, cannot be reached. However, as Fig. 13 shows, the detector is nearly insensitive to the beam position at an effective opening of 2.3 mm.

3.2.6 Sensitivity in X to Beam Angle and Position at the Source Point

The sensitivity to a change in the horizontal angle and position of the beam has been calculated [3] with the following results:

- Provided that the beam intensity across the aperture is constant, the sensitivity is independent of the size of the aperture.
- For beam angles that are physically possible in the Storage Ring, the PSD is not sensitive to the beam angle.
- The position sensitivity is solely given by the lever arms of the pinhole camera such that $\Delta x(PSD) = -1.45 \cdot \Delta x(\text{source point})$

3.2.7 Running the Fill Pattern Monitor

In the **XSR Table** screen, move the **YAG STAGE** out and the **APD PSD STAGE** in.

Click on **FILL PATTERN MONITOR** and the control window for the fill pattern monitor will open.

Look at the **Frequency Counter** reading at the bottom of any of the screens (Figs. 14-16). In the **XSR Front End** screen, adjust the slits so that the count rate is about 100 kHz for multi-bunch fills or about 30 kHz for single-bunch/ few-bunch fills.

Click **Integral Config** and turn on **Show Integral Boundaries** (see Fig. 14). Zoom in as needed and enter the **Centre Position** and the **Bucket Number** for any of the buckets. The purpose of this is twofold:

- To locate the integration boundaries around the peaks,
- To define the bucket numbers the same way the timing system does.

The **Width** should be 81.92, but the current version of the software only allows integer numbers.

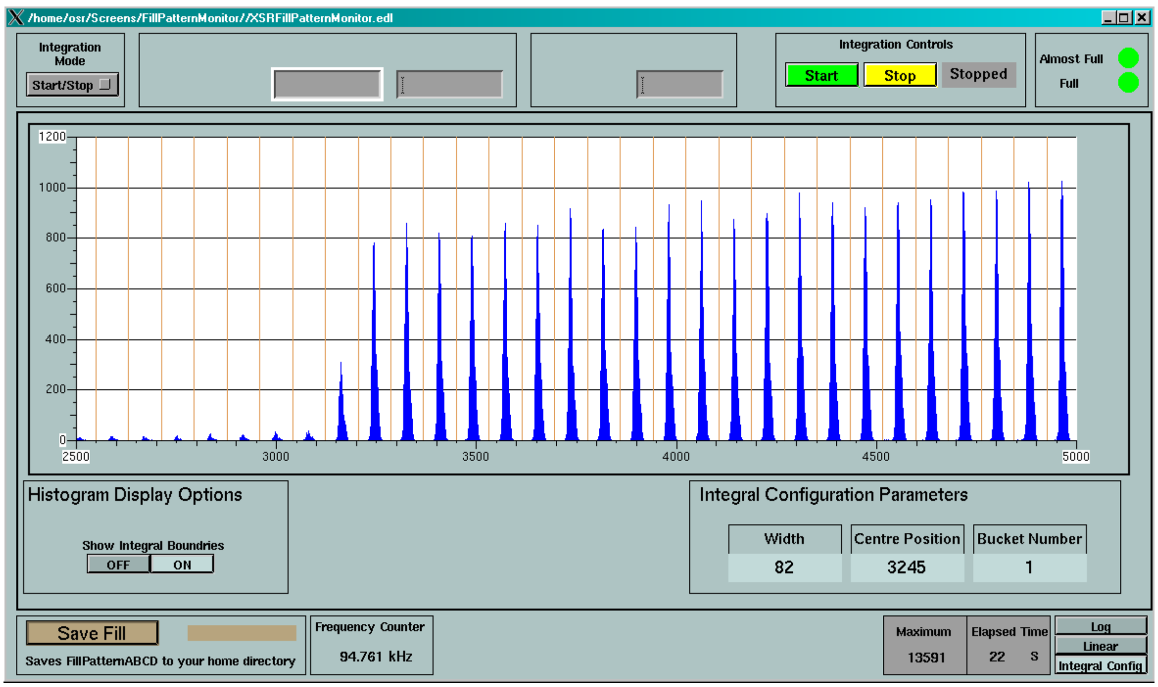


Fig. 14: The **Integral Config** screen of the fill pattern monitor software. **Width** should be 81.92. The combination of **Centre Position** and **Bucket Number** does not change unless machine parameters, such as the RF phase, are changed.

The spectra in the **Log** or **Linear** displays (Fig. 15, 16) show the integrals over the peaks in Fig. 14, adjusted so that the spectrum starts at bucket 1 according to the selection of **Centre Position** and **Bucket Number**. The integral of each bucket is proportional to the charge in this bucket.

Click on your choice of **Log** or **Linear** display. The example shown (Figs. 15, 16) uses the **Linear** display, but the operation is the same if **Log** is chosen.

If the **Integration Mode** is set to **Start/Stop** (Fig. 15) the data acquisition is operated manually. If the **Integration Mode** is set to **Automatic** (Fig.16), the spectrum will accumulate until a preset count is reached in the highest channel, or it will accumulate for a preset amount of time, depending on the **Automatic Mode** chosen. If **Acquisition Repeat** is enabled, the spectrum will be zeroed after a preset amount of time and the acquisition will repeat indefinitely.

It is possible to zoom in on a specific region of interest by selecting the region with the mouse.

The fill pattern can be saved by clicking **Save Fill**. The fill pattern is stored in the user home directory.

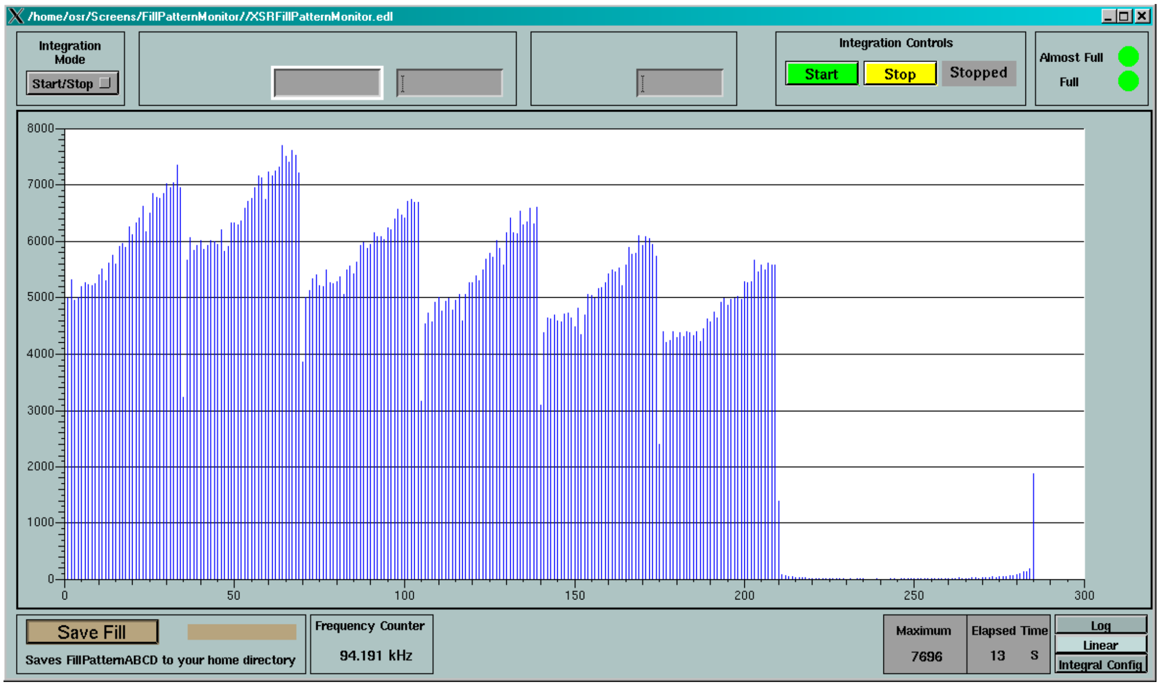


Fig. 15: The **Linear** screen in **Start/Stop** mode.

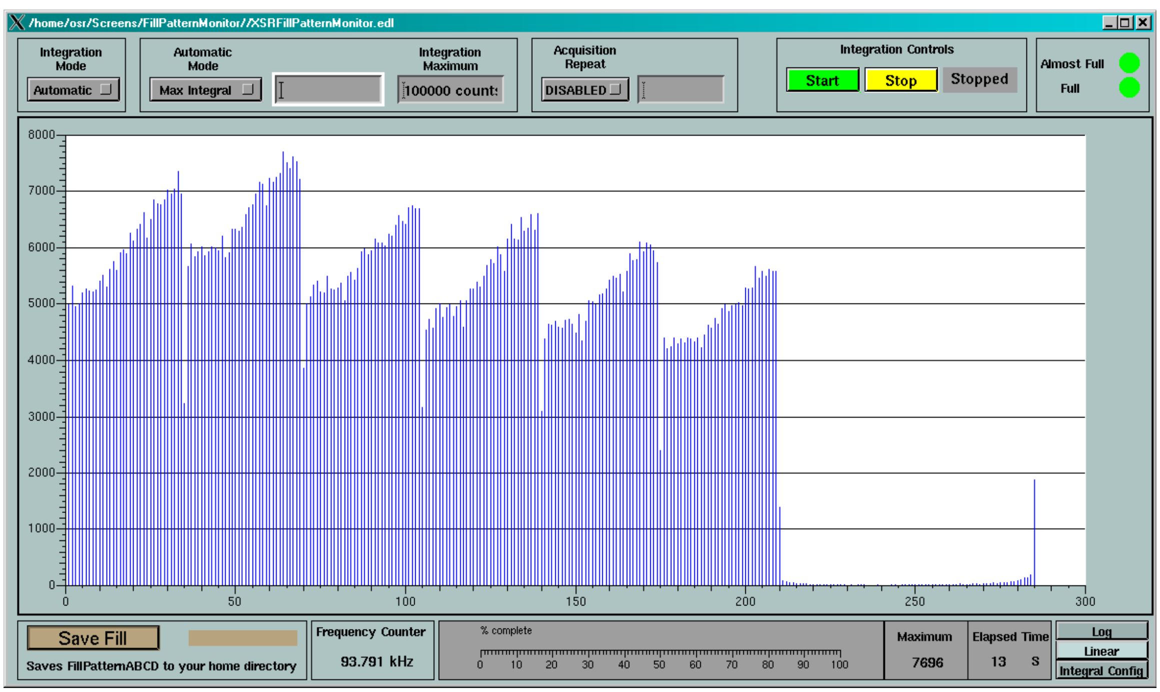


Fig. 16: The **Linear** screen in **Automatic** mode.

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