Periscope Pop-In Beam Monitor

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Abstract. We have built monitors for use as beam diagnostics in the narrow gap of an undulator for an FEL experiment. They utilize an intercepting screen of doped YAG scintillating crystal to make light that is imaged through a periscope by conventional video equipment. The absolute position can be ascertained by comparing the electron beam position with the position of a He:Ne laser that is observed by this pop-in monitor. The optical properties of the periscope and the mechanical arrangement of the system mean that beam can be spatially determined to the resolution of the camera, in this case approximately 10 micrometers. Our experience with these monitors suggests improvements for successor designs, which we also describe.

INTRODUCTION

At BNL our current FEL projects center on single pass designs, in particular the High Gain Harmonic Generation (HGHG) scheme (1). To obtain a high performance FEL, high peak current, low-emittance electron beams must be produced, transported, and controlled throughout the accelerator system. Clearly, one must possess metrology tools to measure these beam attributes in a precise and reliable manner. We have developed a number of intercepting diagnostics for these tasks, many of which utilize YAG scintillation crystals as described elsewhere in these proceedings (2). These screens are especially useful for our experiments since they provide the opportunity to measure both the beam position and profile for a single electron pulse.

The undulators we are using for our FEL experiments are fitted with integral correction stations (3) so beam monitors must be available to determine the proper settings of the steering-focusing magnets. To maintain overlap between the electron beam and the growing radiation field of the FEL, it was felt that the position resolution of the monitors should be at least 10 percent of the beam size and that they should image the beam with comparable resolution (4). For typical parameters of our experiments, spatial resolution and absolute precision on the order of 20 micrometers are required. Since there are no “breaks” in our undulators for diagnostic stations, the monitors must fit in the gap of the undulator vacuum chamber. For the design discussed in this paper the probe must fit inside an 11 mm chamber opening.

DESIGN SYNTHESIS

It is fair to say that the design presented here is the product of a number of constraints imposed by the use of existing hardware, space limitations in the experimental hall, evolution of design ideas, and plain dumb luck. In the spirit of these workshops we freely admit this but, to preserve a modicum of dignity, will refrain from a complete discussion, pleading space limitations in the proceedings volume. Interested readers should feel free to contact the authors should they wish to be regaled with the lurid details. Whatever the process, we have arrived at a design that presents some very nice features which make it durable and precise. In Figure 1, the essential features of the monitor are shown schematically.

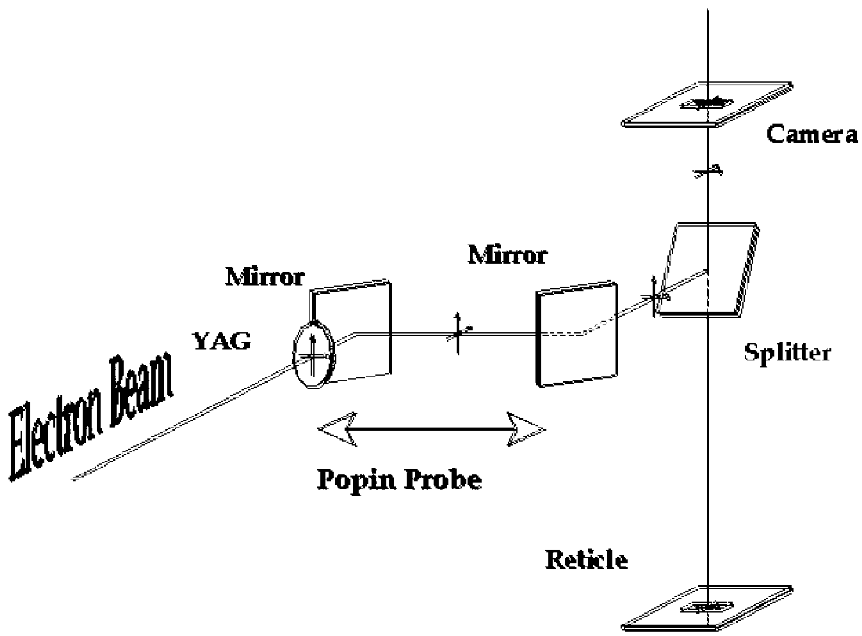

FIGURE 1. The YAG crystal and two mirrors constitute the pop-in probe. It is moved as an assembly in and out of the electron beam. Note the orientation of the arrow and paw figure. It traces the beam image through the optical system. The image presented to the camera is what one would view on the front surface of the scintillation screen.

The probe is configured as a periscope which has the effect of displacing the image from the axis of the electron beam by a distance determined by the mirror spacing. Reproducible insertion of the probe is not required to maintain the precision of the monitor since the camera is firmly mounted to the undulator structure. As long as the probe length is stable and the camera does not move, the precision of the monitor is preserved, so a “sloppy” actuator can be used. To provide fiducial reference marks, a fixed reticle is viewed through a beam splitter at a position for the YAG crystal. An outline drawing of the monitor is provided in Figure 2.

In this design the probe, actuator, and optics are all on one side of the undulator. The light from the screen is collected through the hollow shaft of the probe. The probe itself is made in two tubular sections, the inner of stainless steel and the outer of aluminum. Their relative lengths and materials were chosen to match the material path from the center of the undulator to the camera mount. In this way, temperature drifts in the experimental hall do not compromise the precision of the monitor. An increase in temperature makes the probe longer but it also shifts the camera from the undulator center by the same distance.

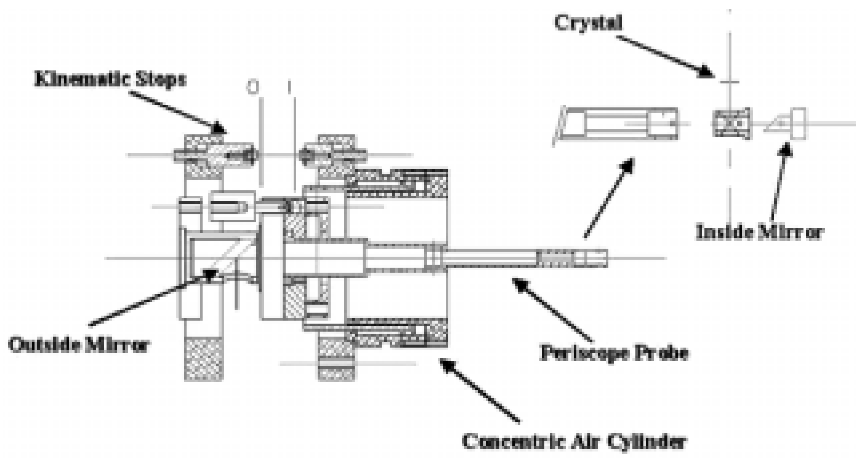

FIGURE 2. This cross-section drawing shows the probe assembly and actuator. In this plan view the electron beam would be traveling from the top to the bottom of the page. The vacuum bellows and chamber mounting have been omitted from this view but are shown in Figure 3. The inset to the figure shows how the crystal and inside mirror are fitted to the inner end of the probe.

The inner diameters of the probe sections become progressively larger as the distance from the screen increases to maintain a viewing angle of approximately 90 milliradians. The minimum outer diameter of the probe is 9.8 mm while the YAG crystal is 0.5 mm thick and 6 mm in diameter. To keep the crystal and inner mirror in place, a carrier was designed as shown in the inset of Figure 2. The crystal sits in a counterbore in the carrier that just relieves its outer edge below the inside diameter of the probe. The inner mirror slides inside the carrier with the assembly secured by a single stainless steel roll pin. The inner mirror was fabricated in its finished shape from aluminum and polished. In retrospect it might have been better to start with a large polished mirror and trepan out the mirror. Holding the small blanks stable to polish a flat surface with minimal edge roll off turned out to be rather time consuming.

A double-sided 2.75" conflat flange holds the probe. Three pairs of ground stainless steel rods are set into the edge of the flange, 120 degrees apart. They form three “vee” grooves that are used to provide kinematic stops for the probe in its inserted and retracted positions as well as providing the location for the outer mirror. A bellows on the inner side of the flange allows the probe to be moved. A non-magnetic window is mounted on the outer side of the flange. The window flange has three extra through-holes to allow the outer mirror adjusters to rest on the probe rods. In this way the entire probe is referenced from these rods. The outer mirror can be adjusted for tilt and rotation. During preliminary assembly, an alignment laser is used to ensure that the inner and outer mirrors are parallel.

The actuator for moving the probe is a concentric air cylinder. Inner and outer cylinders capture the tubular piston so it is a double-acting device. The piston carries the probe and overcomes the vacuum load provided by the bellows. The effective areas of the inner and outer drive have been adjusted so that at the cylinder operating pressure of 25 psig, the clamping forces against the tooling ball stops for the inserted and retracted positions are equal. The stops for the probe are small tooling balls mounted on brass shoulder screws. This allows adjustment for the stop position and tilt adjustment of the probe. The bellows flange is rotatable and the rings supporting the probe stops are dogged to the cylinder. This allows a rotational orientation of the assembly before it is bolted into place. The welded bellows were specified with extra segments so small adjustments of about 5 degrees or less can be made by rotating the stops after the assembly is under vacuum. This rotational adjustment is important to keep the light from the screen traveling down the center of the probe. A plan view of the monitor mated to the chamber is given in Figure 3.

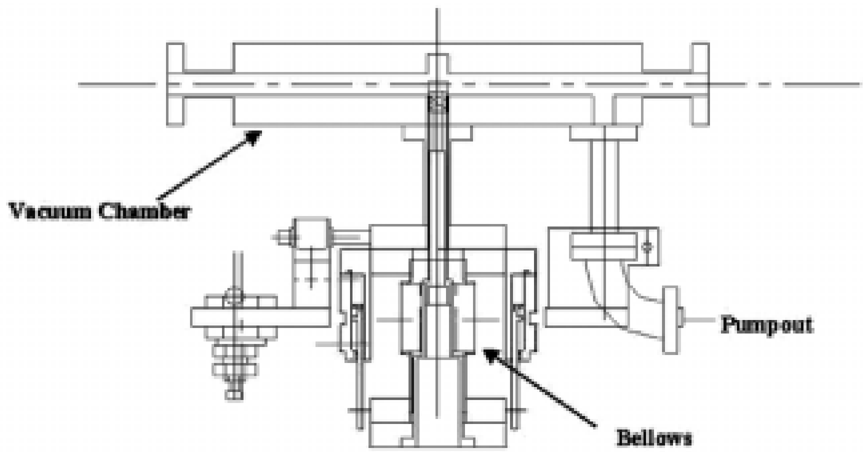

FIGURE 3. This cross-section drawing shows a plan view of a partially inserted probe assembly with its actuator attached to the vacuum chamber. The electron beam would move left to right on the page.

The optical arrangement is essentially as shown in Figure 1. The only additions are a 175 mm focal length achromat lens placed just above the beam splitter and the introduction of a neutral density filter wheel between the probe outer mirror and the beam splitter. The neutral density filters were selected as the method for attenuating the light so that the collection angles would remain constant; an iris would attenuate the light *and* change the aperture of the optical system. In practice an ND 1.0 filter seems to be used nearly all of the time.

A DC motor drives the filter change wheel and the position is encoded by microswitches. The motor drives the filter wheel via a belt which both conserves space close to the probe, and keeps the motor further away from the undulator and electron beam. Figure 4 provides a view of these components.

For imaging the beam, we use a COHU 4910 CCD camera (5). The reticle is also provided with an inexpensive back light (a 12-volt truck running-lamp; the white plastic mount works well as a diffuser!). If the light is turned on, the image of the reticle is superimposed on the beam image. If the light is turned off, only the beam is viewed. The beamsplitters we used were 70 percent reflective, 30 percent transmissive AR coated glass. The viewing scheme worked fine in the laboratory imaging the reticle and a surrogate beam image provided by a He:Ne laser. What we found in using the monitor on the experiment was a multiple image in the vertical of the beam spot. This image seems to be due to multiple internal reflections from the front and back surfaces of the beam splitter. Substitution of a first-surface mirror for the beam splitter provides a single undistorted image. After preliminary alignment of the monitors using a He:Ne laser, placed on the desired electron beam trajectory, we substituted mirrors for the beam splitters. We hope to find a modestly priced, durable beam splitter to use in this and future monitors that does not produce this artifact. The undulator with its five monitors is shown in Figure 5.

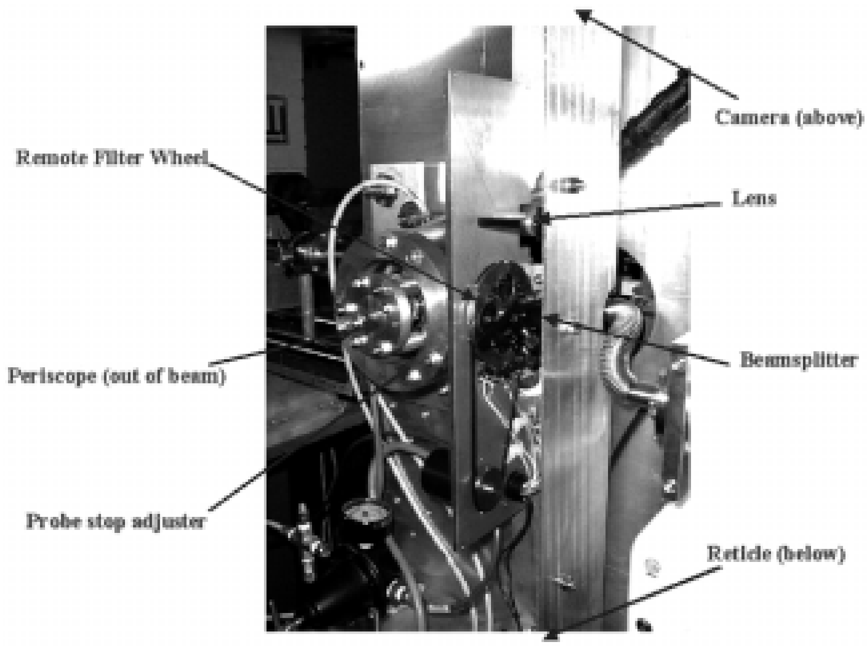

FIGURE 4. This photograph of one of our monitors shows the optical beam distribution components.

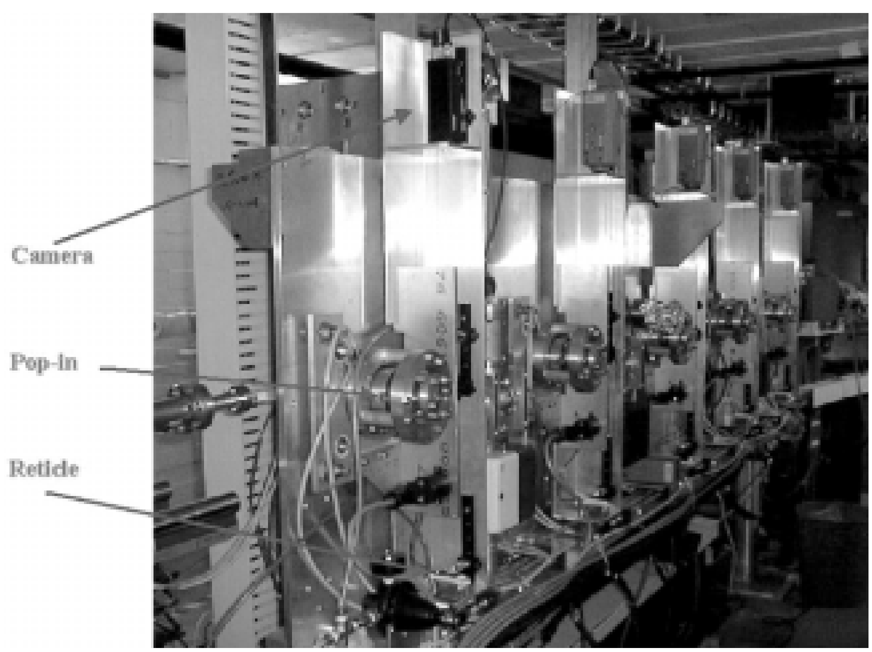

FIGURE 5. The five monitors mounted on the "Cornell undulator" at the BNL Accelerator Test Facility. This undulator, on loan from CHESS was rebuilt and measured by the ANL/Advance Photon Source. The FEL experiment is being undertaken in collaboration with the APS. Note that in this photograph, a Pulinex camera is being used for the first monitor.

EVALUATION AND CONCLUSIONS

On the whole, the monitors have performed quite satisfactorily. At the time of writing we have not had the opportunity to track down the beam splitter problem, although we are confident it can be resolved. Our operating experience seems to indicate that four separate filters are not required. Our next design will probably have two single filters on air actuators that could be put in the beam at the same time. This would give four possible filter settings (none, A, B, A+B) and simplify the design.

The inner mirror fabrication was more time-consuming than originally anticipated, and while convenient, precision machining might eliminate the adjustment of the external mirror. A probe is under development with a precision spacer with reference surfaces to locate two flat mirrors. While this simplifies the probe, it means both mirrors are in vacuum. The ability to remove and relocate the outer mirror turned out to be very useful for preliminary alignment of the monitors; a feature that is sacrificed by the new design. Whether this tradeoff is beneficial will have to await construction and testing of the new monitors.

The coaxial actuator turned out to be a pleasant surprise. We adjusted the design so it could be fabricated from standard tubing, so it was not nearly as expensive to make as we had first thought. One should also note that it does not have precision guides; only precision end stops. For this application the guiding provided by the piston seals was perfectly adequate. Compared with other types of through-vacuum actuators this seems to be a real advantage. We currently have plans to use these actuators on several other instruments at the National Synchrotron Light Source.

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[5] COHU 4910 series camera 1/2" CCD, specified sensitivity as used 0.65 lux. This information provided for reference only, since it was used in this instrument. Equipment by other manufacturers could, in principle, be used for this application.