This document aims to summarize the requirements of CHESS x-ray beamlines for the stability of the particle beams in CESR. This information was gathered by CHESS scientists, and is meant to help inform discussions between CHESS Ops and CESR about future beam position monitoring and feedback systems.

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CHESS-U beam parameters, and the “10% rule": The CHESS-U beamlines are designed (and the science cases for these facilities is defined) based on the following parameters for 6 GeV, 200 mA CHESS-U particle beams.

Horizontal Source Size: 571 microns

Vertical Source Size: 27 microns

Horizontal Divergence: 51 microradians

Vertical Divergence: 11 microradians

[Measured as standard deviation (rms).] As a general rule, beams would be considered “stable” if the variation of each of the centroids is within 10% of the standard deviation. In other words, CHESS-U beams would be fully “stable” in the vertical direction if the vertical position of the centroid drifted less than 3 microns over all time scales, and the beam trajectory simultaneously varied by less than 1 microradian. (The equivalent numbers in the horizontal direction would be 60 microns and 5 microradians). We believe this “10% rule” is a standard goal for light sources (it was the design goal for NSLS-II, for example), and a good target for CHESS. There are only diminishing returns for making the beams more stable than this.

Specific Use Cases: Beyond the standard “10% rule”, we have also looked at several specific use cases, to illustrate where instabilities in the beam position and direction can seriously degrade beamline performance. The goal here is to identify at what point specific beamline components will “break” due to beam instabilities. Typically, these are moderately less restrictive than the 10% rule.

Case #1 - Variation in undulator harmonic energy: The undulator x-ray sources in CESR generate bright harmonic enhancements of the x-ray flux at specific energy values, which are set by the strength of the magnetic field at the particle beam positions. The relative energy bandwidth of the nth harmonic of an undulator with N oscillation periods is ~(1/nN). So, for example, the 3rd harmonic of a CCU (N=52) at 10 keV x-ray energy should have a width of ~60 eV. Applying a similar “10% rule” as above, we should want the harmonic energy to remain stable to within 6 eV. As the particle beams shift away from the axis of the undulator, the magnetic field rolls off and the harmonic shifts. In order to change the 3rd harmonic energy by ~6 eV, it is necessary to change the vertical beam position by 70 microns, or to change the horizontal beam position by 570 microns, inside the undulator chambers. A similar energy shift can also be accomplished by changing the angular trajectory through the undulator, either by 50 microradians in the vertical direction, or 400 microradians in the horizontal. These numbers set the constraints for beam stability to enable robust performance of the undulator sources.

Case #2 – Energy stability of crystal monochromators: Angular stability of the synchrotron beam incident on crystal monochromators defines the stability in energy of the reflected x-ray beam, via the differential form of the Bragg's law

$\Delta E/E = \Delta\theta / \tan(\theta)$

where $\Delta\theta$ is the variation in the incident (Bragg) angle of the x-ray beam and θ is the working Bragg angle. At small Bragg angles of 4-6 deg ($\tan(\theta) \sim 0.1$) the effect of limited angular beam stability becomes more substantial. These angles correspond to frequently used high photon energies for the most practical low-index reflections (e.g., Si 111, Si 311 and Diamond 111) of double-crystal monochromators. High stability of the energy scale ($\Delta E/E \sim 10^{-5}$) is desired for x-ray spectroscopy and for precision determination of materials lattice parameters using x-ray diffraction/scattering. Thus, the desired specification for angular beam stability at the high energies is $\Delta\theta \sim 10^{-6}$ (or 1 microradian). This requirement corresponds to 10% of the angular divergence of synchrotron radiation in the vertical plane (also, the scattering plane of the double-crystal monochromators at CHESS).The energy stability scales simply as 10x the angular stability in this case, so a 10 microradian variation spreads $\Delta E/E$ to 10^{-4}.For the side-bounce beamlines with one-crystal monochromators operating in the horizontal scattering plane, the requirement of 10% is still a reasonable number, because the energy bandwidth is wider for these beamlines by an amount that scales with the greater horizontal divergence of incident radiation. These beamlines are less suitable for the high-resolution work, yet can be more practical for scattering experiments with the conventional level of precision $\Delta E/E \sim 10^{-3}$ - 10^{-4}.

Case #3 – Clearance through fixed apertures: Several CHESS beamlines have narrow fixed apertures far from the source. The x-ray beams must pass through the center of these apertures, which defines a constraint on the angular stability of the electron beams. For example, the 3A beamline features a 1mm tall aperture at a distance of 18m from the undulator. This aperture therefore subtends a full angle of 50 microradians. A beam that is nominally centered in the aperture will become completely blocked if it shifts by 25 microradians up or down. Therefore, a strong constraint of <10 microradians vertical angular stability applies to beamline 3A, just to get beam into the optics cave. Conversely, beamline 4B does not have real fixed vertical apertures, but features a diamond monochromator crystal which presents a small target for the beam, and becomes an effective vertical aperture. At 40 keV, a ~1cm long diamond crystal presents a shallow incident angle of 4.3 Deg, and an effective vertical footprint of ~750 microns. This crystal is 17.3m from the undulator, and therefore subtends a full angle of ~40 microradians, yielding a similar constraint to the aperture on 3A for vertical stability. The sector of the diamond which give optimized (wavefront-preserving) diffraction is of order 1mm wide as well, and there is a 2mm wide horizontal mask, which gives a similar constraint for stability in the horizontal direction, up to a factor ~2.

Time scales: Typical CHESS experiments last between 1-12 days. Stability of the incident beam over these time scales is crucial for reliable data collection. In the past, user would often seek to make detailed quantitative comparisons between data sets collected several days apart. As we begin to generate and analyze large data volumes with more sophisticated routines, we will become even more demanding - it will be increasingly common to quantitatively compare data sets collected months or even years apart. Therefore, long term beam stability is needed, essentially permanently. At the opposite end of the scale, CHESS users will take time resolved data with frame rates as fast as MHz, for example using the Cornell-developed KeckPAD, and beam instabilities in this time scale will be very detrimental. Therefore, we have need for beam stability both on very short, and on very long time scales.

Summary: We propose the following near-term requirements and long-term goals for beam position stability in CESR, to enable best performance of the x-ray beamlines for user science. Key near-term constraints are in red.

Criteria	**Vert. Position**	**Vert. Angle**	**Hor. Position**	**Hor. Angle**
Fixed Apertures	200 micron	10 microrad	400 micron	20 microrad
Undulator Harmonics	70 micron	50 microrad	570 micron	400 microrad
High-res Mono (dE/E~10^{-5})	20 micron	1 microrad	-	-
Standard Mono (dE/E~10^{-4})	200 micron	10 microrad	-	-
Ideal CHESS-U Goal (10% of sigma)	**3 micron**	**1 microrad**	**60 micron**	**5 microrad**
NSLS-II Reference [1] (2016)	0.5 micron	0.14 microrad	1 micron	2 microrad
APS Reference [2] (2018)	2 micron	0.85 microrad	8 micron	1.5 microrad

[1] https://www.aps.anl.gov/sites/www.aps.anl.gov/files/APS-Uploads/Workshops/BES-Light-Sources/Yuke%20Tian%20-%20Fast%20Orbit%20Feedback%20at%20NSLS-II.pdf

[2] https://www.aps.anl.gov/sites/www.aps.anl.gov/files/APS-Uploads/Workshops/BES-Light-Sources/Nick%20Sereno%20-%20Fast%20Orbit%20Feedback%20at%20APS.pdf