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DREAM - A NEW SOFT X-RAY (DYNAMIC REACTION MICROSCOPY) COLTRIMS ENDSTATION AT LCLS-II*

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Abstract

SLAC National Accelerator Laboratory is building new soft X-ray beamlines to take advantage of the LCLS-II upgrade to 1 MHz. One of the new beamlines is called TMO (Time resolved Molecular Optical science) also known as NEH 1.1. It will be a soft X-ray beamline featuring a sub-micron X-ray focus at its second, most downstream interaction region where the DREAM (Dynamic REAction Microscopy) COLTRIMS (COLd Target Recoil Ion Momentum Spectroscopy) endstation will be situated.

DREAM will feature; large magnetic coils to provide a strong uniform magnetic field through the spectrometer, rigid in-vacuum laser in- & out-coupling optics decoupled from the chamber support stand for pump-probe experiments, a multi-stage differentially pumped gas jet with catcher, insertable diagnostics, a long-distance microscope, scatter slits, a steerable gas jet, jet slits, and an adjustable stand to bias the spectrometer off-center from the interaction region.

In order to achieve a spot overlap spec of 0.5 um; the KB mirrors, laser optics, & beam position diagnostics all sit on a common granite support structure to minimize mechanical vibrations and thermal drifts. An in-vacuum UHV hexapod will be utilized for fine positioning of the laser in-coupling optic.

BACKGROUND

For the new DREAM endstation at SLAC National Accelerator Laboratory, the required X-ray spot size is 0.3 um, and the required pump laser spot size is 5 um. They need to be overlapped with incredibly tight precision to achieve spatial overlap of the pump laser with respect to the X-ray laser with sub-micron repeatability. In addition to this challenging requirement the DREAM endstation needs to achieve an outstanding UHV (Ultra High Vacuum) base pressure of 3e-11 Torr. It also needs to have a multi-stage differentially pumped gas jet for delivering the sample and a Helmholtz coil pair for generating a magnetic field around its COLTRIMS spectrometer at the center of the chamber. Figure 1 shows the complete model of the DREAM endstation and labels its major components.

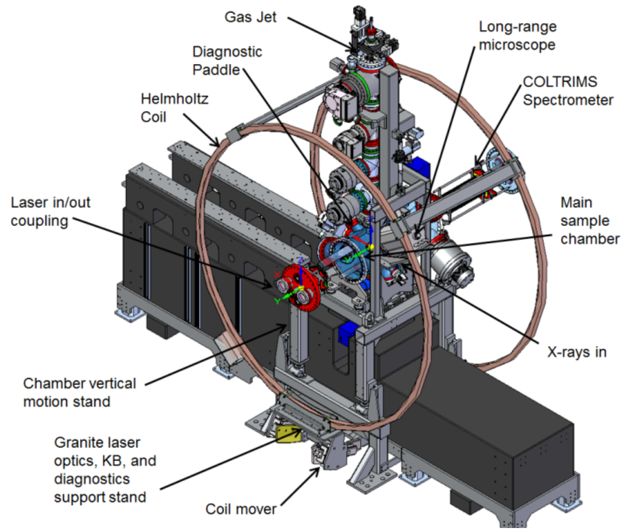

Figure 1: The DREAM endstation in its preliminary design phase. The major components of the endstation are listed.

HELMHOLTZ COILS

A pair of high-power Helmholtz coils is used for providing a linear magnetic field of up to 30 Gauss through the central ion/electron spectrometer. The coils will each be built by winding 16 turns of hollow rectangular copper tubing around a fixture, and curing a high-temperature fiberglass/epoxy mixture. At a diameter of approximately 2.2 meters, the total cross sectional amperage needed for each main coil ring is about 3800 amps; therefore each section of coil tubing will have 1/16th of the total; about 240 amps. The expected voltage required to drive both coils in series is 16 volts DC, resulting in a total power requirement of 3.7 kW. The Helmholtz coils will be water-cooled to keep them safe to touch while additionally not contributing unwanted thermal currents to the surrounding air near the endstation.

In order to correct the magnetic field vector of the earth, the coils have two motorized angular degrees of freedom to correct both roll and yaw of the coils. This will ensure the resultant magnetic field vector from the combination of earth's magnetic field and the coil's magnetic field is running axially horizontal along the center of the main chamber perpendicular to the two detectors in the spectrometer.

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SUPPORT STANDS

There are a total of three unique and separate support structures on this endstation. First, the large granite base is meant to support all the critical elements on a common module; the KB mirrors, the DREAM laser in-coupling and out-coupling optics, the DREAM diagnostics paddle for tuning spot overlap, and the downstream X-ray beam diagnostics. The laser optics in the center of the granite at the DREAM endstation are then decoupled by bellows, allowing the chamber to vibrate independently of the rigid pump laser optics.

The second support structure supports the weight of the main chamber, spectrometer, gas jet, and gas jet catcher system. This stand has 6-degrees of freedom of mechanical adjustability with one motorized degree of freedom in the vertical direction to move the main chamber and spectrometer vertically below the X-ray beam axis by up to 20 mm to accommodate the space needed for gas ions to make a 90-degree turn into the spectrometer detectors at either end of the main chamber. This stand will be constructed primarily of non-magnetic stainless steel to minimize any distortion to the magnetic field lines from the Helmholtz coil pair.

The 3rd stand is for holding and moving the Helmholtz coils, and is a separate stand that is packaged tightly below the granite stand and main chamber support stand. While located relatively far away from the main chamber, it too will be constructed primarily of non-magnetic stainless steel to minimize field distortions of the coils. Using large bearings, it will support the coils and move them by up to +/- 3 degrees in both roll and yaw with respect to the X-ray beam axis.

BEAM OVERLAP

Perhaps the most demanding requirement of this endstation is the goal to have an overlap of the X-ray spot and pump laser spot to within 0.5 um. Once this requirement became solidified, a few metrology studies of the building that the endstation will occupy were performed to get a better understanding of the floor that DREAM will be bolted to. To summarize our findings, we discovered that the floor itself can move roughly between 20-40 um daily depending on the outside temperature and sun exposure, which is way beyond the required beam overlap specification of 0.5 um. If the beamline were constructed with a single set of KB mirrors focusing to this endstation, the floor motion error would be de-magnified, but in the case of this beamline, there are two sets in series. With simulations we found that the spot overlap error (x-ray spot to laser spot distance) would roughly correspond around a 1:1 ratio with the floor motion amplitude, which was very undesirable. Through experience gained at our other lightsource, the SSRL (Stanford Synchrotron Radiation Lightsource) we learned that insulating the concrete buildings can have a large reduction on solar-induced daily floor deflection amplitudes by over 10X at SSRL, and simulations showed up to a 40X reduction for the NEH (Near Experimental Hall,) therefore in order for the DREAM endstation to work properly with minimal spot drift, the NEH housing the DREAM endstation will have exterior siding and insulation installed prior to first light in this endstation.

In order to find beam overlap, a 3-step alignment process is envisioned. First, the diagnostics paddle with YAG screens will be inserted into the center of DREAM. A long-range microscope with a resolution of 2.2 um will view the two spots and work out a delta X (horizontal error) and delta Y (vertical error.) The in-vacuum hexapod will then steer the OAP (off-axis parabola) to overlap the pump spot to the x-ray spot to within a few um. In step two, the insertable diagnostics paddle will scan two knife edges vertically and horizontally to map out the two spot positions in an effort to further refine the pump laser focus position. In step three, the paddle is retracted, a pre-calibrated sample gas is turned on into the main chamber, and the spectrometer is used to look for maximum overlap as the pump laser spot is carefully rastered in a small (few um x few um) space to achieve sub-micron spot overlap by using the OAP on an in-vacuum hexapod. At LCLS-II, it is a goal to automate these steps to facilitate faster beam overlap. Figure 2 shows the interaction region of the DREAM endstation, while Fig. 3 shows a cross-section view of the interaction region.

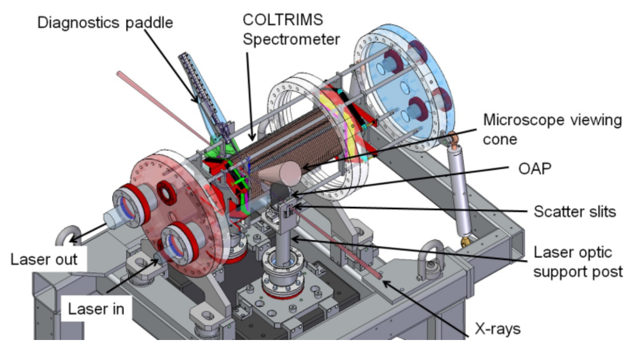

Figure 2: The DREAM interaction region noting positions of spectrometer, microscope view, diagnostics paddle, x-ray path, laser path, and optics support post with integrated scatter slits.

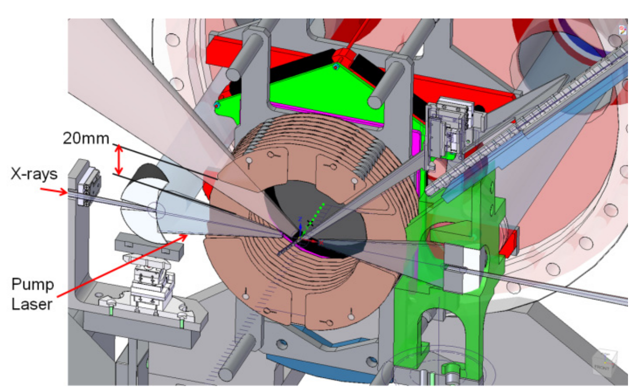

Figure 3: Cross section view at the center of the DREAM instrument. Note that the clearance cuts in the spectrometer voltage plates allow for 20 mm of vertical movement of the main chamber while the laser in-coupling and out-

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coupling optics and support posts stay rigidly coupled to the stationary granite stand below the main chamber. The Insertable paddle is shown coming in from the upper-right of the image and the microscope viewing cone through the spectrometer is shown in the upper-left of the image.

VACUUM

The DREAM endstation has a physics requirement for the vacuum pressure in the experimental chamber to be 3e-11 Torr or better. If the pressure is higher, there is a chance that the background noise in the spectrometer will be so high that no meaningful signals are visible in the noise. This is challenging for a static chamber, but even more challenging for an endstation featuring a gas jet sample where the gas jet chamber operates up to 1e-3 Torr. In order to reach the main chamber pressure goal, a 4-stage differentially-pumped skimmed gas jet, and a 2-stage differentially-pump catcher will be built. Figure 4 shows a cross-section of the gas jet assembly.

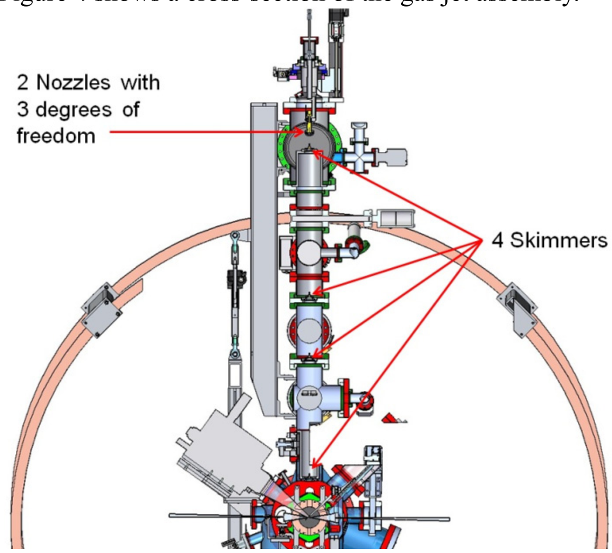

Figure 4: Cross section view of the multi-stage skimmed gas jet assembly.

The resulting gas load into the chamber from both the jet and the catcher should end up being less than a tenth of the total gas load of the main chamber, therefore by using a highly pumped gas jet and catcher, the dominant gas load in the main experimental chamber becomes the outgassing loads. We will extensively treat surfaces by electro-polishing, firing, baking, etc. to drive out as much hydrogen, water and impurities from the SST bulk material as possible. A final long-duration low-temperature bake-out is envisioned for when the entire system is assembled. The main chamber will have a combination of getter pumps and turbo pumps to optimize pumping of outgassed materials and jet gasses with an estimated total nominal pumping speed of 9,000 liters/second. Figure 5 shows the expected pressure profile across all chambers of the DREAM endstation.

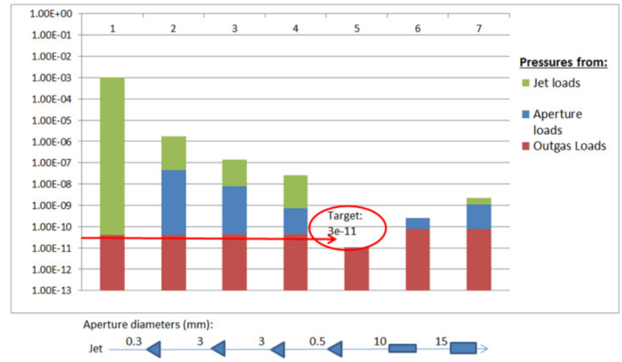

Figure 5: Calculated pressure profile in DREAM starting from the gas jet chamber on the left through 4 skimmers to the catcher chambers on the right. Starting with a pressure of 1e-3 Torr in the gas jet chamber, the main chamber at bar graph position 5 should still be able to reach a base pressure of 3e-11 Torr, but will be highly dependent on the outgassing rate of parts in the main chamber.

CONCLUSION

The DREAM endstation has numerous technical challenges: tight beam overlap requirements, extremely low UHV vacuum pressure in the main chamber with a gas jet providing the gas sample, very tight space constraints for packaging a large number of features (in-vacuum optics, insertable diagnostics paddle, scatter slits, a 2-axis Helmholtz coils, steerable gas jet assembly, large COLTRIMS spectrometer) but the design seems well on its way to achieving the ambitious set of requirements laid out for this instrument. First light in DREAM is expected near the end of 2020, but will be dependent on SLAC project priorities and resources.