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Engineering at SLAC: Designing and Constructing Experimental Devices for the Stanford Synchrotron Radiation Lightsource

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ABSTRACT

Thanks to the versatility of the beam lines at SSRL, research there is varied and benefits multiple fields. Each experiment requires a particular set of experimental equipment, which in turn requires its own particular assembly. As such, new engineering challenges arise from each new experiment. My role as an engineering intern has been to help solve these challenges, by designing and assembling experimental devices. My first project was to design a heated sample holder, which will be used to investigate the effect of temperature on a sample's x-ray diffraction pattern. My second project was to help set up an imaging test, which involved designing a cooled grating holder and assembling multiple positioning stages. My third project was designing a 3D-printed pencil holder for the SSRL workstations.

INTRODUCTION

The Stanford Synchrotron Radiation Lightsource (SSRL) is a facility within the SLAC National Accelerator Laboratory, operated by Stanford University for the U.S. Department of Energy (DOE). The SSRL emits extremely bright x-rays, called synchrotron radiation, which are used to investigate materials at the atomic and molecular level.

The electrons which produce SSRL's x-ray beams are circulated at nearly the speed of light around a 234-meter circumference storage ring, called SPEAR3 (formally called the Stanford Positron Electron Asymmetric Rings). The electrons do not travel in a perfect circle, but instead alternate between linear and curved paths. It is at each bend where the electrons emit x-rays, and where each experimental station is located. In order to keep researchers safe from radiation, each

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experimental station has a lead-lined hutch within which the x-rays are emitted. There are 33 experimental stations, 135 staff, and over 1600 scientific users at SSRL. Since 1974, over 12,200 scientific publications have resulted from the experiments conducted at SSRL.

The 33 experimental stations house beam lines that emit radiation at various energies, ranging from as low as 2 eV to as high as 45000 eV. The beam lines employ several different experimental techniques, including spectroscopy, microscopy, macromolecular crystallography, and diffraction, among others.

Walking around SPEAR3 from hutch to hutch, one is able to observe many different experiments being conducted; thanks to the versatility of the beam lines, research at the SSRL is varied, and benefits multiple fields, including energy production, nanotechnology, and new materials. Each experiment requires a particular set of experimental equipment, which in turn requires its own particular assembly. As such, new engineering challenges arise from each new experiment. My role as an engineering intern has been to help solve these challenges, by designing and assembling experimental devices.

In the following paper, I will describe the three projects I worked on: a heated sample holder, an imaging test setup, and a 3D-printed pencil holder. I will begin by first describing the general pattern that my projects followed – that is, their common methods, materials, and procedures. I will then describe each project individually, in greater detail.

METHODS AND MATERIALS

The first step in all my projects was design. My mentor, Doug Van Campen, would communicate to me the requirements and parameters of a part, and I would design the part on Solid Edge, a 3D modeling program. Next, I would use Solid Edge to draw a draft of the part, and after being approved by my mentor, my drafts would be sent to an on-site machine shop to be machined from aluminum. (My final project, a pencil holder, was made from plastic with a 3D-printer, rather than from aluminum at a machine shop.)

I was lucky enough to watch a machinist, Dave Day, make a few of the parts that I designed. This experience helped me better understand how a machinist interprets a drawing, and how I could improve my drawings to make them more efficient and more easily interpreted by a machinist.

I also used Solid Edge to create 3D models of devices that we already had, in order to visualize how they would fit with the parts that were to be machined. Many of the parts that I designed for my second project were plates that would hold positioning stages together. As I will explain later in my paper, it was very important to model these stages before assembling them, in order to visualize how they would fit together. So, I would model these stages on Solid Edge unless their models were available to download online, and then I would use the models to create a Solid Edge assembly.

After drafting parts, having them machined, and planning out how we would assemble them, our next step was actually assembling them. My first project was simple enough for me to assemble on my own, but my second project involved many different electromechanical components, and therefore required a team to assemble. After being assembled, these projects were tested, and from testing them we were able to determine weaknesses that required improvement.

PROJECT 1: HEATED SAMPLE HOLDER

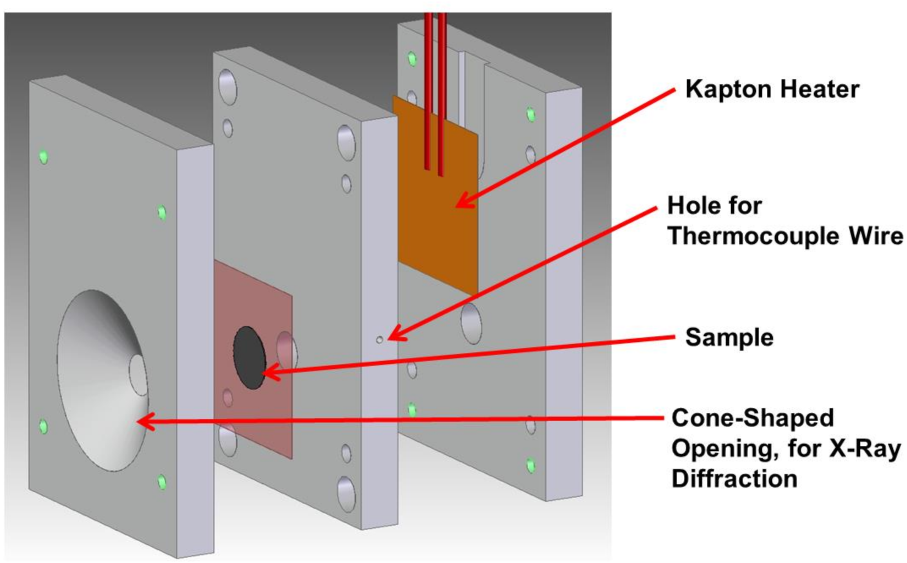
My first project this summer was for a researcher from UC Santa Barbara, who wanted to heat a sample while observing its x-ray diffraction pattern. Therefore, I was tasked with designing a device with the following features: 1) holds the sample while still leaving the sample exposed to x-rays, 2) holds a thin heater, connected to a temperature controller, without blocking the path of the x-ray, 3) holds a thermocouple wire, connected to a temperature controller, 4) distributes heat quickly and evenly, 5) has an opening wide enough not to block the x-ray diffraction, and 6) is relatively easy to assemble and use.

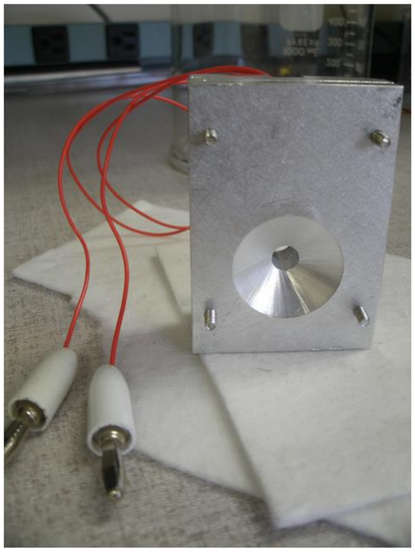
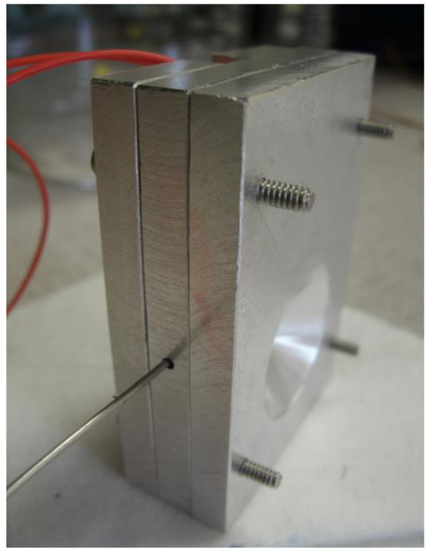
The sample would be a powder held between two layers of Kapton tape. Kapton tape is a clear orange polyimide film with silicone adhesive on one side. It remains stable under a wide temperature range, from as low as -259˚C (-452˚F) to as high as 260˚C (500˚F), making it ideal for holding a heated sample. The thin heater we used was a Minco Polyimide Thermofoil Heater. It is also comprised of Kapton tape, which holds an etched foil pattern that heats up when connected to the controller. The heater's temperature range is -200˚C to 200˚C (-328˚F to 392˚F).

The solution that my mentor proposed was a three-plate assembly, which would be held together by eight #4-40 screws. The heater would be held between the first and second plates, and the sample would be held between the second and third plates (counting the plates in the order through which the x-rays would pass through them).

The side of the second plate features a small hole that goes halfway through the plate and serves as a holder for the thermocouple wire, which measures the temperature of the plate. Through the first two plates is a continuous hole of 0.25 inches in diameter, through which the x-ray would travel, and in the third plate the hole opens into a cone with an angle of 118˚, through which the x-ray diffraction would exit. The heater and thermocouple were both connected to a Cryo-Con 24C Temperature Controller.

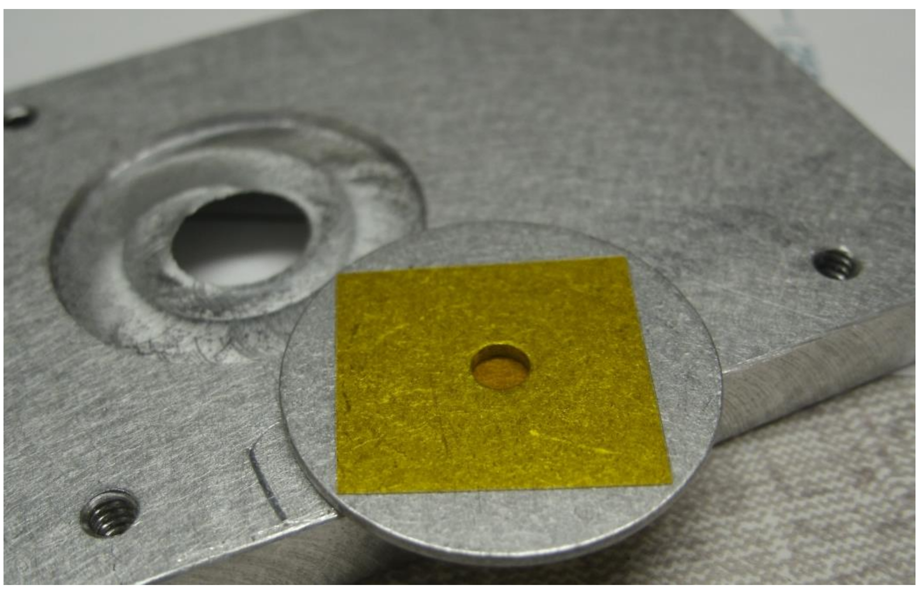
Below I have included an image of the Solid Edge model of the first iteration of the assembly, and photographs of the assembled sample holder:



Initial testing of the sample holder was successful. We were able to heat the sample to the desired temperature range (200˚C), in a relatively short amount of time (about 20 minutes).

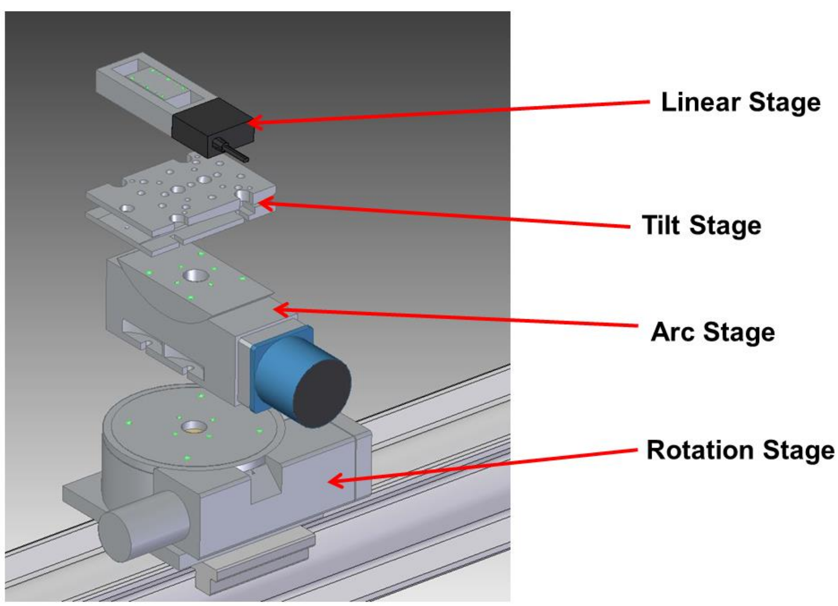
The researcher visited SLAC on August 5th, 2015, to run some tests with the sample holder. After her testing, a few modifications were made to the plates in order to improve them. A shallow hole was made on the opposite side of the cone-shaped opening on the third plate, in order to hold a washer in which the sample would be held between two pieces of Kapton tape. I have included a picture below:



PROJECT 2: IMAGING TEST SETUP

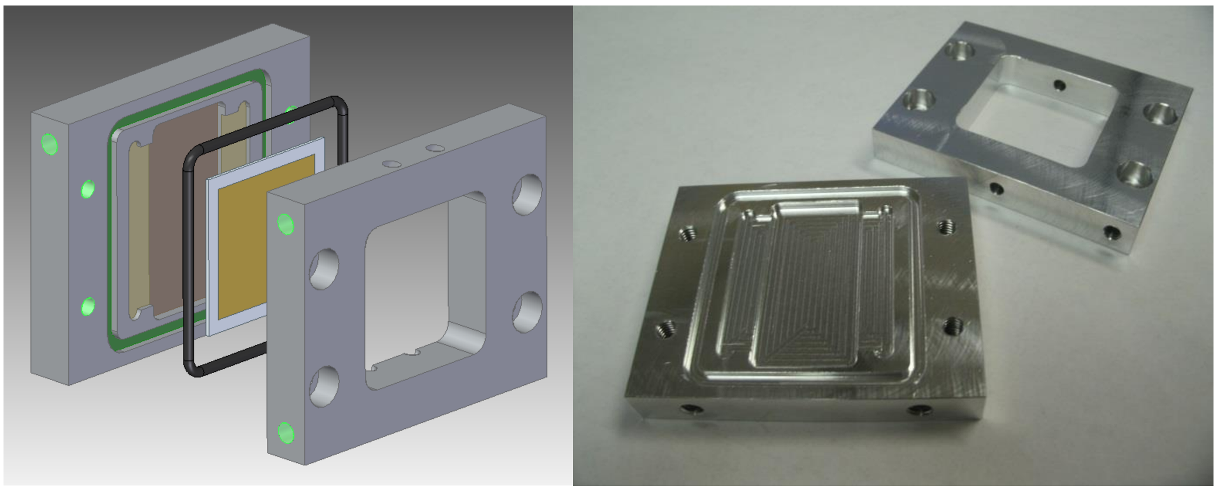
My second project was considerably more complex than my first. A researcher from Stanford wanted to shine x-rays through a series of three diffraction gratings in order to investigate a method of x-ray imaging called phase-contrast imaging (PCI) that offers improved soft-tissue contrast. Conventional x-ray imaging (like at a dentist's office) produces images by shining x-ray beams through a sample and recording areas of reduced x-ray intensity. On the other hand, PCI takes advantage of the fact that an x-ray beam will undergo phase shifts when traveling through a sample. The variations in an x-ray beam's phase shift are transformed into variations in intensity, which are then recorded by a detector to create an image. This transformation can be performed by several means, and in our experiment it was hoped to be achieve via diffraction gratings.

The positioning of the gratings had to be extremely precise, and easy to control. Thus, they were each mounted on four positioning stages; a rotation stage on the bottom, then an arc stage, then a tilt stage, and finally a linear stage. I modeled these stages on Solid Edge (except for the tilt stage, which I was able to find online) in order to better visualize how they would fit together. I have included an image of the models below:

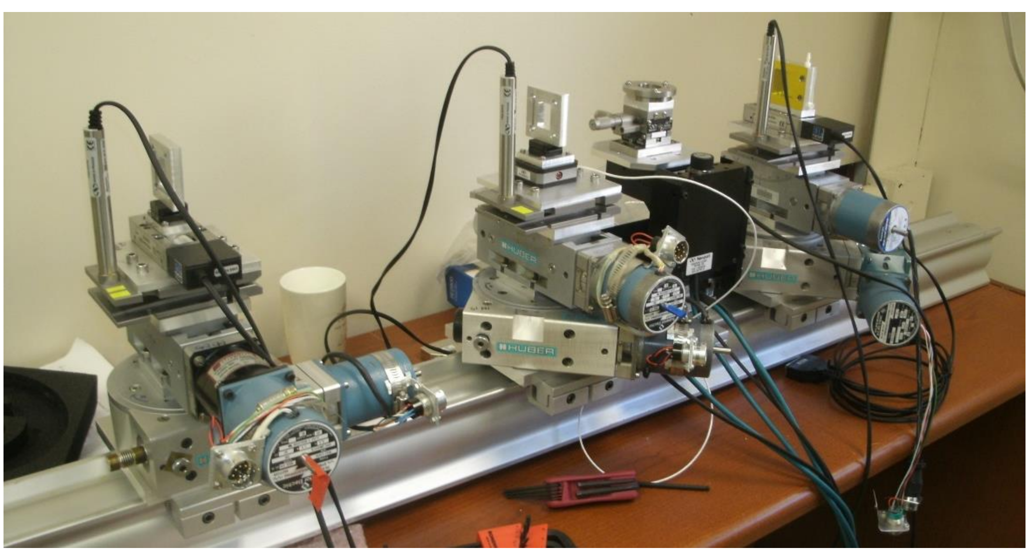


In order to mount the stages together, I designed plates that were machined and placed between the stages.

I also helped design a holder for the gratings. It has holes for helium to be flowed across the gratings, and water channels in the holder to keep the holder cool.



Here is a photograph of the entire assembly:



All the positioning stages were motorized and connected to a computer, and controlled with a program called SPEC.

PROJECT 3: 3D-PRINTED PENCIL HOLDER

My third project was done as a fun side project to work on while I was waiting for my plates to be machined and/or there was nothing else to work on. At SSRL there are three 3D printers, including a MakerBot Replicator Z18. Because the desks at the experimental station often get quite messy and disorganized, my mentor suggested that I design a pencil holder to be 3D printed.

I designed the pencil holder to be 11.7 inches wide, in order to fit within the limit of the MakerBot, which was 11.8 inches. My design has 14 pencil holes with diamters of 0.75 inches, in order to fit a wider variety of pens and pencils. There is also a tray in the front (for paperclips, screws, and etc.), as well as two larger rectangular openings, one on either side, to hold rulers, scissors, screw-drivers, and etc.

The pencil holder took a little less than 30 hours to print. If I were to print another one, I would use a larger resolution; I used layers with a thickness of 0.2 mm, but if I were to use layers with a width of 0.3 mm, the print time would be about 20 hours. If I used layers of 0.4 mm thick, the print time would be about 15 hours. In addition, I would like to try printing the holder without supports; I enabled the 3D printer to add supports under the words, so that they would not sag while being printed. However, the supports were difficult to remove, and I think the supports may not be needed in order to hold up the words, since the side protrusions were successfully printed without supports.

CONCLUSION

New problems arise – and new devices are required – when new experiments are conducted. Due to the versatility of the beam-lines at SSRL, there are a wide range of new experiments being conducted there, and as a result, there are many new challenges to face, and I am honored to have had the opportunity to face some of these challenges at the SLAC National Accelerator Laboratory.

ACKNOWLEDGEMENTS

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