Colorado State University’s

Accelerator Lab: Summer 2013 Internship

Josh Smith

Internship Report

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2. What Our Group Hopes to Accomplish

Facility's purpose and goals:

The group is dedicated to furthering professional and student understanding of accelerator engineering. This is accomplished by involving others in both projects and research related to accelerators and high energy partial beams. Some of the projects this year's interns were involved in include: automation of a bead pull experiment, assembly of a THz kit for a Ti-sapphire laser, and design of a shield vault for the new facility. [i]

The group's facility is located at CSU's Engineering Research Center on the Colorado State University foothills campus, and will soon be moving to the new CSU Advanced Beam Laboratories. The program is headed by professors Stephen Milton and Sandra Biedron with the support of many other professors, researchers, grad students, undergrads, high school students, and other collaborators and sponsors.

Purpose of high energy beams and particle accelerators:

The purpose of the particle accelerator program at CSU's Accelerator Facility is to training students on the uses and design of particle accelerators for real world applications and research. Some industries that utilize these technologies include some of our sponsors. Our sponsors are the Office of Naval Research's Innovative Naval Prototyping Program, Boeing an Aerospace and Defense Corporation, and the University of Twente, in Enscheda, Netherlands. All of theses groups and others help by donating materials, money, and expertise.

3. What I've Worked On:

For my internship I helped redesign and code a bead pull experiment, to be more robust, versatile, and automated. This required learning how to program and use LABVIEW to modify the current program to request and save the Q value, and other data to a spreadsheet. It also required learning the function and operation of a network analyzer, to find the cavity's resonate frequency. I also design the new pulley mounts and drive pulley making the system more versatile and accurate. Finally, I incorporated some calculations about the cavity's properties in to the program's printout to expedite the process of characterizing the cavities.

In addition to this experiment, I also helped with design and build a model shield wall like the one that will be installed in the new facility. This shield wall will be used to stop any radiation that the experiments might produce, protecting both people and equipment. In addition to the concern of shielding, the vault's structural strength and block size/weight needed to be considered for transport and structural integrity.

Finally my largest project was to design and price out a system to transport the laser in to the vault form the laser room. It was decided that a four inch PVC pipe filled with a dry gas such as nitrogen would be the best most cost effective way to accomplish this with the least loss of power. Having the laser transported from the laser room (next to the vault room about 20 ft away) in to the vault required a minimum of two mirrors, placed in the pipe and sealed to be both air and light tight. To adjust these mirrors in the pipe it was decided that the best option would be to have the mirrors on motorized stages that would change the mirror's angle and position along the pipe.

4. Uses for What I've Worked On:

What resonator cavities are used for:

A radio frequency resonate cavity uses high power radio frequencies to accelerate charged particles to relativistic speeds. In the case of CSU's Advanced Beam Laboratory, a series of five and a half resonate cavities will be used to accelerate electrons forming a free electron laser. This will then be used to perform other experiments dependent on high energy electron beams. The bead pull experiment allows us to test the characteristics, such as shunt impedance, and resistance of different cavity designs and find possible ways to improve the accelerator. This will allow the accelerator to be more efficient and hopefully more cost effective, powerful, and reliable.

Why we need a shield wall:

The shield wall being designed for the new building is meant to protect both personal and equipment from the potentially harmful radiation the free electron laser could produce. To do this we use four feet thick walls of concrete and a three feet thick ceiling of concrete. These walls and ceiling will be made out of blocks, to allow for removal later. The blocks are staggered to prevent any line of sight to the accelerator from outside the vault. Local shielding will also be added to other areas such as the cyclotrons and beam dump, as needed, to further stop any potentially harmful radiation.

5. The Bead Pull Experiment:

The bead pull experiment uses a small bead of metal or dielectric material to test characteristics of a resonant cavity. The peak frequency is found and reported by the network analyzer while a LabVIEW program records the data and does calculations based off the data. The first thing the program records is a base line graph, before the bead has entered the cavity. This graph is the first graph displayed on the network analyzer and graphs amplitude in terms of frequency.

The peak of this graph represents the resonant frequency of the cavity before the bead is introduced. For the full small aluminum cell this was found to be 2.857GHz. The program then request the Q value displayed on screen and save it to the file along with the base line graph. For the full cell the Q was found to be on average, 4475 (when clamped down tightly). The program then moves the motor the total number of steps divided by the number of data points to be collected, and records the peak frequency and bead position in steps. This is used to graph the peak frequency by the number of steps the motor has taken. -+

Finally using this graph's first value as the unperturbed frequency (ω_0) the program calculates the square root of the deviation over the unperturbed frequency.

This data is then used to give the approximation of the integral in this equation.

$$\frac{R}{Q}=\frac{1}{f}\frac{1}{2\omega_0}\left(\int_{gap}\sqrt{\frac{\Delta\omega\left(X_{gap},Y_{gap},Z\right)}{\omega_0}}\,dz\right)^2$$

With the approximation, Q value, and relative permittivity of the bead the shunt impedance (R) can be found.

Multiple cells:

Multiple cell cavities have two or more openings and an equal number of resonant frequencies. This provided a problem for the current program as the maximum the program finds can jump frequency as two peaks grow and shrink. To account for this I made a modified program that takes an additional center value. The center value is used to split the graphs in to an upper and lower graph that can then be analyzed to find both resonant frequencies. If needed the program could easily be expanded to find more resonant frequencies for cavities with more cells. Below is an example of the display at the beginning of the test (and later when the bead has entered the first chamber).

6. Shield Wall Project:

The challenge of designing the shield wall came from needing a vault that was capable of both; protecting people from any potential radiation or beam originating from the accelerator, and connecting to the outside world for things such as power and RF wave guides. Prior to my arrival it was decided that four foot of concrete would be used on the walls and three foot of concrete on the ceiling. We also got a basic layout of what the finished walls should look like. It was also decided that the best choice for the shield wall would be to use large concrete blocks for the walls and ceiling. The feature used to pass the RF guide, laser and other power cables in to the vault as well as the size and shape of the blocks used to make the vault had not been decided on.

Wall and ceiling blocks:

The three types of blocks used to make the walls of the vault are nine feet high and had foot prints of 2’x2’, 2’x4’, and 2’x5’. These sizes were chosen to keep the number of types of blocked to a minimum as well as allow us to uses a forklift to transport the blocks in to place. Our weight limit was set at 16,000 pounds or eight tons. This was found to be a reasonable number based on the desire to keep the number of blocks to a minimum for easy and quick construction while not requiring a forklift to large to fit within the building. The wall blocks also feature a groove and two hard points to lift the blocks by on the top side of the blocks. This groove will also be used to chain the blocks to one another once complete and in which to rest a 6”x6” I-beam for additional support over the two door ways.

The ceiling is comprised of four types of blocks each one and a half foot thick. These will be layered with over lapping seams to block any line of sight like the wall blocks. The blocks over the maze are six foot wide allowing for the least number of pieces and most support on those that have to clear the door way openings. The celling blocks will also have rebar running the length of the blocks in addition the indented rebar hard points that will be used to lift the blocks. This rebar helps the otherwise low tensile strength of concrete to resist the tensile stress applied to the bottom of the blocks as a result of spanning an unsupported distance. The celling over the main vault area are only four feet wide to prevent there weight from exceeding eight tons and will need more rebar to account for there larger unsupported span of twelve feet.

The hutch:

The hutch is used to pass cables, RF guide, and the laser transport tube in to the vault while maintaining shielding integrity. This is done with several holes of five and eight inch drilled in the top of the vault and then surrounded on three sides with concrete and a denser material on top. These holes are separated by four feet on center and a two feet concrete block to prevent and interference between cables. The blocks will be 1.5’x2’x4’ blocking most scattered radiation and holding up a top that will stop all lines of sight out of the vault. This top will not be made out of concrete due to the lack of available space above the hutch, instead a denser material such as lead (two inch) or steel (four inch) will be used.

7. Laser Transport Project:

When looking for a motorized kinematic mount online, I came across two concerns, first the physical size and shape of the few two inch mounts I found were far to big for our four inch pipe, and secondly the cost exceeded that of a in house mount with similar specs. I found one motorized kinematics mount which is capable of holding a two inch mirror was from Edmund optics[ii]. This mount came at a cost of $1,595 plus the additional cost of a driver and power supply, and still does not fit within the pipe or hold the mirror at a 45degree angle to the pipe. For the cost and fact that a premade mount would still require severe modifications for our application, it was decided that the best course of action would be to make an in house mount capable of controlling the mirrors angle like a kinematics mount as well as linear position along pipe.

Motion and motors:

Two linear actuators and a ball joint are used to change the mirrors angle. Care had to be taken to keep the face, that the actuators pushed against, perpendicular to the motor’s shaft to prevent the shaft from bending. It was also a concern that no single part was to large or complex to machine out of available stock. This lead to the division between the 45degree piece and the mounting plate and provided a place to implement a slot to provide core adjustment of the mirror's height. The ball joint mounts to the back plate and the axle attached to the mounting plate. This connection will need to be extremely rigid. To do this I recommend the uses of Loctite (red, the strongest) on both the axle and threads of the ball joint, this should lock the joint from moving and prevent the axle from sliding through the joint. If the Loctite does not seem sufficient I would try adding splines to the shaft with a press and then pressing the shaft into the joint.

The first two motors push against two springs like the mounts from Newport and Thor Labs, however due to space constraints the two contact points are not perpendicular. This results in the motors changing the mirrors angle along lines from the ball joint's center to the contact point. As a result the control system's programing will have to take into account the fact that the motors need to work in unison to control the mirrors angle along the x and y axis. Also due to the two resulting lines, between the contact points and ball joint, not being perpendicular the system will have slightly more precise control over the vertical angle.

The final motor is used to position entire mount over the T-joint's opening. Doing this with the design and manufacturing capabilities here would prove difficult and impractical for our desired size and accuracy. As a result a hybrid design that involved modifying a linear translation stage from Thor Labs to accommodate the linear actuator already being used in the mirror's angular positioning is the best option. The stage from Thor Labs will have to be disassembled in as clean an environment as possible, and have one small lip milled off to make room for the actuator. The stage will then be reassembled with new plate and actuator replacing the micrometer.

Control systems:

Each actuator consists of a 2.5v bipolar stepper motor capable of a maximum draw of .49A per phase. This means that to control the actuator, you need a driver capable of controlling two circuits in states of forward, reverse, and off, and a power supply capable of supplying 1A at 2.5v. To do this there are several premade driver from Haydon with regulators built in or an in house device. One possible driver from Haydon is programmable and would connect to a computer via USB and be controlled by Haydon's control software. Haydon's other driver[iii] is significantly cheaper but would require an independent controller and programing. Finally the in house solution is to use a Pololu low voltage dual serial motor controller.

For the cost and opportunity to control every thing with Lab VIEW I recommend the Pololu driver.[iv] This setup will require a 2.5v power supply to provide power to the motors and a cable to connect a computer's USB port to the drivers. [v]

Both the in house Pololu driver and Haydon drivers would also be capable of doing up to 1/128 micro steps, further increasing the potential accuracy of the stepper motor. [vi]

Piping and joints:

The laser will be transported inside of a four inch PVC pipe filled with a dry gas, such as nitrogen. This pipe will extend from the optics table in the laser room, up over the celling, into the first mirror, through the wall, and into the next mirror in the hutch. After this the laser will be directed onto a laser table under vacuum and into the cathode. Four inch PVC was chosen for the size of the laser and availability of piping and fittings as well as its structural rigidity. While the pipe should be rigid enough to hold its shape it would not be a bad idea to attach it to whatever solid object it is passing by. The PVC will have to be cut to length and then have the appropriate fittings glued to it with the PVC solvent and glue. Them finally the in the final assembly the larger parts will be threaded together with Teflon tape for a air tight seal.

Citations and Suppliers:

i For more information see: http://www.engr.colostate.edu/accelerator/index.php

ii Mount can be found at: http://www.edmundoptics.com/optomechanics/optical-mounts-plates/mirror-mounts/motorized-kinematic-mount/3303

iii

iv For programing and communication information see: http://www.pololu.com/catalog/product/120/resources

v See wiring diagram on next page.

vi More information on micro steps can be found at: http://www.stepperworld.com/Tutorials/pgMicrostepping.htm