Summer 2012

Internship Report – Colorado State University, Electrical & Computer Engineering Department, Accelerator Facility

Hannah Yehudah

Table of Contents

I. Introduction - The CSU Accelerator Facility

The Electrical and Computer Engineering department at Colorado State University began a research project focusing on the establishment of the linear accelerator center. The research team is headed by Stephen Milton and Sandra Biedron and consists of several graduate students and three summer interns. The team's focus is the expansion of accelerator science through education and innovation. The research included the creation of new labs in the center, such as the installation and automation of the radio-frequency test laboratory, the magnetic measurement laboratory, and the design of the laser transport line for the linear accelerator vault.

The research team is funded by the Office of Naval Research's Innovative Naval prototype program. Boeing, an aerospace and defense corporation based in Chicago, donated the Ti-Sapphire laser. The accelerator was donated by the University of Twente, in Enschede, Netherlands. The teams work centers around the use of Free Electron Lasers (FELs) that can release beams of laser light, which can be turned into atmosphere penetrating wavelengths.

II. Motivation - Why build a new facility?

The ECE department at Colorado State University strives to create a state of the art research facility for accelerator engineering and technology. The goal in creating a new facility are to take advantage of the small and efficient set up for the lab and more cost affective resources that a new facility would create. The department also plans to use the building as a new facility to train a new generation of accelerator scientists.

The goals of this new research are parallel to Accelerators for America's Future, an initiative started by the U.S. Department of Energy to utilize the power of accelerators in energy, medicine, and security. Both emphasize that in order to continue to cultivate accelerator sciences in the United States we must use education to create a new generation of accelerator engineers and scientists. These new engineers are the key to expanding the use of accelerators in the aforementioned fields. By supporting this initiative we are also encouraging progress in accelerator technology, such as improving the efficiency of proton and ion beam therapy and the use of radio-isotopes in medical accelerator science.

Accelerators can be used in a multitude of industries replacing many types of machinery, which would save energy and benefit the environment. Industrial electrons beams could be used in manufacturing wire cable tubing, ink curing, shrink film and tires. The transition from metal coating facilities to electron beam technology has the potential to reduce 95% of power demand. This is only one example of how accelerators can reduce the energy deficit and are more environmentally safe than other machinery in the US. Aside from industry and medicine, accelerators also provide many opportunities in security and defense. Nuclear forensics is only one of the many areas that can be improved by the use of accelerators.[i] The research being conducted at Colorado State University's Electrical and Computer Engineering Department focuses on the use of accelerators in discovery science, as well as, defense and security and general education.

III. The Educational Perspective

The CSU-ECE Department plans to approach their research through an educational perspective. By supporting the creation of a new generation of accelerator scientists the CSU-ECE Department also plans to use their research as an opportunity to improve accelerator science and engineering as well as to educate others about it. During the summer of 2012 the CSU-ECE Department offered a summer internship program for four to eight weeks to high school and undergraduate students, which focused on particle accelerators and radio frequency devices. The program allowed the interns the opportunity to learn about the field of accelerator science while also working alongside current students in the ECE department. The interns also had the opportunity to work beside Sandra Biedron and Stephen Milton, ECE professors and researchers, who developed the program. The CSU accelerator faculty set out to create a lab where the research and training of high school through graduate school students could be successful.

The creation of new facilities and the installation of the linear accelerator will give the team the tools needed to observe the effects of generating long wave length free electron lasers and electron beam components for FEL's and other light sources. The labs will also be used as a test bed for particle beam and laser beam exploratory research. The CSU accelerator facility has four major systems, the linear accelerator, a microwave test stand, a magnetic test stand and a laser room.

IV. My Role

I took part in the design and development of the laser room. My role was to design the entire laser transport line from the laser room to the linear accelerator. This included choosing the specific type of lens, mirrors, beam splitters, irises, energy meters and mechanical mounts to be used. I also used a number of calculations in order to maintain the correct beam size, the number of photons and energy needed from the quantum efficiency of copper. This process also required some research on the photo-electric (PE) effect.

V. The Photo-Electric Effect

The Photoelectric Effect, discovered by Hertz in the late 19th century and proven by Einstein, is the outcome when a short wave length of high frequency light, such as ultra-violet radiation, hits a metallic surface. When the PE effect is in place the metallic surface will emit electrons. Albert Einstein won the Nobel Peace Prize for the discovery of this theory.[ii] In order to create this effect we must start with a photoconductive metal, such as copper and place in it in a vacuum. When the light, in our case a Ti:Sapphire laser, shines on the copper the photoelectrons move through the vacuum toward the collector, which in our case was the linear accelerator. This theory was explained by Einstein using Planck's quantum hypothesis of the electromagnetic field. Using that method every photon emitted from the PE effect will have an energy of $E = h\int$ with h is Planck's constant and $\int$ is the frequency. Thus the kinetic energy is given by $K_{max} = h\int - \phi$, with ϕ being the work function of the metal.[iii] The goal of our test bed is to observe the outcomes of the PE effect and how they apply to the operation of the linear accelerator.

VI. The Photo-Electric Effect generation of Electrons in radio frequency guns

The first lasing of the TEUFEL experiment was conducted August 23, 1995 in collaboration with the University of Twente, Netherlands Centrum for Laser Research, and the Eindhoven University of Technology. The TEUFLE experiments have a similar premise to those that the ECE department at CSU will be conducting, in terms of using the Photoelectric Effect to generate electrons in RF guns.[iv]

VII. University of Twente - System Accelerator

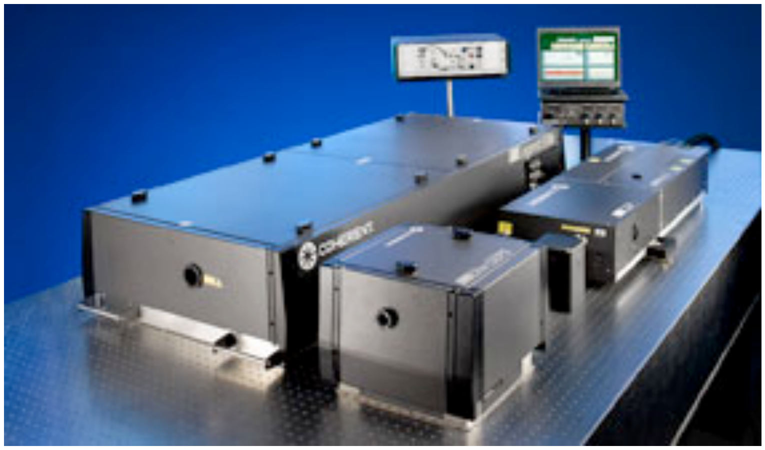
The accelerator is a five and a half cell copper structure with a RF gun operating at a frequency of 1.3 GHz, at a 10 Hz repetition rate and a micro-pulse rate of 81.25 MHz, constructed at the Los Alamos National Laboratory. In our research the copper cathode is assumed to have a 5x10^-5 quantum efficiency based on the observations conducted in the LCLS RF Gun Copper Cathode Performance study in 2011. The University of Twente system accelerator is an L-Band 1300-MHz copper conduit structure, set for operation with a copper cathode but can also house other cathodes, such as CeK_2Sb, K_3Sb, and Copper.[v]

Linac Characteristics	
Energy	6 MeV
Number of Cells	5 ½
RF Frequency	1.3 GHz
Shunt Impedance	50 MW/m
Q-Value	18,000
Axial Electric Field	
Cell no. 1	26 MV/m
Cell No. 2	14.4 MV/m
Cell No. 3 – 6	10.6 MV/m
Solenoid Field Strength	1,200 G

VIII. Boeing Laser

The laser being used, which was donated by Boeing, is a Ti:Sapphire laser manufactured by Coherent. The Ti:Sapphire is a tunable laser that is typically used to emit ultra-short pulses of near infrared light from approximately 650 to 1100 nanometers. The laser works through a sapphire crystal medium that is infused with titanium ions. Our laser will be working at a repetition rate of 81.25 MHz and a regenerative amplifier operating at 1 KHz, that will be the drive laser for the photocathode. For our intended purposes we will be using the laser at a work function of 265 nanometers. The laser includes a micra-oscillator, pulse selector, synchro-lock system, and an elite dup USP regen Amp. with an additional single pass Amp. powered by two diode pumped Nd:Ylf lasers, also manufacture by Coherent.[vi]

Basic Laser System Performance	
Micra Oscillator	
Avg. Power	> 300 mW
Rep. Rate	81.25 MHz
Pulse width	< 15 fs with ext. comp.
Legend Elite Duo Amplifier	
Avg. Power (at 800 nm)	> 10 W
Avg. Power (at 256 nm)	> 1 W
Pulse Duration	40 fs (FWHM)



IX. Work Function

The laser and cathode in the ECE CSU department is assumed to have a 5x10^-5 quantum efficiency. With that QE the number of electrons and protons produced can be calculated.

$$QE = \frac{\#\,Electrons}{\#\,Photons}$$

$$5x10^{-5} = \frac{6.24x10^{9}electrons}{\#\,Photons}$$

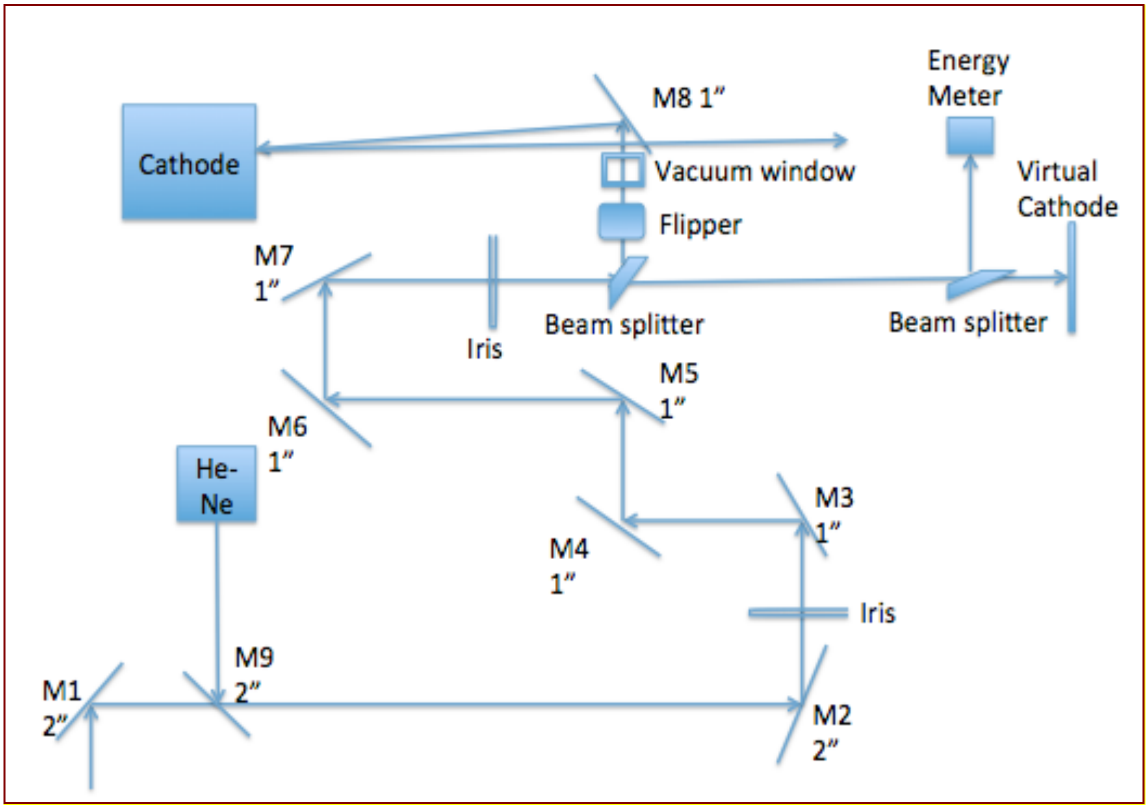
$$(\#\,Photons)(5x10^{-5}) = 6.24x10^{9}electrons$$

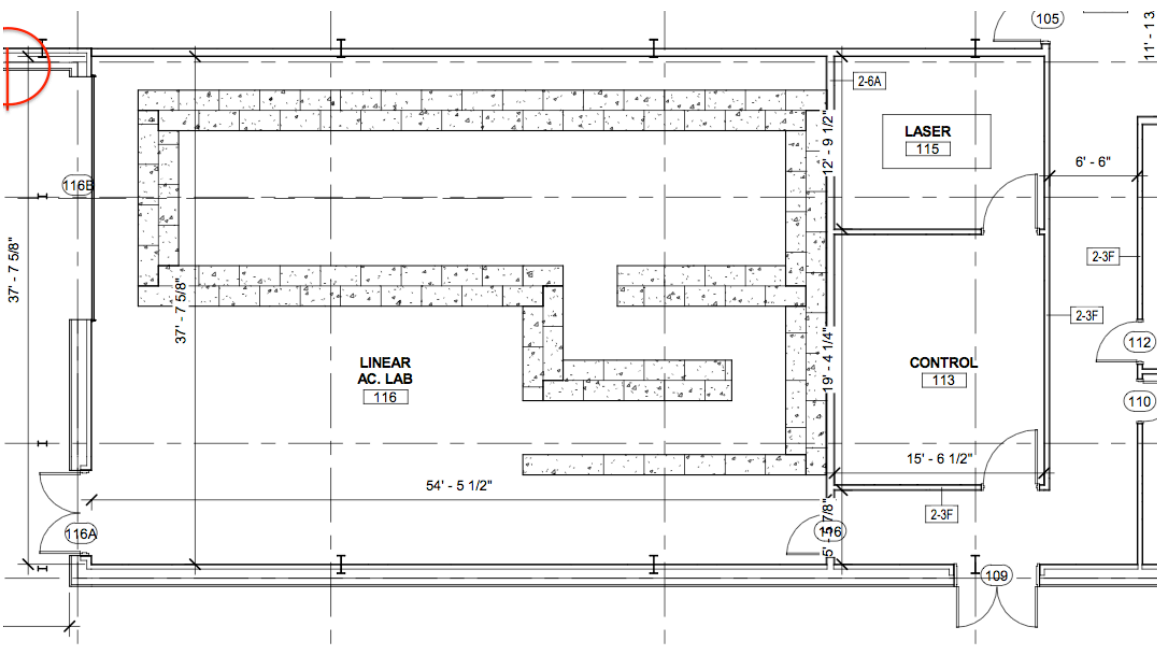
$$\#\,Photons = \frac{6.24x10^{9}e^{-}}{5x10^{-5}}$$

$$\#\,Photons = 1.24x10^{14}$$

X. Transport Line

The transport line I created includes several mirrors, iris's, and beam splitters. In order to get the proper alignment before hand the transport line is adjusted to use the Helium-Neon test laser. The He-Ne laser allows for all the mirrors, beam splitters, etc, to be position before the actual Ti:Sapphire laser is used. This is done by inserting a removable mirror in order to get the He-Ne laser in alignment with the transport line. Near the end of the line two beam splitters are used in order to split the beam so that part of the beam is sent to another beam splitter which divides the beam into two beams sending one to an energy meter and another to a virtual cathode. Because these two smaller beams are the same distance from the laser as the beam going to the real cathode they give an accurate depiction of the size and energy of the beam on the real cathode, so that we may observe it. In order to maintain the highest beam quality the correct mirrors and beam splitters had to be chosen. The tools used were chosen based on their reflectivity, size, quality, and the wavelength that they were designed for. The mirrors used had to be available in two sizes 25mm (1 inches) and 50mm (2 inches), and also have high reflectivity at 265nm for the Ti:Sapphire laser, and 633nm for the He:Ne test laser. The mirrors also had to be effective at a 45-degree angle of incidence. By shopping through several optics companies, such as CVI Melles Griot, Newport, and Edmund Optics and looking through several possibilities the best option out of the available mirrors was a Newport Optics ND:YAG Laser Line Mirror. This particular mirror has a high damage threshold and ultra hard dielectric coating, which makes it ideal for beam steering. It is available in 25.4mm in diameter (6.35mm thick) and also in 50.8mm diameter (9.53mm thick). The mirror has a 45 degree angle of incidence and >99.7% reflectivity for the S-Pol and >99% reflectivity for the P-Pol at the designed wavelength (266nm), and is $235/$412 respectively.[vii] The best fitting beam splitter was a CVI Melles Griot UT High Energy ultra thin beam splitter with specified resistance from 1 to 99.5%, and is customizable. It is dielectric and non-absorbing making it ideal for high energy beam splitting. The designated wavelength can be specified from 244nm to 2100nm.





The entire laser transport line includes a laser control room, a laser room, and the laser line transport room. The laser transport line would be equipped with an iris, mirrors, and lenses in order to maneuver the laser beam in a way that the beam quality and size would be maintained, while still fitting in the predetermined 10m space. The positions of the iris's and lenses are calculated using matrices to determine how the beam changes as it goes through the calculated drift space. When the beam gets too big or scattered a lens or iris is used to bring it back to the desired size and focus. The laser room and laser transport room will be filled with nitrogen instead of air because air would degrade the beam.

XI. Safety

Pre-determined safety requirements must be met while building labs and conducting experiments. In order to maintain the required level of safety proper attire and protection, such as protective gogles, must be worn while the laser or particle acclereator is in operation. There is also seperate rooms designated for control of the laser and accelerator so no one is in the presence of the laser or accelerator while it is in operation. This rooms have walls of concrete that are the proper width to sheild the operating engineer from radiation and other safety hazards. For further safety precautions no person under 18 is allowed to handle or be in the presence of the laser.

XII. Conclusion

In conclusion, the CSU ECE research team is thrilled to lauch a new era of accelerator science. Through the generous donations of University of Twente, Boeing, and the Office of Naval Research the team is able to create a state of the art lab, featuring 6Mev photocathode linac system with a powerful new laser capable of delivering pulse trains at 81.25 MHz over 10 microseconds. The CSU team plans to use the creation and experiments of this labs to conduct basic beam research and diagnostic development, training for graduate, undergraduate, and high school engineers, a small high power THz free electron laser, and other research projects. By late October of 2012 the system was crated and put on pallets for shipping. With labs already being built, and the layout of the facility drawn up the new accelerator facility should be starting construction summer of 2013.

XIV. ONR Thank you

The Colorado State University Electrical and Computer Engineering Research team would like to make a special thank you to the Office of Naval Research for their generous donations to the construction and development of the lab, and also their unwavering support of the educational objectives of the project. Because of their support the team is not only able to create this new innovative linear accelerator system but we are also able to inspire new accelerator engineers and scientists from to graduate school.

---

[i] See, for example, “Accelerators for America’s Future,” Department of Energy, Office of Science, 2010.

[ii] See, for example, "The Nobel Prize in Physics 1921". Nobelprize.org. 7 Jan 2013 http://www.nobelprize.org/nobel_prizes/physics/laureates/1921/

[iii] See, for example, “Introduction to Quantum Physics,” _______ and _________, 19__

[iv] See, for example, G.J. Ernst, et al., “First lasing of TEUFEL,” Nuclear Instruments and Methods in Physics Research A 375 (1996) 26-27.

[v] See, for example, “University of Twente 1961 Los Alamos National Laboratory, Enschede, Netherlands”

[vi] See, for example, “Coherent Inc 1966,” 7 Jan 2013 http://www.coherent.com/

[vii] See, for example, “Newport Corporation 1969,” 7 Jan 2013
Model: 10QM20HM.75/20QM20HM.75 http://www.newport.com