LCLS Newsletter JUNE-2000

Project Management *Lowell Klaisner, Max Cornacchia*

LCLS General Seminar

The next LCLS seminar will be held on Monday, July 3rd, starting at 3:00pm in the LOS 2nd floor conference room. Paul Emma and Patrick Krejcik will report on the plan to measure short bunches in the SLAC Linac.

FEL Physics Section Report *C. Pellegrini, H-D Nuhn*

PARMELA SIMULATIONS

Little progress has been made in the attempt of getting the required run with the Parmela code as described in the Newsletter on May 8, 2000. J. Rosenzweig made a run with 15,000 particles that included thermal emittance. The total beam emittance at the 150 MeV point predicted by that run is very small, less than 0.4 microns. One of the effects of the thermal emittance is that the degree of variation of the beta-function along the bunch is reduced. The variation of the beta-function is amplified by the linac. P. Emma has tracked this distribution through the accelerator with the ELEGANT code. The output of that run has been used by Yong-Chul Chae at the APS for FEL simulations with GENESIS and by Bill Fawley at LBNL for FEL simulations with GINGER. It turns out that the small number of available particles creates artificial numerical effects. For the time being and for the development of the interface between ELEGANT and the FEL codes, particle distributions with 50,000 and 100,000 particles are used that are based on an ideal distribution created by P. Emma at the 150-MeV point.

Urgently needed is work with the Parmela code towards the desired configuration!

UPGRADES TO THE FEL SIMULATION CODE GINGER (Bill Fawley)

Work on the GINGER simulation code recently has been concentrated in two areas. First, a Fortran90 package to read and write simple ASCII SDDS files has been implemented and GINGER (in monochromatic, multiple slice mode) has successfully read SDDS files from Elegant runs (via the ANL "Elegant2Genesis" application kindly provided by ANL) to set input electron beam parameters. Second, GINGER has also been successfully ported to the second NERSC MPP platform, the IBM-SP with 640 processors (which will be upgraded to 4096 processors later in FY2001). The MPP version of GINGER was extended in capability to use multiple processors in multi-slice, monochromatic (FRED-mode), in addition to its previous ability to use multiple processors in normal, polychromatic runs. Finally, an updated version of the GINGER manual is also nearly complete and will be made available to interested
parties by the end of July 2000.

Photoinjector R&D News **_J. Clendenin_**

1. GTF Status.

The immediate goal of the GTF is to measure the emittance of a 1 nC beam using a temporally as well as spatially uniform laser pulse. The intent is to do this before the summer shutdown, which for the GTF begins about August 19th. (Some additional beam time during the following 2-3 weeks may be possible.) In meeting this goal, we expect to also measure the emittance as a function of charge and other parameters.

The Nd:glass laser system has now been installed for about 15 months and is still not fully commissioned. Despite extensive and multiple reconfigurations and fine-tuning, we still experience an unacceptable level of optical damage.

The regen has been operated in dual-head configuration since last October. This reduces the required pumping energy. We also switched to Schott rods, which are suppose to be more robust, but are also stronger focusing. This spring we reconfigured the optical cavity to more nearly duplicate the system as used at LEUTL at that time; e.g., we now have f=-2.5 m convex mirrors with output mirror 40% reflectivity. Operating the laser at 2.5 Hz, the spot size in the regen is now about 2.4 mm, which is significantly larger than with the previous configuration. With a pump energy of 35 J we get an output of 8 mJ in the IR. However, to avoid damage we operate with only 6 mJ or less.

Some small damage was noted on the rods soon after this latest configuration was implemented. The initial damage could have occurred before we imposed the lower energy operational limit. The rod damage has recently escalated, reducing laser energy and stability.

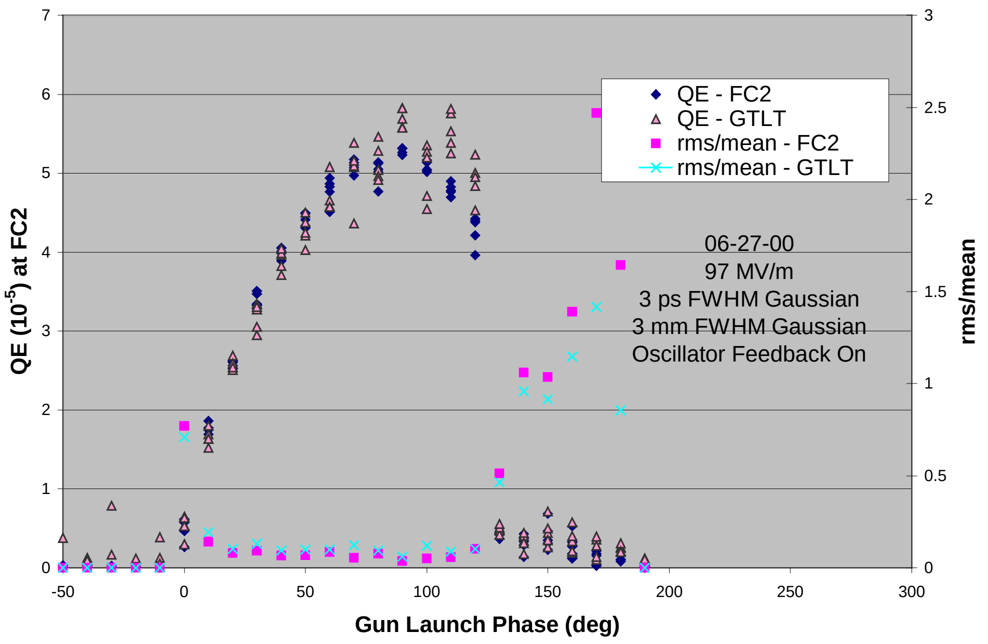
Our new policy is to maintain the laser system in a usable but not necessarily ideal condition and press ahead with electron beam measurements. The first reliable QE data with the Cu cathode installed last fall is shown below. The maximum QE of $\sim 5.5\times 10^{-5}$ is consistent with the lower QE reported in Newsletter 13 March, since we have now eliminated the double pulsing effects from the laser. For the data below, the maximum charge was ~0.65 nC, the laser energy at the cathode (because of the damage on the rods) was only ~55 μJ.

Some of the good QE performance may be due to the extra pumping now provided by the ion pump behind the cathode.

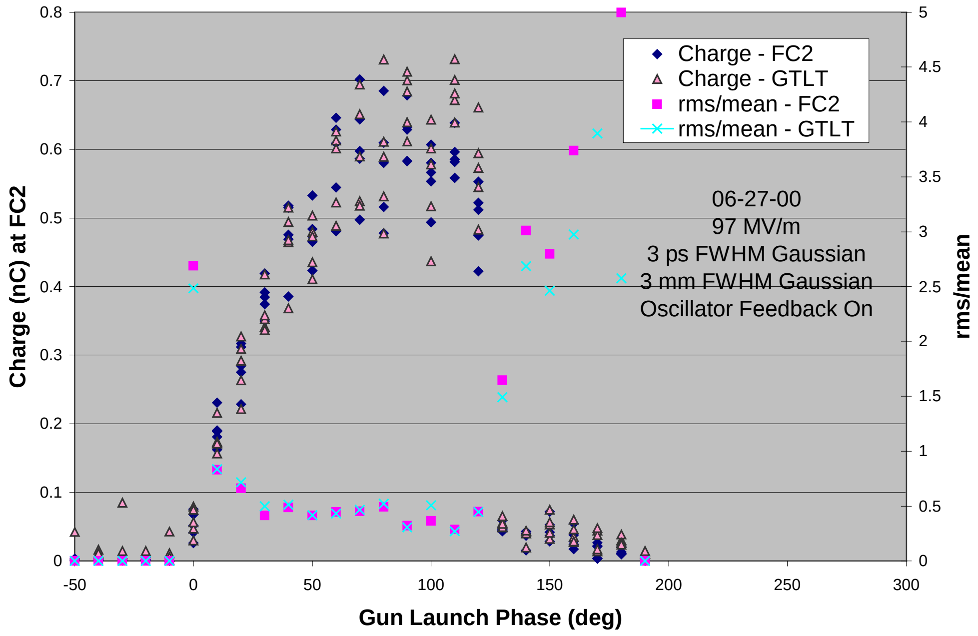
2. Cathode Testing.

The vacuum chamber with cathode is still at SLAC, ready to be sent to LLNL.

Schottky Scan



Schottky Scan



3. Streak Camera

The SSRL streak camera has been determined to have a badly deteriorated MCP, which is built into the streak tube. Hadlund has agreed to replace the tube, but this may not happen until August since these tubes are manufactured to order. Although the camera now does not have sufficient sensitivity for SPEAR bunchlength measurements, it should still be ok for UV laser bunchlength measurements at the GTF and hopefully also for the AFEL low emittance measurement this summer.

4. AFEL Low Emittance Experiment

Despite some delay caused by the Los Alamos fire, the low emittance experiment is still planned for later this summer

Linac

Vinod Bharadwaj/Paul Emma

The idea for measuring the micro-bunch using a transverse RF deflecting structure is progressing well and continues to look promising. The idea is an old one, but was revived with two independent suggestions at the LCLS Diagnostics Workshop at BNL in March, from Joe Frisch (SLAC) and X. J. Wang (BNL). There are also published studies from the early 1960's by Greg Loew (SLAC), et. al.

The traveling wave S-band structures used 35 years ago have been re-discovered after a long mummification in the SLAC linac gallery. One 12-foot and three 8-foot long structures have been "dug-up". Low power tests have already been conducted by Patrick Krejcik and Ron Akre (SLAC). In addition, plans are under way to propose the insertion of an 8-foot structure very soon into the SLAC linac in order to measure the existing 0.5-mm rms bunch length at 30 GeV. Space and RF power is available, and a profile monitor is presently located at nearly the perfect location.

Calculations (PE) and tracking simulations, using *Elegant* (Borland; ANL), show that 10 MV of peak voltage (7 MW of peak power) on an 8-foot long structure can easily measure the 0.5-mm bunch length at 30 GeV. For the LCLS, a voltage of 20-30 MV is required at ~5 GeV in order to measure the 25-μm rms bunch length. In the latter case, a peak power level of 12-25 MW is required (using the 12-foot section), which is the maximum tested by Greg Loew, et. al., in 1962. The measurement is destructive, but the RF phase could be set in order to provide a mean kick, as well as a y-z tilt, and an off-axis screen might be placed to steal pulses at ~1 Hz. This measurement is simple, gives an absolute bunch length, and can be self calibrated by sweeping the phase. It is also insensitive to initial y-z tilts (from upstream wakefields) if two separate phases are used (φ and $\pi - \varphi$). The slice emittance, and possibly even the slice energy spread, might also be measured in this way. Studies continue.

Stability studies and remedies also continue. A new code has been written (PE) which does a fast, semi-analytical calculation of the bunch compression process through the entire LCLS (rather than lengthy tracking). The code includes wakefields, non-linearities in the RF and chicanes, and the many parameter stability sensitivities (charge, timing, RF phase, etc.). The code can be ‘called’ as a simple function from a simplex minimization driver and the optimal compression parameters (RF phases, where to locate the chicanes, chicane strengths, etc.) can be found by minimizing stability sensitivities while forcing the required final bunch length and energy spread. In this way, a whole new operating point has been located which is significantly more stable, but requires stronger chicanes (potentially increased CSR emittance growth). One of the tricks used to stabilize the final energy against injector timing errors is to use an off-crest RF phase in the L3-linac (previously set exactly on-crest). There are many trade-offs, and we do not want an entirely new design unless it is clearly superior to the present. Having alternate operational parameter sets, however, is a very attractive feature. This work also continues.

Undulator *Efim Gluskin/Liz Moog*

The mechanical prototype undulator section (with fake magnets) is now in manufacturing and should be ready in mid-July. The design work on the eccentric cam system has been completed and the drawings are out for quotation for a test system. The motors, gearbox, and brakes for the test version have been ordered.

The first-pass mechanical design has been completed for the quadrupoles. Work now is focusing on methods for mounting them. There will be mechanical movers to use for rough positioning. These will be manually locked down after adjustment. For finer positioning, two-dimensional Piezo movers will be used.

Work will soon be beginning on the mounting for beam position monitors. Consideration needs to be given to the changing cross-section of the vacuum chamber and to how the BPM will be aligned relative to the undulator.

X-Ray Optics *Art Toor*

Beam Slice/Compression

Richard Bionta has completed his study of time-slicing using zone plates and transmissive gratings. A full version of his report is now available at <http://www-ssrl.slac.stanford.edu/lcls/technotes/LCLS-TN-00-7.pdf>

Fundamental Physics Experiments

At our June 15 X-ray Optics Meeting, Toshi Tajima from the Laser Directorate presented some seminal ideas concerning possible fundamental physics experiments at LCLS. His charter was to think about high-risk, high-payoff applications that were fundamentally new. He pointed out several potential exciting areas of research that could be addressed at field intensities high enough that relativistic effects fully enter the dynamics, e.g. $\geq 10^{24}$ W/cm^2. Toshi suggested six topics of research that are worthy of further study if the LCLS x-ray intensity can enter this relativistic regime.

1. Extreme high energy accelerating gradient:

The x-ray frequency is sufficiently high that the density of metallic electrons is underdense for the X-rays of the LCLS. As it has been previously pointed out (Tajima and Dawson,1979; P.Chen and R.Noble,1995?), short bursts of x-rays in a metal are capable of exciting a wakefield inside the metallic electrons. The wakefield may be accentuated by the seeding technique (Fisher and Tajima 1996). The wakefield strength is proportional to the square root of the electronic density:

$$E = \text{Sqrt}(\,n/n18\,) * a_0^2 \text{ GeV/cm},$$

Where $n18$ is a density of 10^{18} cm^{-3}, and a_0 is the normalized vector potential of the x-ray FEL. When the laser becomes relativistic, a_0 becomes unity. If the electron density of a metal is $n=10^{24}$ cm^{-3}, the wakefield electric field amounts to

$$E = a_0^2 \text{ TeV /cm.}$$

One possible example of how we can take advantage of this tremendous accelerating gradient induced by the LCLS x-rays is by creating a nanoscale size hole (nanohole) in a thin metal plate. The electron density in the nanohole may be slightly below the density in the surrounding material. If the metal and the nanohole radius are chosen such that the electron density is $\sim 10^{23}$ cm^{-3}, the dephasing length of the x-ray with the electron is of the order of 10-cm and the plasma wavelength is of the order 100nm. If the X-rays are focused into the nanohole and kept focused either by the self-focusing mechanism, or by the geometrical optical arrangement of the nanohole, over the length of the metallic slab thickness d, the energy gain by this x-ray wakefield through the slab nanohole is $d*eE$. If the slab thickness is 10 cm, the energy gain of electrons may be as great as $3*a_0^2$ TeV. If the laser is relativistic, the energy gain is ~3 TeV through 10-cm slab.

2. Ultrahot Matter

The irradiation of relativistic X-rays on a metallic target should show a remarkable new phenomenon. It is well known that the hard X-rays produced by LCLS will penetrate any material over several microns. However, when the intensity of X-rays is raised to the relativistic regime, the absorption of X-rays may dramatically increase. This phenomenon was discovered at optical wavelengths in the laser-cluster phenomenon (Ditmire et al; Kishimoto et al,1999). The efficacious cluster radius for laser absorption is 10s of nm to 1 micron. If one scales this phenomena to x-ray wavelengths there are some interesting possibilities. With 4-orders of magnitude reduction in the scales, the cluster size of 1-micron translates into an Angstrom or the size of the atom. The inner shell electron orbital size is a fraction of this. Thus, metallic atoms may become very effective absorbers of X-rays, just like clusters are for optical lasers. Typically, relativistic laser light is absorbed by a few layers of clusters. This leads to the possibility that a relativistic

XFEL may be absorbed by a few atomic layers. For optical wavelengths, the typical absorption rate by a few layers exceeds 50%. If 1 J of X-ray energy is suddenly absorbed by a micron square sheet with thickness of 1 nm, this would amount to an average energy deposition of 1-GeV per particle (or nucleon). This is extraordinarily hot matter. Such matter not only creates copious positrons, but perhaps gives rise to exotic matter such as quark-gluon matter.

3. (Coherent) Gamma Rays

Similar irradiation of strong X-rays on a metal target should lead to copious emission of gamma rays. The energy conversion from X-rays to gamma rays is high, possibly in excess of 50%. With clever manipulation of the target material and the laser frequency, it may be possible to make these gamma rays into coherent gamma rays. Since the X-rays are so intense, and the conversion efficiency so high, one expects extremely brilliant gamma rays.

4. Recreation of Astrophysical Conditions

LCLS in the relativistic regime may be able to provide access to astrophysical conditions that so far are only dreamt of. An example would be the conditions near a gamma-ray burst. The above techniques can potentially give rise to an X-rays irradiance so high that it resembles that of a gamma-ray burst. In a typical gamma-ray burst core, it is believed that gamma rays (~ 100 keV energy) have a flux of 10^{30} W/cm^2. This is just about the relativistic limit for gamma rays at this energy, yielding a_0 for the 100 keV gamma rays of about unity. X-rays from the LCLS, if relativistic, once again have a_0 of the order unity. Thus the nonlinearity of photons in a gamma ray burst and that of the XFEL are in a similar ballpark. In addition, there are other astrophysical extreme conditions that may be recreated at LCLS.

5. Violent Acceleration, Gravity, and Horizon Physics

The acceleration by the relativistic XFEL's electric field is so enormous that an electron may be accelerated sideways with accelerating gradient that resembles that near the surface of a black hole horizon. As has been demonstrated in P.Chen et al. (1999), a proper setup of a standing X-ray laser will cause so large acceleration that the electron in the accelerated frame of reference feels tremendous gravity. This causes the horizon of the electron to emerge at a finite distance. This is the fundamental reason why Unruh radiation arises, which is a sisterly phenomenon of the Hawking radiation from a black hole horizon. Perhaps with the LCLS we will be able to get insight into the physics at a horizon, just like that at a black hole horizon.

6. Nonlinear QED

Similar to the above, with a sufficiently strong X-ray laser, the electric field of the laser begins to polarize the vacuum causing the vacuum to 'split'. This would cause spontaneous generation of copious electron-positron pairs. Again this nonlinear QED phenomenon is expected to play an important role near a gamma-ray burst. The LCLS may provide an experimental tool to validate aspects of nonlinear field theory at X-ray wavelengths.

Bending Magnets and Beam Dump

For the past several months work has been ongoing to develop a new design for the LCLS electron bending magnets and a new electron beam dump (e-dump). The goal for the new system is to deflect the electron beam more rapidly into the ground to provide more useable space for X-ray Optics and to eliminate the existing muon shielding located after the e-dump. One option to reach this goal was to replace the existing seven permanent magnets with new permanent magnets having ~ 2-times the magnetic field. The magnet field strength of the existing permanent magnets is about 5 kG. The costs to purchase seven permanent magnets having 10 kG magnet field was found to be quite high. Another option would be to use DC magnets instead of permanent magnets. Such a design is not safe because high levels of radiation could reach occupied areas of the Experiment Hall if the first DC magnet failed. After considering these two options, Dieter Walz and Stan Mao submitted a new proposal for the LCLS electron bending magnets and e-dump at the LCLS-Hutch Radiation Safety Meeting on June 27.

The new design will deflect the electron beam with energies from 1.5 GeV to 15 GeV to a new dump located ~ 1-meter underneath the ground. The new design will use five existing permanent magnets followed by 2 DC-magnets. The DC-magnets will be type 4D56C. The integral of Bdl for the permanent magnets is 21.15 kG-m and the integral Bdl for the DC magnets is 50 kG-m. The length of the seven magnets will be about 10 m. From the downstream end of the magnets to the e-dump is about 15 m. A 15-GeV electron beam will be deflected to about 1 m below the floor at the e-dump location. Therefore, there will be no muon shielding requirements after the e-dump. This design will provide the X-ray Optics with more vertical space and be considerably cheaper than purchasing seven new permanent magnets. To meet the safety requirements the new design will incorporate two meter relays to monitor the on/off status of the DC magnets and two Burn Through Monitors (BTMs) associated with protection ion chambers to stop the electron beam in case of the failure of the meter relays.

The LCLS Radiation Safety meeting also discussed several designs for the electron dump. A new aluminum e-dump designed by Dieter Walz will be used because the aluminum dump will not need a radioactive water system and H-O re-combiner.

CAMEL

D. Ryutov and A. Toor have proposed a new approach to high power-loads on optics and adaptive optics based on the use of liquid optical elements (i.e. planar and parabolic mirrors, and liquid diffraction gratings). The use of liquid optical elements, by itself, is not a new concept. One can cite studies of large-area (many square meters) planar liquid mirrors for laser power plants and the development of rotating 2.5-m diameter parabolic mirrors for telescopes . What Ryutov and Toor are proposing is entirely different. They propose to develop a new class of optical elements consisting in most cases of thin liquid films. The principal features associated with these optics are: 1) the film thickness is in the range from a few microns to a few tens of microns, 2) the film's behavior is strongly affected by capillary forces, and 3) electrostatic and **j**×**B** forces are used to control the shape of the surface of the film. The resulting optical elements, in most cases, can be arbitrarily oriented with respect to the gravitational force. This new class of optics is being designated by the acronym "CAMEL" (CApillary-Magneto-Electrostatic"). In most cases the optical elements are applicable for short-pulse rep-rate sources and they possess the unique feature that between two successive pulses the optical elements can be created anew.

Experimental Program *Ingolf Lindau*

As reported earlier, six working groups have been formed by the Scientific Advisory Committee (SAC) to describe the initial experiments to be performed on the LCLS. The sixth, and final, working group on femtosecond chemistry is now in place. It is headed by Dan Imre of BNL. Other members of the group are John Arthur (SSRL), Michael Wulff (ESRF), Philip Anfinrud (NIH), Richard Neutze (Uppsala), Jerry Hastings (BNL) and Chi-Chang Kao (BNL). The six working groups will have their first drafts ready and present them for SAC at the July 14 meeting. HASYLAB (DESY) is organizing a series of workshops on both instrumentation and science for their proposed 1 Angstrom XFEL. More information can be obtained on their homepage: <http://www.desy.de>

VISA Report from ATF Newsletter (June 9) *Ilan Ben-Zvi, Aaron Tremaine*

(REPORTED BY AARON TREMAINE AND ALEX MUROKH)

For the past couple of months, Alex has been working on the upgrade of BPM optics, and alignment laser systems. The last run was a "beta"-test for both.

A. The BPM optics scheme remains the same, but uses new mirrors, lenses, and standard mounting components. The new set-up has 4 times bigger acceptance solid angle (factor of 2 gain in OTR intensity), has special arrangement for inserting filters and polarizers and is much faster to align. Also, the mirrors are used to filter out undulator radiation, with no appreciable attenuation of the OTR. All these improvements became possible after the realization, that we can remove the starboard side-poles from the steering magnets, and open up a space for optics. Also the pop-in was added at port #1 (half the size of a standard BPM), and will be tested this Friday.

B. The laser system was upgraded during the shut-down:

1. The focusing scheme of the red laser had been changed from 1 lens to 3 lenses. As a result, with less aberrations and better control, the spot size was decreased by a factor of 2/3, almost reaching a fundamental minimum of sigma = 0.5 mm. The beam quality became sufficient to make a red laser - primary for BPMs (Just in time considering an IR laser failure).

2. The monitoring system was added and pre-aligned during laser alignment. Now we can align the laser at any time, without opening vacuum. Alignment down to 50 microns can be done in 15 minutes, thanks to new, big arm mirrors, made by Brendon (from Robert Ruland's team). Better accuracy is achievable, but time consuming. Sub-50 microns accuracy is below the kinematic limit of the mirrors, therefore optical flat was added and used for pure translation. With that set-up an alignment accuracy of 20 microns was achieved, which is a shot-to-shot fluctuations level.

3. The problem of ND-filters was not solved at the first attempt. A reminder of the problem: the ND filters used to change the laser intensity, randomly (but repeatably) deflect beam by up to 500 microns. The replacement single plane variable filter that I bought was better, but still produced up to 100 microns errors. Unexpected help came from changing the laser alignment procedure. Replacing the Quadrant detector with the miniature CCD camera (borrowed from Xijie) enabled us to align laser at exactly the same settings as used for the beam steering.

4. The 800-nm laser is at Melles Griot. It is quite possible, that diode replacement will be necessary. We will know the exact delivery date by next week. With the monitoring set-up it can be installed and aligned, even when the system is under vacuum. Also, we will do an alignment on the alignment lasers. On our next run days we will try to do in-depth trajectory studies and come to a conclusion of the undulator alignment. Unfortunately, we were not able to get any meaningful info from our last run days which were after a shutdown. We find it takes about a day to a day and a half to come back online after a shutdown. The mounts for the mirrors and lenses for the transport is up. We need to install and align the mirrors to the FEL room. This is hard to do without the 800 nm laser.

During July and August we have several run days.

(VISA UPDATE FROM H-D NUHN)

After finishing the last VISA alignment procedure, R. Ruland found that, due to communications / data reduction errors, the VISA undulators had been aligned to incorrect tooling ball position numbers all along. The impact of these misalignments on the electron trajectory in VISA has been analyzed. The amplitudes of the transverse misplacements of the undulator segments have initially been estimated to be 0.3 to 0.6 mm and they are in both planes. The large trajectory oscillations that these undulator displacements generate for an electron beam launched on the reference line can be significantly reduced by selecting appropriate launch conditions. The remaining trajectory amplitudes are still above tolerance and are expected to prevent saturation if they are not corrected.

Trajectory measurements taken on VISA on April 27, 2000 have been analyzed, again, while taken these misalignments of the undulator segments into account. The fit to the vertical trajectory data is very good. The modeling of the horizontal trajectory data still requires the assumption that the beam receives an additional kick in order to make the fit work. While a proper location for that kick can not be predicted with certainty, a kick of 12.8 mrad at the 2.5-m-point improves the fit quality, significantly. The kick could also be caused by a large horizontal misalignment of the third undulator segment.

The most recent assessment of the fiducialization errors is that the correct magnitude of the misalignments can not be fully reconstructed. The problem can only be corrected with a refiducialization of the tooling balls. It has been decided that this effort will be carried out under the control of R. Ruland during the months of July and August. The effort will include the reassembly setup of the pulsed stretched wire measurement system. After a preparatory phase, the VISA vacuum tank will be opened in the second half of July and the undulator sections will be removed and refiducialized using the pulsed stretched wire system and straightness interferometers provided by the SLAC alignment group. Two of the four segments (#1 and #3) will be removed for repair and replaced by the extra "SDL segments" (#5, #6), i.e., the sequence to be reassembled in the vacuum tank after refiducialization will be #5, #2, #6, #4.

During the preparatory time for this procedure, attempts will be made to straighten the electron beam in the present VISA setup with the steering magnets with the goal of maximizing the FEL gain in order to further characterize the system and hopefully achieve gain at significantly higher levels that has been in the past. H.-D. Nuhn will participate in these shifts during the July 13-18, 2000 period.