CTFII laser and optical system : 2000

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The CTF2 laser system was modified during 1999 and 2000 in order to increase the reliability and performance of the system. In effect, several optical elements were damaged in the operational run of 1998, but due to the need to keep CTF2 operational, even at a reduced level of functionality, the time was not available to analyse the problem and provide a coherent solution. This analysis was done at the end of the 1998 run and during the 1999 shutdown, when several areas were identified for modification, and tests were made to establish a reliable system.

The study identified three areas for improvement, these were Infra-Red Production, Conversion efficiency from IR to UV and Transport of the UV energy to the photocathode

Production

In order to meet the CTF2 requirements for electron bunch charge, the laser must produce two pulses of 8mJ at 1047nm. The pulse length is estimated to be 10ps, there are no diagnostic instruments available to measure this with accuracy, the streak camera measures the light converted to the second harmonic, 524nm and the 4th harmonic, 262nm, as having pulse lengths of ~8ps. The pulse power is therefore 1GW, the final amplifier rod diameter (6.35mm) limits the size of the beam to about 4mm, which brings the peak power density to ~10GW/cm2, within a factor of 3 or 4 of the damage level of some laser materials and coatings.

Analysis of the operational records shows that the laser, when correctly set up and aligned, would operate for several days with a slight loss of (UV) energy, which was often corrected with increases of the amplifier flashlamp voltage, which increases the amplifier gain. After some time, a damage point could be identified on one of the elements of the laser power section, either the pulse compressor grating, the faraday rotator in the final 2-pass amplifier, the final amplifier rod itself, or one of the harmonic generating crystals.

Optical miss-alignment of the beam (due to poor quality mechanics, supplied with the laser) was causing a loss of efficiency in the amplification process and was being corrected by increased gain, as re-alignment would take an entire day and a gain adjustment takes only a few seconds. This compensation would have been valid if the misalignment was at the beginning of the amplifier chain, so that the power levels were returned to the correct intensities. However, if the losses are caused at the end of the amplifier chain, the IR energy in the laser can be increased to damage levels. So the situation exists where the same observed lack of output energy could have two causes, and where increasing the amplifier gain is acceptable for one, it will cause damage for the other.

Conversion

The efficient conversion of light from IR to UV is necessary to minimise the power levels in the amplifier chain and to provide stable, long-term operating conditions to the CTF. The conversion is made by two non-linear optical crystals, KD*P (KD_2PO_4) and BBO (ß-Barium Borate), both of which require accurate alignment with the laser beam and stable temperature conditions. Alignment of these elements implied the removal of the covers on the laser table (which reduce air currents, a source of instability in the beam) causing temperature changes which took 10-15 minutes to stabilise. In addition, the crystals themselves absorb some laser power and attain an equilibrium temperature, which may require further angle adjustments.

Transport

Included in the heading of Transport are all of the optical elements in between the laser and the cathode, including the pulse train generators. The problems of transport were found to be both alignment stability and mirror reflectivity. As the aperture of the system is limited, and the path length is in excess of 30m, small errors of alignment “clip” some of the pulses in different parts of the pulse train generators, resulting in a lower energy level at the cathode for some pulses. The effect is observed on the electron bunch signal, as an increase in the pulse to pulse intensity variation along the pulse train, and an overall drop in electron bunch charge. The reflectivity of all of the beam steering mirrors in the path to the cathode were checked, several were found to have 10-15% losses, and were replaced. The mirror coatings will absorb humidity, which changes the optimum wavelength of operation, the CTF2 environment is often affected by water leaks from the cooling systems.

Changes and improvements

Many changes were implemented as a result of this study, and will be detailed in the following sections. One of the most significant was the replacement of all of the optics mounts in the laser with ones of better mechanical stability, thus reducing the miss-alignment problem. Another major change was made to the amplification and pulse compression sequence, which had pulse compression before the final amplifier, the pulse compression is now performed after the amplifier, with a larger beam size on the compressor grating to avoid damage to this delicate component.

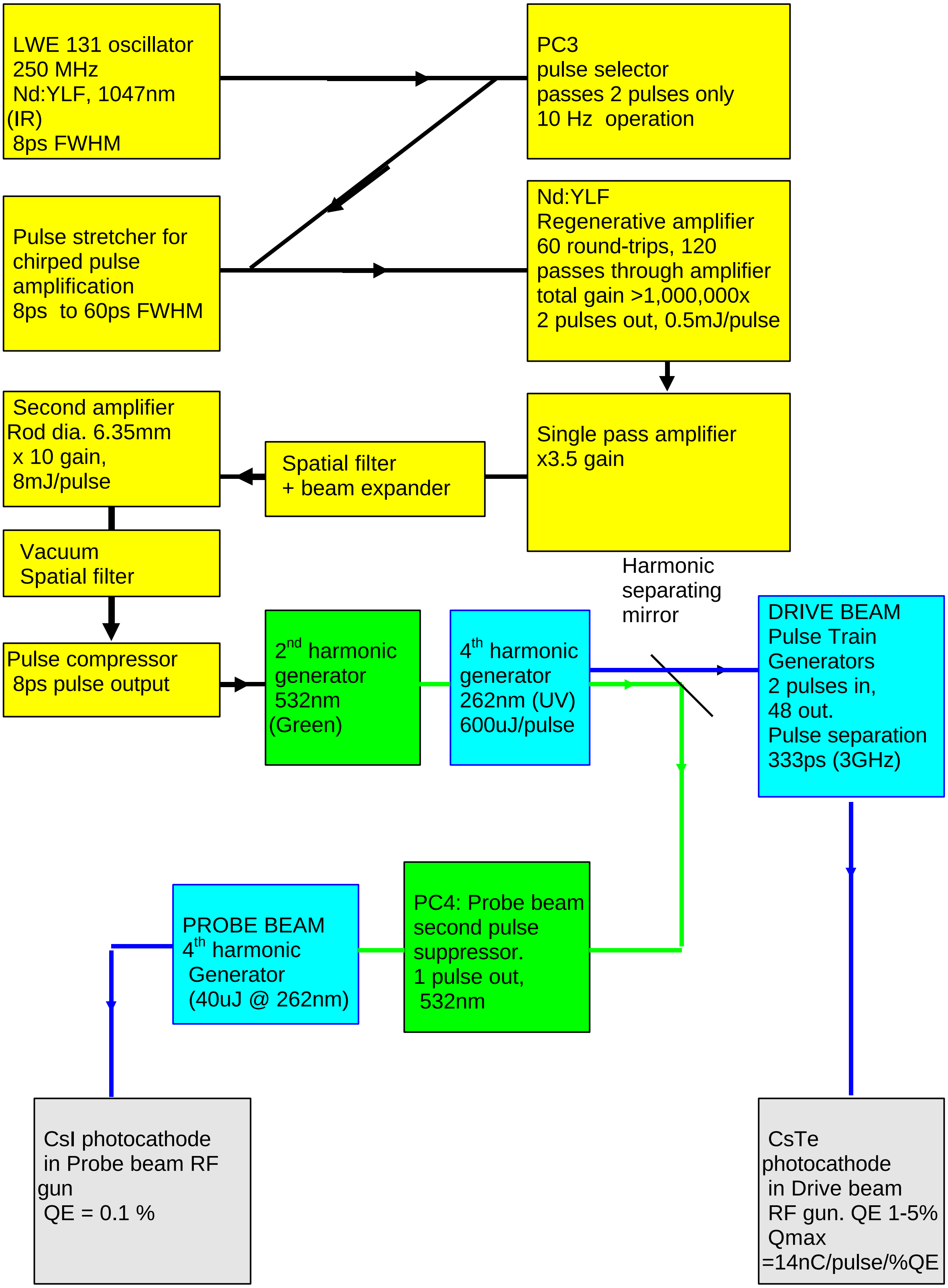
The operating method has also changed, the amplifier levels are no longer used to compensate for errors elsewhere. Alignment drift is now much reduced, but if the IR level changes, the cause is investigated before the effect is compensated.

New spatial filters were included between the amplifiers, to improve the energy distribution in the laser beam, this also protects items like the amplifier and compressor grating from interference effects which could cause damage, and improves the conversion efficiency, as beam quality is a major factor for good harmonic conversion.

Motorised, remote-controlled alignment was added to the harmonic converters, the covers can now remain in place during tuning changes. This has reduced the time needed to obtain stable operating conditions.

Several other improvements were made, and a test performed during the shutdown of Jan-Feb. 2000, where the laser was left to operate at the nominal level for 10 days non-stop while monitoring the IR beam. The result was that the level remained constant, there was no observed miss-alignment, over a period of operation equivalent to an entire month of CTF2 usage.

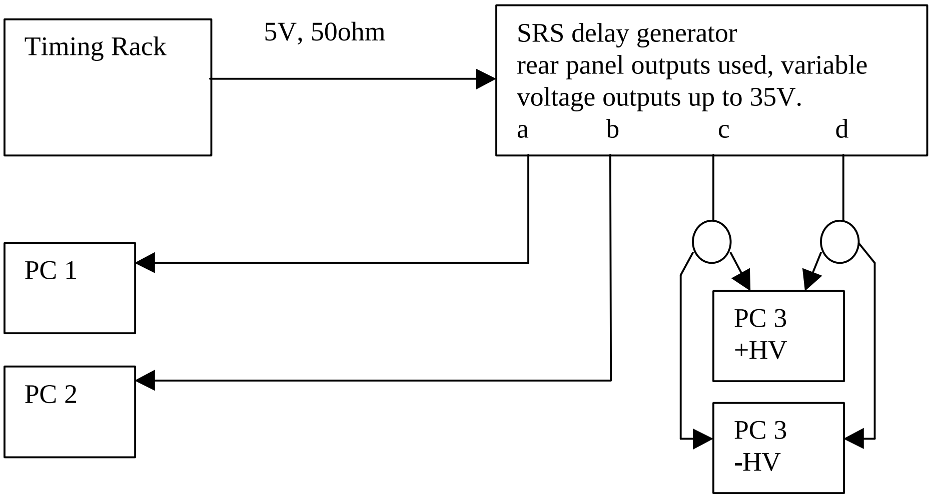
CTF laser schematic diagram (2000)



Timing system

In order to balance the two amplified pulses, the leading one must have slightly lower energy at the output of the RA, as it is preferentially amplified in the following single-pass amplifiers. The second pulse experiences a slightly lower gain due to the energy depletion caused by the passage of the first pulse. The best method to achieve this was found to be a fine adjustment of PC1 timing (the injection Pockels Cell) in the regenerative amplifier. PC3 (two-pulse selector cell) can also be used for this purpose. As the Pockels cells are now used as variable attenuators, the timing jitter translates into amplitude jitter, so a timing system with lower drift and jitter was required. A secondary problem has been the ability to set PC2 accurately, the timing drift coupled with the step size of 0.5ns and rise-time of 4ns often lead to one of the output pulses being cut, with the subsequent generation of satellite pulses.

The solution has been the development of a single channel, stable timing in the timing rack. This was originally intended for the streak camera timing, and has now been duplicated for the Pockels cells (this work was done by R.Pittin). The delay is controlled locally on the rack by a series of binary-weighted switches that set the delay counter. A single 5V pulse is generated, it has a fast risetime, and low jitter with respect to the RF signals, 250MHz and 3GHz.
This fast signal is the trigger for a 4-channel delay generator (Stanford Research Systems, SRS 535) which is mounted locally in the laser control rack. The 4 channels are used to trigger Pockels cells 1,2 and 3 (Pockels cell 3 requires 2 triggers, one each for the leading and trailing edges). The other timing channels for instrumentation, flashlamps, PC4 and HV control remain as before, controlled by the CTF camac timing system.



The HV (Belke) switches of the Pockels cell drivers, are designed to operate with a trigger pulse of between 2-10V, the original timing system provided 20V pulses, the pulses were split using resistive dividers. The inputs of the HV switches were adapted to permit the use of standard 20V input pulses to the system, PC1 and PC2 (channels a and b) should have 20V at the input of the HV modules. The trigger pulses for PC3 (channels c and d) were all derived from one 20V pulse, in the present (SRS delay generator) system they are generated from two, each of 14V and then divided to give 10V at the input of the HV module, as can be seen from fig.1. The levels of the rear panel outputs can be individually set, up to a maximum of 35V, the output level is 10x the front panel output, which is the displayed value.

Injection

The LWE 131 oscillator is now used in place of the model 130, it has the advantage of a higher output level (400mW) than the older unit, which is now used for CTF3 laser developments, but remains available as the spare unit for the CTF. The model 131 unit, although installed in the CTF for the first time in 1999, should not be considered as “new”, it was ordered in December 1994 and has suffered 4 years of transport damage, modifications and repairs, it has not yet proved its reliability or stability specifications. The performance is strongly dependant on the ambient temperature, as there is a minimum temperature below which it is impossible to achieve stable output levels and phase stability. One or two degrees higher and satellite pulses are produced. It is in service due to the reduced performance of the model 130, which with an aging laser diode pump, has reduced output levels and often creates satellite pulses, which cannot be controlled.

The RF drive for the (LWE131) mode-locker is provided from timing rack in the laser room. A stable 249.879MHz signal is derived from the master oscillator of the timing system that also produces the 3 GHz pilot for the RF system.

RA Cavity

Several optical mounts were suspected of causing alignment stability problems in RA cavity and the injection path to it. These were exchanged for better quality mechanical pieces, having hardened bearing surfaces, ball-bearing drives and fine pitch adjusting screws. The system now remains in good alignment for periods of weeks, it was never determined if the problem in this area was caused by one element or was an accumulation of small errors from several mounts.

Spatial filtering

Several changes have been made to the CTFII laser with the aim of improving the IR-UV conversion efficiency and reducing the energy density in the system to avoid optical damage. The output of the regenerative amplifier is expanded before the first amplifier by a Galilean beam expander, due to the lack of space at this point a spatial filter cannot be fitted. The beam is expanded to 2.5 mm dia, which is the largest possible avoiding interference effects in the 4mm diameter amplifier rod.

A spatial filter (SF) has been installed between the first and second amplifiers, pinhole diameter 0.3mm, input lens f=200mm, output lens f=400mm, the beam is thereby expanded to ~4mm diameter. The diameter of the second amplifier rod is 6.35mm, the beam passes with only small interference rings being generated.

Amplifier 2 and vacuum spatial filter

The final amplifier is now in single-pass configuration, not double-pass as before, in the previous configuration the pulse was compressed to 8ps before the final amplifier, generating a large peak power which was the cause of damage to several elements. One of the most delicate elements was the pulse compressor grating, in order to avoid damage to this, the output of the first amplifier was limited, requiring extra gain from the second amplifier.

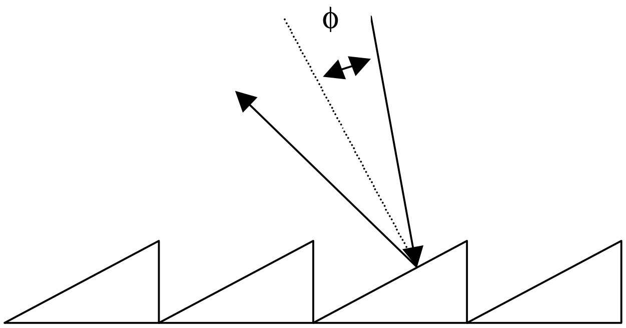
The output from the second amplifier, 2 pulses of 8mJ, enters a second spatial filter (made and installed by P.Legros), pinhole diameter 0.3mm, input lens f=250mm, output lens f=500mm. At this energy the beam causes electrical breakdown in air, so the filter assembly is vacuum pumped to 10^{-4} Torr. The input lens forms one window of the assembly, the output window is an AR-coated window 200mm from the pinhole. This filter also expands the beam to 10mm dia, and provides control of the beam collimation before the pulse compressor.

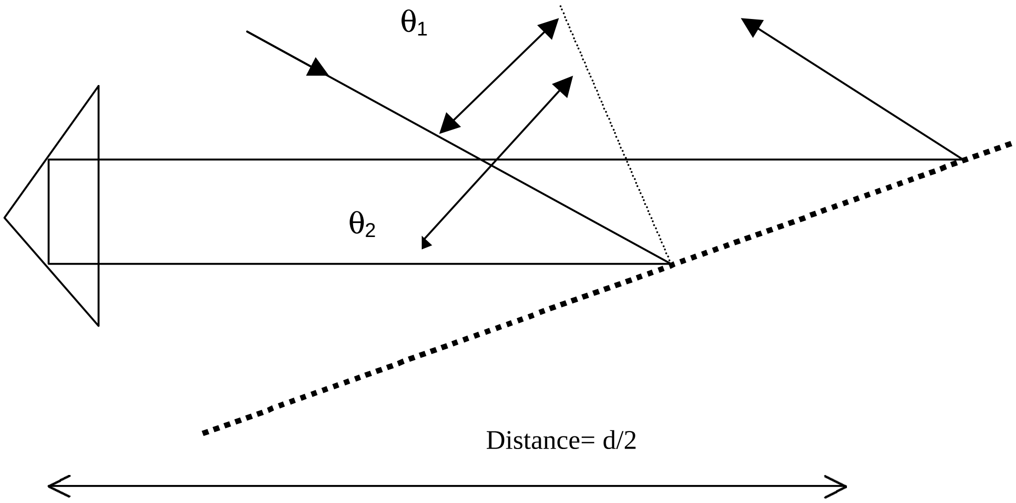
Gratings, pulse compression

The pulse compressor system that was originally installed had suffered damage due to the high power density, the beam diameter was ~1mm with an energy of ~1mJ. In addition, the pulse compression was made before the final amplifier, which resulted in unnecessarily high power densities on the compressor grating and in the final amplifier. Placing the compressor grating after the amplifier requires a larger beam diameter and a good beam quality (absence of interference fringes and "hot" points), which are provided by the vacuum spatial filter.

The Gratings used in the CTF are ISA (formerly Jobin-Yvon)
1740 lines/mm gold, blazed at 65°.

For best transmission "$\theta_1 \approx \theta_2$" Littrow condition: $\theta_1 = 65° - \phi$, $\theta_2 = 65° + \phi$





First order diffraction:

$\sin\theta_1 + \sin\theta_2 = \lambda / g$ (g is line spacing, 0.574um)

Angles measured from old setup: $\theta_1 = 59°$, $\theta_2 = 75°$
(this is a little way off from Littrow, ideal would be $\theta_1 = 60°$, $\theta_2 = 73°$)

So if $\lambda = g(\sin\theta_1 + \sin\theta_2)$:

= 0.574(0.866+0.9558)= 1.045nm (YLF is 1047) so these angles are correct.

Gdd for these angles:

$Gdd = -2\,\lambda^3 / (c\ g\ \cos\theta_2)^2$ where c =speed of light

For $\theta_2 = 75°$, Gdd = d x 1.2ps/GHz (d is path length in compressor, in meters)
For $\theta_2 = 73°$, Gdd = d x 0.895 ps/GHz

The stretched pulse bandwidth is about 120GHz, pulse length about 70ps.

Gdd x 120GHz = 70ps .

For $\theta_2 = 75°$, Gdd = d x 1.2ps, so d= 70/144 , = 490 mm
For $\theta_2 = 73°$, Gdd = d x 0.895, so d= 70/118 , = 650 mm

So for $\theta_2 = 74°$ +/- 1°, the prism should be 250 to 320 mm from the grating "center".

This also shows that the beam entering the compressor must be collimated to less than1 degree also, or the compression will not act correctly on all of the pulse, creating a longer pulse with "wings". This would be observed as a poor harmonic conversion efficiency, as the available "fast" detectors lack the dynamic range and/or bandwidth to observe such a pulse shape, or in the case of the streak camera, are not sensitive at this wavelength.

Motorised mounts for the harmonic generators

Motorised angle control has been installed for the drive beam harmonic generators, to reduce the problems of temperature fluctuations during system "tuning". These are based on the "picomotor" system of New Focus (USA) which uses high voltage pulses to actuate a pietzo-electric element, causing small advances of a micrometer screw drive. This system has several advantages in this application. The units are extremely compact and are easily placed in small locations, also the level of control is extremely fine, enabling micrometer advances of a few 10's of nm. Finally, the position is not held by an active circuit, as in a dc or stepping motor system, so the set position is as stable as a normal micrometer drive.

The drive beam path

Changes in the laser now produce a UV beam diameter of 4mm, this is passed through the UV collimator which is adjusted to give a uniform beam in the pulse train generators. The maximum aperture allowable is 5mm diameter in order to maintain good transmission, larger beams would be clipped in the pulse train generators.

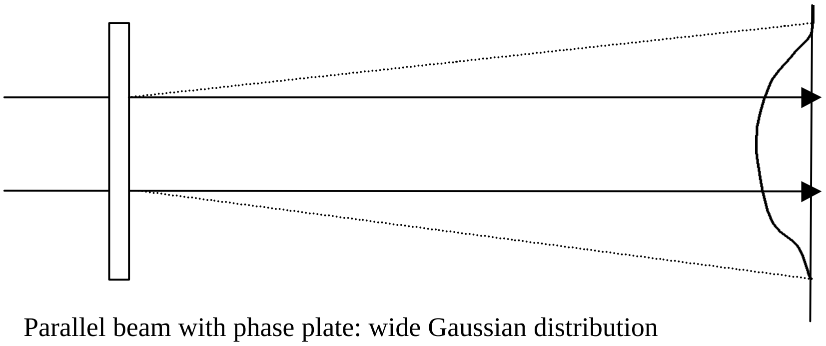
Phase plates for Drive and Probe beams

The distribution of energy and the position of the laser pulse on the cathode are both important factors affecting the stability of the electron beam. The energy distribution varies slightly from shot to shot due to random effects of flash-lamp intensity variations, water cooling turbulence, air currents in the laser beam path and thermal effects in the optical elements. The beam position is also affected by these (beam pointing stability), and has the added problem of the beam path distortion due to thermal effects on the building.

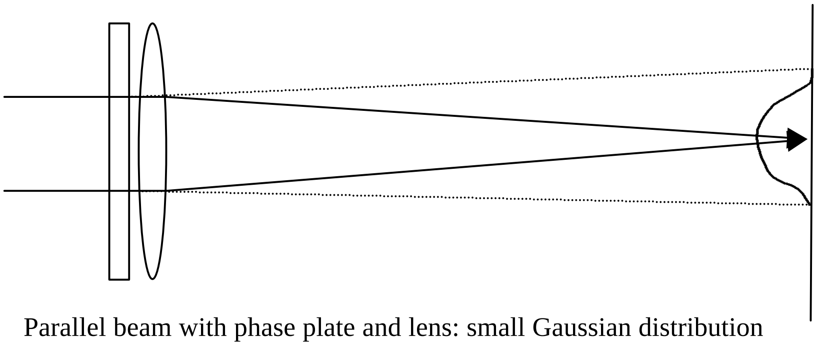
The probe beam is now equipped with a diffractive diffuser plate (phase plate), which provides a uniform Gaussian energy distribution on the cathode, irrespective of the laser beam distribution at the end of the optical path.

A phase plate is a transparent, flat element covered with small zones of different phase advance. The different zones will diffract a parallel beam passing through the plate to a surface. The final distribution will be a convolution of the original distribution and the diffraction pattern, which can be Gaussian for a random pattern, or any other distribution (lines, flat top, square…) can be calculated and the appropriate zone pattern applied to the plate.

In our application a lens is added, which would focus the UV beam to a point on the cathode, the convolution is then of a Gaussian distribution and a point: only the Gaussian remains.



Parallel beam with phase plate: wide Gaussian distribution



Parallel beam with phase plate and lens: small Gaussian distribution

This arrangement has the advantage that for lateral movements of the incoming beam, as long as the aperture of the system is not exceeded, there is no change in the position or distribution of the UV light on the cathode.

The complex nature of the Drive beam, having 12 converging parallel beams, a severely limited aperture and >7m distance from the cathode to the vacuum chamber window, complicates the application of such a system, but it is hoped to be able to improve the Drive beam distribution in the future.

Conclusion

The improvements made to the system have both increased the performance of the system and reduced the operational load of keeping the laser in a working state. It is to be regretted that much of this work was the result of bitterly gained experience which could have been avoided if suitable thought had been taken in the original design of the system, but it is experience that is proving useful in current work for CTF3 systems.

See also:
PS-LP Note 96-10 S.C.Hutchins, PS-LP

CTF Note 96-13 S.C.Hutchins, PS-LP

CTF Note 98-18 S.C.Hutchins, PS-LP