1. Eye Safety

The lasers you will be working with are sources of intense optical radiation. Their safe use depends on your being aware of their unique characteristics and treating them with the respect due instrumentation that can cause serious bodily harm.

At almost every stage of the system alignment procedure, the intensity of the beams from the argon-ion laser, the ORC–1000 Nd:YAG laser, the NJA–5 Ti:Sapphire oscillator, and the TRA–1000 Ti:Sapphire regenerative amplifier can cause serious damage to the eye, including loss of vision, when viewed directly or when reflected off another object.

The radiation generated and amplified by the Ti:Sapphire is in the near IR wavelength range where the sensitivity of the retina is minimal. When the Ti:Sapphire laser is operating in the near infrared, the weak appearance of the beam may **mislead** you into believing it is of low intensity and therefore of little concern. However, serious permanent eye damage can still occur.

The various wavelengths, pulse energies, and optical powers emitted by the lasers of the CPA–1000 system are listed in Table 1–1. Use this table and good sense to decide what level of eye and skin protection is needed.

Laser	Wavelength (nm)	Power	Pulse Energy
argon-ion	460 ~ 520	< 20 W	cw
ORC–1000 Nd:YAG	532	< 65 W	< 25 mJ
NJA–5 Ti:Sapphire Oscillator	700 ~ 1000	< 2 W	< 20 mJ
TRA–1000 Ti:Sapphire regenerative amplifier	700 ~ 1000	< 5 W	< 5 mJ

Table 1–1
Laser parameters affecting the user's safety.

Attention !

Post the laser parameters (shown in the preceding chart) near the laboratory to alert everyone to the presence of laser radiation.

Please see the original manufacturer's manual for additional safety information. Read the safety instructions of the CDRH certified ion laser (used to pump the regenerative amplifier). Incorporate the safety recommendations into your standard laboratory practice.

Please refer to Chapter 13 for the locations of the safety labels affixed to the TRA–1000 housing.

Caution !

When setting up or aligning the system or subsystems, KEEP ALL BEAMS BELOW EYE LEVEL.

Never look in the plane of propagation of the beam.

The beam from the Ti:Sapphire pump laser system can cause serious eye damage even when it appears to be of low intensity! Intense coherent and incoherent radiation is emitted from the Ti:Sapphire rods when they are being pumped by other lasers. Avoid all direct exposure to the laser beams. Wear LASER SAFETY GOGGLES.

Remember that safety goggles *can be a hazard as well as a benefit.* To protect the eyes from the laser beam, the goggles must attenuate to the point where the beam is no longer visible. Therefore, the user can be exposed to **flesh burns** or **clothing fire** without seeing it happen. *Be aware of this potential.* Follow the specific recommendations called for in this manual at various stages during the alignment procedure.

Attention !

Assemble and operate this system in an enclosed room.

Periodically inspect the area for stray beams and reflections.

Block those that propagate outside of the work area during assembly and alignment.

Avoid uncontrolled reflections.

The laser beams can remain collimated over large distances and remain a hazard far from the original source. It is good safety practice to clearly mark the door to the room with warning signs and interlocks connected to the two pump lasers to prevent accidental exposure to the beams.

Attention !

Post warning signs that alert everyone to the presence of laser radiation.

Do **NOT** operate the system while untrained personnel are present. Warn anyone in the area where beams are located of the dangers associated with laser beams. **Verbal warnings** help to ensure that others in the area are *not* injured by stray radiation.

Attention !

Limit access to the equipment to trained personnel who have need to use it.

The *Eye Protection Required* symbol warns you that **serious bodily harm** may result from exposure to radiation either present in the area, or radiation that may be created when doing the step detailed along side it (see also *Graphic Symbols Explained* at the beginning of this manual).

Observe and understand the symbol that follows:

Remember, safety is your responsibility!
Follow these safety procedures when working with this product.

2. Site Preparation

2.1 Laser Room

The CPA–1000 system is designed to operate under standard laboratory conditions. A list of the most common requirements is given below.

- The laboratory site must be easily accessible, because large pieces of equipment will have to be moved to the site, including the optical table(s) and the various power supplies.
- Water and electricity must be available (see Sec. 2.2 below).
- The room temperature must be stable to ± 2°C, and the humidity level must be maintained below the condensation point at all times.
- The site must be reasonably free of sources of vibration.
- The site must be clean. The cleaner the facility, the less often cleaning of the optics will be required.
- The airflow in the room (air conditioning) must be directed away from the lasers. Turbulent airflow will disturb the laser system and degrade its short-term stability.
- The laser table must be well lit. If an overhanging platform is located above the table, it may be necessary to install some additional lights. The light level control must be easily accessible as some of the alignment steps call for a darkened room.
- The table temperature must be stable to ± 2°C.
- The table's top surface must provide some type of anchorage points located on a regular basis (such as a 1″ or 25 mm square grid).
- For safety, the laser site access must be restricted.
  (See Chapter 1: Eye Safety.)

2.2 Utility Requirements

2.2.1 Argon-Ion Laser

For your convenience, we provide information for the following, most commonly found argon-ion lasers. listed in Table 2-1

Argon-Ion Lasers Listed in this Manual

Company	Model	Denote As
Spectra-Physics	BeamLok™ 2060	SP2060
Spectra-Physics	Millennia	Millennia
Coherent, Inc.	Innova® 310	I – 310
Coherent, Inc.	Innova® 90	I – 90
Coherent, Inc.	Verdi	Verdi

Please refer to your argon-ion laser's original manufacturer's manual for update information and for instructions on other models not listed above. Clark–MXR, Inc. makes no warranty or representation, either expressed or implied with respect to this document.

Electrical Connections

All argon-ion laser power supplies require a three-phase, approximately 200 VAC electrical service. Details on the electrical requirements are given in Table 2–2.

Additional instructions regarding the electrical installation are as follows:

- Do not exceed the rated input voltage.
  Use a transformer to bring the voltage within the specified range.
- Connect the *Green* lead to *Earth Ground*, not to Neutral.
- Connect the remaining three leads to the legs of the 3-phase service.
  Note: The sequence is not important.

Water Connections

Open-Loop System

Cooling water may be supplied from an open-loop system consisting of a tap water source and a direct connection of the outgoing flow to a drain.

Closed-Loop System

A closed-loop cooling system can be used to regulate the pressure, temperature, and flow rate of the cooling water, and to avoid buildup of scale in the plasma tube. This can enhance the stability of the laser, improve its performance, and prevent premature tube failure due to reduced cooling efficiency. Any such system must meet or exceed the cooling requirements listed in Table 2–3.

Pressure Stability

The water pressure must be stable throughout the work period. Large pressure changes, even for short periods, will affect the stability of the argon-ion laser and Ti:Sapphire oscillator.

If your water supply is subject to frequency pressure changes, we recommend you install a pressure-regulating tank ahead of the argon-ion laser. (See flow diagram in Fig. 3–5.) 9

Water Lines

The diameter of the incoming service line (supply hose) should be at least 15.9 mm (5/8 inch).

All hose connections are USA garden variety.

Water Filter

A water filter is provided with the argon-ion laser.
Install the filter in the supply line. (It must be installed.)
Note: The water flow direction is indicated on the filter case.

Detailed specifications of the water cooling systems for the argon-ion lasers listed above (Table 2–2) are given in Table 2–3.
1

Argon-Ion Laser Electrical System Requirements

Laser	SP2060	Millennia	I – 310	I – 90	Verdi
supply phases	3Ø		3Ø	3Ø	
supply voltage	208 VAC (+ 10%, – 5%)		208 VAC (± 10%)	208 VAC (± 10%)	
maximum current	60 A		65 A	50 A	
power cord length	3.6 m (12 ft.)		3.6 m (12 ft.)	2.9 m (9.5 ft.)	

Table 2-2 Electrical requirements for argon-ion lasers listed in Table 2-1

See Table Captions Doc

Argon-Ion Laser Water System Requirements

Laser	SP2060	Millennia	I – 310	I – 90	Verdi
minimum flow rate	11.3 l/min (3 gal/min)		9.5 l/min (2.5 gal/min)	8.3 l/min (2.2 gal/min)	
inlet temp.	< 30°C (< 86°F)		(10 ~ 35)°C (50 ~ 95)°F	< 35°C (< 95°F)	
temp. stability			± 1°C		
differential pressure	> 172 kPa (> 25 lb/in^2)		(152 ~ 276) kPa (22 ~ 40) lb/in^2	> 1.8 kg/cm^2 (> 25 lb/in^2)	
max. input pressure	517 kPa (75 lb/in^2)		620 kPa (90 lb/in^2)	3.5 kg/cm^2 (50 lb/in^2)	
water hardness	< 100 ppm		< 100 ppm	< 150 ppm	
water pH level	7.0 ~ 8.5		6.0 ~ 8.0		
heat load	< 21 kW (1224 BTU/min)		< 21 kW (1224 BTU/min)	< 21 kW (1224 BTU/min)	
max. particulate size	< 200 μm		< 200 μm	< 200 μm	

Table 2-3

2.2.2 ORC–1000 Nd:YAG Laser

The ORC–1000 laser consists of a free-standing laser head and a separate power and cooling station connected by electrical cabling and water cooling lines. The electrical specifications are given in Table 2–4, and water specifications are given in Table 2–5.

Electrical Connections

The ORC–1000 comes in a US version and a European version. Specifications are listed in Table 2–4.

ORC Laser Electrical System Requirements

ORC Version	Line Frequency	Supply Phase	Supply Voltage	Maximum Current	Cable Length
US	60 Hz	3Ø	208 VAC (± 5%)	30 A/leg	12 ft.
European	50 Hz	3Ø	400 VAC (± 5%)	20 A/leg	3.6 m

Additional instructions regarding the electrical installation are as follows:

- Do not exceed the rated input voltage.
  Use a transformer to bring the voltage within the specified range.
- Connecting Power Cable
  US (4-wire) version:
    Connect *Green* wire to *Ground*.
    Connect *White*, *Red*, and *Black* wires to terminals for loads.
    Note: The sequence is important. (Relative AC-phases)

  European (5-wire) version:
    Connect *Blue* wire to *Neutral*.
    Connect *Green/Yellow* wire to *Earth Ground* (not neutral).
    Connect *Brown* and two *Black* wires to terminals for loads.
    Note: The sequence is important. (Relative AC-phases)
- Correcting Power Service Phase
    Connect power supply cable as above.
    Switch rear panel relays (circuit breakers) to ON.
    Turn MAIN POWER key switch to ON.
    If the power supply does not function,
      exchange any two of the load wires.
    This inverts the phase rotation and enables proper operation
      of the power supply.

Note: A phase sensor built into the ORC–1000 power supply detects the relative phases among the load lines. If the phase sequence is incorrect, the sensor disables the power supply.

Note: The three phases must deliver the same amount of electrical power to the ORC power supply. The AC-voltages between any two of the three load lines should be close in value. Phase imbalance in the electrical supply results in optically noisy output from the ORC laser.

Water Connections

Open-Loop System

Cooling water may be supplied from an open-loop system consisting of a tap water source and a direct connection of the outgoing flow to a drain.

Closed-Loop System

A closed-loop system can also be used if desired.

The ORC power supply/cooling station operates using a two-stage (primary and secondary) cooling method. Since the primary stage is a closed loop using distilled or deionized water, the benefit of an additional closed loop is not significant.

Water Lines

The diameter of the incoming service line (supply hose) should be at least 15.9 mm (5/8 inch).

All hose connections are USA garden variety.

Specifications for the water cooling system are given in Table 2–5.

ORC Laser Water System Requirements

laser	ORC–1000 Nd:YAG (SHG)
minimum flow rate	7.5 liter/min (2.0 gal/min)
maximum inlet temp.	24°C (75°F)
maximum input pressure	620 kPa (90 lb/in^2)
minimum input pressure	208 kPa (30 lb/in^2)
pH level	7.0 ~ 8.5
heat load	< 4 kW (234 BTU/min)

Primary Water Cooling Circuit

The power supply cabinet contains a closed-circuit heat exchanger with a 30-liter (8-gallon) coolant reservoir. This reservoir must be filled with approximately 7 gallons of distilled or deionized water.

Water connection requires that the INPUT hose from the laser head (with the attached *red tie wrap*) be connected to the TO HEAD water port on the lower left side of the rear panel of the power supply. The OUTPUT hose is then connected to the FROM HEAD water port.

Secondary Water Cooling Circuit

When the temperature of the primary cooling water reaches approximately 29°C (84°F), the ORC supply thermostat opens up the "city water" valve and allows the external tap water to cool the closed-loop distilled water.

Water connection requires that the external tap water source hose be connected to the CITY WATER IN port, and a drain hose be connected to the CITY WATER OUT port.

2.2.3 NJA–5 and TRA–1000 Ti:Sapphire Lasers

Electrical Connections

The electrical system requirements for power supply to the feedback electronics, temperature stabilization circuits and Pockels cell driver are given Table 2–6.

CPA–1000 Modules' Electrical System Requirements

System Version	Line Frequency	Supply Phase	Supply Voltage	Maximum Current
US	60 Hz	10	110 VAC (+10%, -5%)	2 A
European	50 Hz	10	220 VAC (+10%, -5%)	2 A

Note: A minimum of two outlets is required.
Additional outlets will be needed for the power meter, the oscilloscope, the autocorrelator, etc. …

Water Connections

Ti:Sapphire Rod Cooling (NJA–5 and TRA–1000)

Open-Loop System

Cooling water may be supplied from an open-loop system consisting of a tap water source and a direct connection of the outgoing flow to a drain.

All hose connections are USA garden hose variety connected to Swagelok-type connectors. These connectors are supplied with the CPA–1000 system.

Specifications for the water cooling are given in Table 2–7.

CPA–1000 Modules' Water System Requirements

flow rate	~ few liters/hour
maximum inlet temp.	24°C (75°F)
temperature stability	± 1°C
minimum input pressure	208 kPa (30 $\mathrm{lb/in^2}$)
pH level	7.0 ~ 8.5
water filter	optional

Pockels Cell Assembly Cooling (TRA–1000)

The Pockels cell requires cooling when operating at repetition rates above 100 Hz. In practice, only a little water flow is required to cool the Pockels cell assembly, even when operating under the demanding conditions at 5 kHz repetition rate.

Note: A thermal sensor shuts the system down if the temperature exceeds a preset value.

Since the flow required to cool the Ti:Sapphire rods and the Pockels cell is very low, we recommend cooling all rods and the Pockels cell using only a single water cooling loop.

Water Filter

If there is a high level of particulate matter (undissolved solids) in the cooling water, installing a water filter will improve the cooling efficiency and stability, and extend the life of the system.

Nitrogen

High-peak-power laser systems are particularly sensitive to the quality of the optical surfaces. Air-borne contaminants, such as dust, degrade exposed optical surfaces with time. System performance (especially of the regenerative amplifier) will decrease noticeably.

When working at wavelengths above 900 nm, water vapor absorption becomes significant, as shown in Fig. 2–1. The femtosecond oscillator is very sensitive to water vapor, and precautions need to be taken.

Note: For optimum long-term stability, the oscillator needs to be pressurized with dry nitrogen at all times.

For better performance and long-term stability, the oscillator and regenerative amplifier need to be slightly pressurized with clean, oil-free, water-free nitrogen.

Maintaining the CPA–1000 with a nitrogen overpressure keeps the optics clean of dust contamination and lowers the water vapor level in the oscillator.

In order to lower the nitrogen consumption, the NJA–5 oscillator and the TRA–1000 amplifier are fitted with *low-flow* valves.

Note: Nitrogen must be provided at a pressure no higher than 0.2 bar (2.9 lb/in^2) through a 1/4″ OD, 1/8″ ID tubing.

2.3 Support Equipment and Supplies

The following equipment/supplies are required to set up, align, and operate the CPA–1000 laser system.

- One analog oscilloscope (bandwidth ≥ 300 MHz).
- One infrared viewer (model FJW *Find-R-Scope*, or equivalent).
- One analog laser power meter,
  range up to 15 W, with sensitivity ≥ 10 mW,
  (model Molectron *Power Max 5100* with head *PM10*, or equivalent).
- One autocorrelator.
  The autocorrelator must be able to measure pulses as short as 30 fs at 100 MHz (oscillator) and at 1 kHz (amplifier),
  (model Clark–MXR *AC–150*, or equivalent).
- Tool set including:
  wrench set,
  utility knife,
  screwdrivers,
  ruler,
  set of U.S. Allen wrenches,
  voltmeter,
  measuring tape.
- Flashlight.
- 30 liters (8 gallons) of distilled or deionized water.
- nitrogen (see above).
- Optics cleaning supplies:
  spectroscopic or research grade *methanol* and *acetone*,
  lens tissue,
  powder-free gloves,
  dust-free compressed gas (several cans).

3. System Overview

3.1 System Layout

The CPA–1000 system supplied from Clark–MXR, Inc. is a laboratory tabletop-based system designed to produce femtosecond pulses of "white" light at kilohertz repetition rates. The system is comprised of:

- one argon-ion laser,
- one NJA–5 Ti:Sapphire self-mode-locked oscillator,
- one PS–1000 pulse stretcher and isolation stage,
- one ORC–1000 frequency-doubled Nd:YAG laser,
- one TRA–1000 Ti:Sapphire regenerative amplifier,
- one PC–1000 pulse compressor and white light generator (optional),
- associated isolation and transport optics.

A $4' \times 8'$ table is the minimum size that is able to accommodate the entire system. A larger table, such as $4' \times 10'$, is recommended.

Section 3.2 describes the overall positioning of the various subsystems forming the CPA–1000.

3.1.1 Temperature Stabilization

To improve long-term stability, the CPA–1000 system is provided with a built-in internal temperature stabilization system. Use the following procedures to set up the temperature controller.

1. Press the INDEX switch on the temperature controller located on the front panel (side closest a table edge) of the laser enclosure.
   The green characters SP1 will blink.
   The red number is the *set temperature* (in °C) for the enclosure.
2. Press the UP or DOWN selector to make the necessary temperature adjustments. After selecting the set point, press the ENTER switch. Finally, press the INDEX switch.

   Note: For the NJA–5 and TRA–1000, the set point should be
   no more than 5°C above average room temperature.
   For the PS–1000 and PC–1000, the set point should be
   no more than 2°C above average room temperature.

   Note: The temperature gradient between enclosures should be no more than ± 2°C, or a vortex may develop in the enclosure and disturb the NJA–5 oscillator.

3.2 Initial Positioning

3.2.1 General Positioning

The preferred layout of the CPA–1000 system is shown in Fig. 3–1. Our subsystems are compatible with metric or English tables. The table shown in the figure is a $4' \times 8'$ table, with holes every inch. There is an untapped 1.5″ border zone at the edge of the table (as found on most commercial laboratory tables).

It is important that all modules, with exception of the pump lasers (Ar^+ and ORC lasers), be easily accessible for alignment purposes.

Please do not deviate from this layout without first consulting with us, as the designs of the various subsystems depend on how they need to be aligned with respect to each other.

Power Supply Location

Argon-Ion Laser

The power supply for the argon-ion laser will fit under most tables, and should be positioned so that the power supply electrical line inside the umbilical cord can reach the rear connections on the power supply.

ORC–1000 Laser

The power supply of the ORC–1000 laser may not fit under the optical table. If this is the case, place it at the end of the table near the argon-ion laser.

Baseplates

The baseplate of each module is rectangular with a 1″-square unit-cell grid of $\frac{1}{4} - 20 \times \frac{1}{2}''$ tapped screw holes.

The CPA–1000 system is designed so that each module (excluding pump lasers) has an edge to be mounted parallel and flush with an edge of the optical table.

The NJA–5 is mounted with two of its edges flush with table edges (in a corner), and serves as the starting point for installing the CPA–1000.

Baseplate Clamps — “random” disc clamps

For optical tables having tapped mounting holes based on a 1″ or 25 mm (or less) square grid spacing, it should be possible to locate at least one mounting hole on the optical table by rotating the disc.

If the hole spacing is larger than this, it is important to check desired positions for accessible tabletop holes.

Fig. 3-1

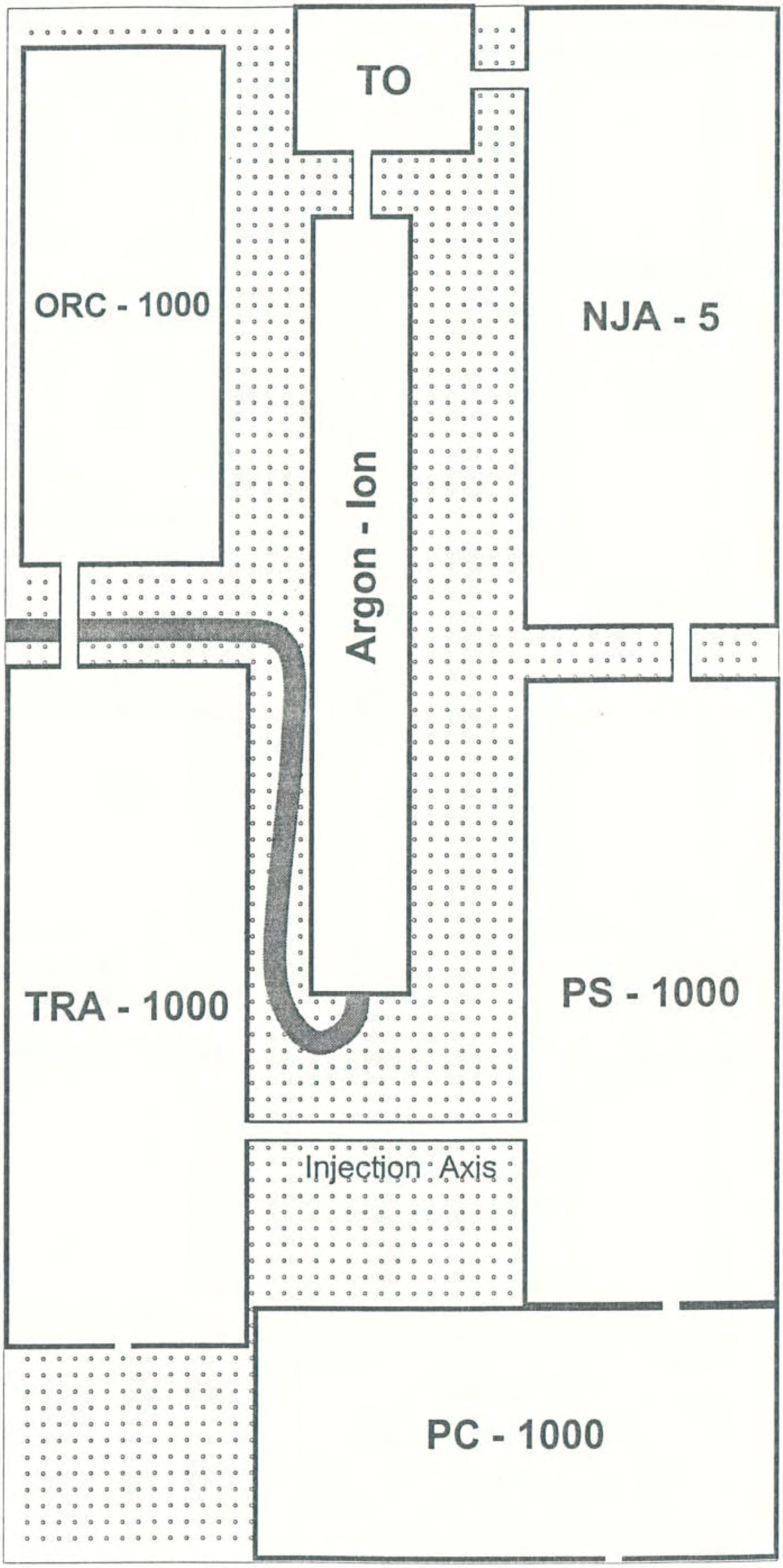
General Layout of CPA-1000

Argon-ion Laser	
Transport Optics	(TO)
Oscillator	(NJA)
Pulse Stretcher	(PS)
Regenerative Amplifier	(TRA)
Amplifier Pump Laser	(ORC)
Pulse Compressor	(PC)

Beamtubes connect the output and input ports of the various CPA components.

Since the size and position of the argon-ion laser varies with installation, the schematic is not intended to be completely accurate.

Note: The scale is about 10% of the actual table layout.
of
The scale is about 10:1 for a layout on a 4 ft. x 8 ft table



Each subsystem baseplate has four (4) random disc clamps, all of which should be used. To avoid slight shifts in the baseplate position during clamping, gradually tighten each screw in turn until, after a few repetitions, the enclosure is securely attached to the optical table.

During the installation sequence, position and clamp down a subsystem enclosure only after the previous subsystem has been properly aligned and clamped.

Beam Input/Output Coupling between Modules

Inside the input port of each module there are two mirrors dedicated to matching the input beam to the input axis of the optical subsystem. These turning mirrors form a so-called "dog leg" by producing a short, moderate fold in the optical path.

Mirror 1:	Accepts input optical beam (height and angles). Relays beam to center of Mirror 2 at the desired height.
Mirror 2:	Accepts beam from Mirror 1 at correct height. Directs beam into the proper path (orientation angles).

The *dog leg* arrangement provides a convenient means of adjusting the beam between modules. Each CPA–1000 subsystem enclosure has one just inside its input port.

Beam Propagation between Modules

Optical beams traveling between pump lasers and CPA–1000 modules, and between modules require special attention during system installation and optimization.

Safety

The intensity of the argon-ion laser beam and the ORC Nd:YAG laser beam can clearly cause eye damage. These visible beams from the pump lasers are easily recognized as potentially dangerous, but it is easy to pass an object, piece of clothing, or hand through the beam without thinking. This may lead to burns or dangerous stray reflections. (See Chapter 1 for a discussion.)

The best way to avoid these situations is to install a physical barrier between the user and the beam. The beamtubes supplied by Clark–MXR are designed for this purpose. The tubes install easily and make the user aware of the beampath, while physically inhibiting access to the beam.

Stability

Air turbulence can affect the beam direction and quality. It is recommended that beamtubes be installed for path lengths over 2″ or 5 cm. Beamtubes are thus provided for all exposed paths except for the small path between the PS–1000 pulse stretcher and the PC–1000 pulse compressor.

The argon-ion beam is very sensitive to air currents, which degrade its beam pointing stability. It is critically important that beamtubes cover the entire argon-ion laser beampath outside of the enclosures at all times.

Note: The NJA–5's long-term stability specification cannot be met if the beamtubes are not fully in place.

Note: The entrance port of the NJA–5 enclosure is located on the cover. Remember to carefully detach the beamtube from the NJA cover before opening the NJA enclosure.

3.2.2 General Alignment Principles

The optical design of the CPA–1000 and PC-1000, system is such that the beam travels in a fixed horizontal plane (parallel to the tabletop). The exception to this occurs in the PS–1000 and is designed to effect a double-pass path in the grating section (see Chapter 5).

The height of the standard plane above the baseplate is chosen to be 3.75″ (9.5 cm). Since the baseplate is 1/2″ high, the height above the optical table is 4.25″ (10.8 cm).

In order to standardize the alignment for each CPA–1000 system, an *alignment tool* is included. This tool was used by Clark–MXR technical staff to align and test your system before it was shipped. The alignment tool consists of two holes of different diameters at each of three different heights, as shown in Fig. 3–2.

top row:	standard beam height above optical table	(4.25″)
middle row:	standard beam height above baseplate	(3.75″)
bottom row:	auxiliary beam height	(3.5″)

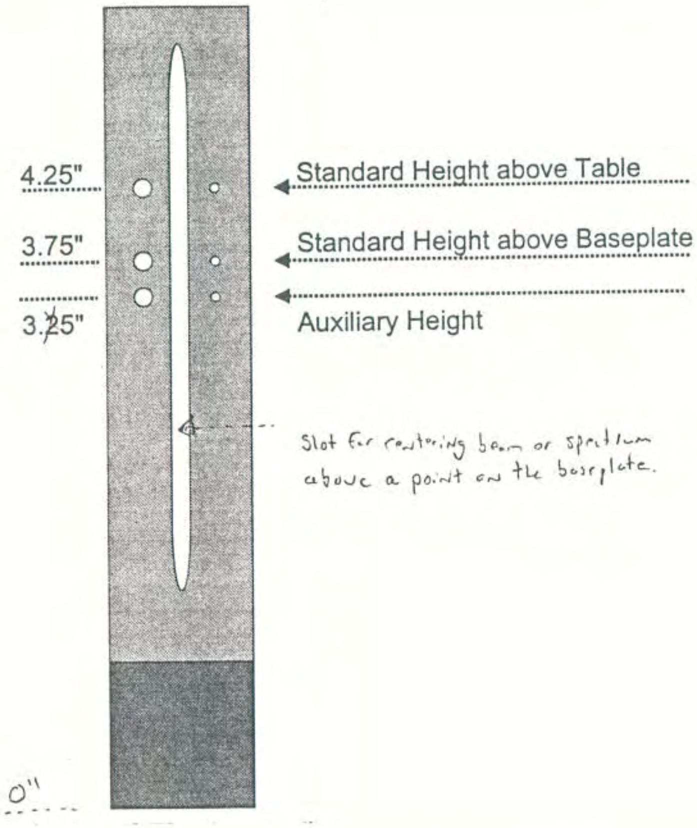
When aligning the beam inside an enclosure, you need to use the **middle** row of holes to keep the beam in the correct plane.

Note: Whenever you are performing critical alignments, it is easy to forget where the path of the beam and its various reflections are relative to your eye. Remember to be careful and not look anywhere near the plane of the beam (roughly 10 cm above the surface).

Argon-Ion Pump Laser

The height of the argon-ion beam varies from model to model, but the vertically-oriented polarization of the beam is standard.

Since the NJA–5 oscillator requires a horizontally polarized beam delivered parallel to the short axis of the table, passing through the center of its aperture, and at the standard beam height, the argon-ion beam must be corrected for height, direction, and polarization.



Slot for centering beam or spectrum above a point on the baseplate.

Fig. 3-2

Alignment Tool

Simple tool for setting and checking the laser beam height inside CPA-1000 enclosures and above the optical table.

Horizontal positioning is performed using the narrow vertical slot

In order to obtain optimum polarization rotation, we recommend pre-adjusting the argon-ion laser feet so that the output beam travels parallel to the tabletop and parallel to the long axis of the table.

3.2.3 NJA–5 Initial Positioning

The position of the NJA–5 relative to the argon-ion laser and transport optics on a 4′ × 8′ optical table is shown in Fig. 3–3. The NJA–5 is positioned flush at the corner of the table, with its main axis parallel to the table's main axis.

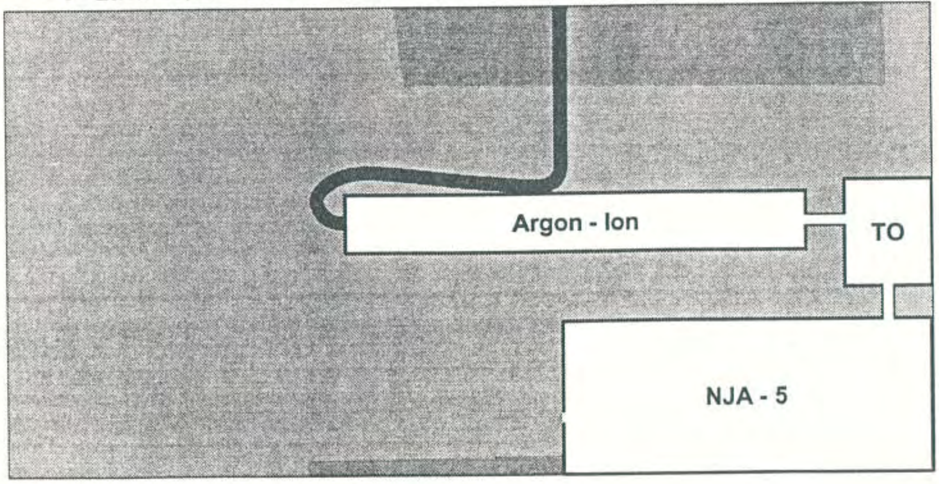


Fig. 3-3

Layout of NJA-5, Argon-ion and Relay Optics

CPA installation starts with positioning the NJA-5 in the corner, flush with the optical table's edges.

The NJA–5 input port position determines the distance from the short edge of the table to the argon-ion pump beam.

3.2.4 Transport Optics

In order to relay the argon-ion laser output beam to the input of the NJA–5, a set of *transport optics* is required to change the beam height and direction, and rotate the vertically polarized output to horizontally polarized input. This is accomplished by simple transport optics consisting of a two-mirror periscope assembly.

Figure 3–3 shows the position of the transport optics TO–1.
The beam propagating from the polarization rotating periscope to the NJA–5 oscillator must be perpendicular to the NJA–5 long axis, and should enter through the small aperture located on the back side of the NJA–5 enclosure cover.

The distance from the periscope enclosure to the NJA–5 enclosure varies slightly with the argon-ion laser model, but is typically 8″ (20 cm).

3.2.5 Argon-Ion Laser Initial Positioning

The argon-ion laser is placed parallel to the table's main axis, with the output facing towards the closest table edge, as illustrated in Fig. 3–3.

The water cooling hoses and power umbilical cord should lie closely along the side of the argon-ion laser as shown in the figure. The turning radius at the end of the argon-ion enclosure should be "tight."

1. Adjust the argon-ion laser output so that the beam travels parallel to the tabletop and is perpendicular to the short axis of the table.
2. Lock the laser using foot clamps supplied by the manufacturer.

3.2.6 PS–1000 Initial Positioning

Before placing the PS–1000 on the optical table as in Fig. 3–4, we need to determine the correct orientation for the enclosure.

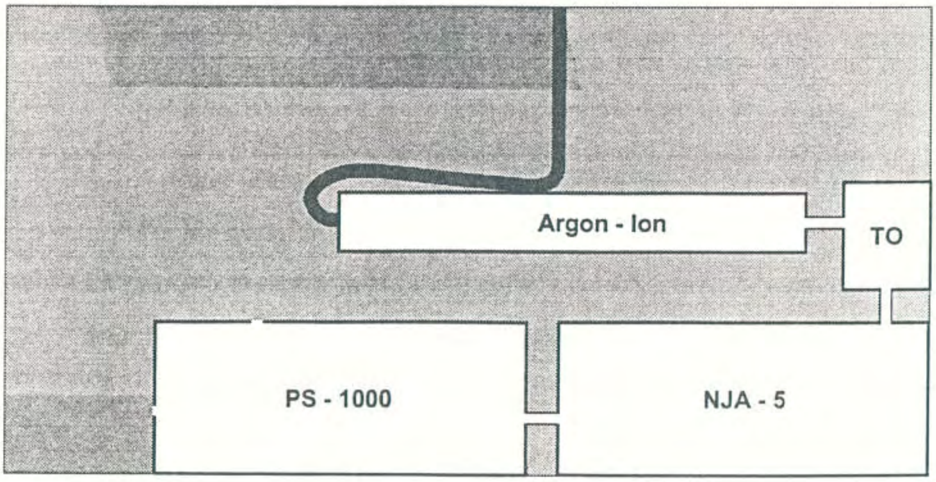


Fig. 3-4

Pulse Stretcher Position

After the oscillator is fixed to the optical table and operating properly, the PS-1000 is placed in position approx. 3 inches away from the NJA-5.

Place the PS–1000 on the table so that:

1. Long axis of PS–1000 parallel to long axis of table with
   a) output port (on long side) facing table center,
   b) input port (on short side) in line with NJA–5 output port.
2. Long edge of baseplate mounted flush with edge of table.
3. Distance from table's short edge to baseplate is approx. 39.5″.

?)
41.5"? (hole 41)

Note: The PS–1000 is placed to the left of the NJA–5 with the two stages separated by ~ 3 inches (~ 8 cm).

Note: The position of the output port on the PS–1000's rear panel (injection axis) dictates the position of the input (injection) port of the TRA–1000. Placing the TRA–1000's baseplate shifted ~ 1 inch in the ORC–1000 direction relative to the PS–1000's baseplate gives a good initial position.

3.2.7 TRA–1000 Initial Positioning

Before placing the TRA–1000 on the optical table as in Fig. 3–5, we need to determine the correct orientation for the enclosure.

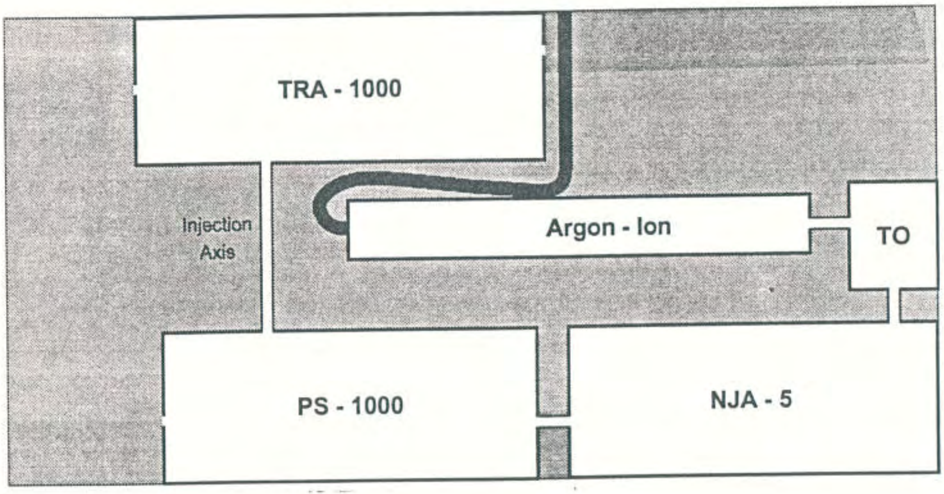


Fig. 3-5

Regenerative Amplifier Position

The TRA-1000 is positioned flush with the opposite edge of the table as the PS-1000, with the injection axis ports aligned.

Place the TRA–1000 on the table so that:

1. Long axis of TRA–1000 parallel to long axis of table with
   a) output port (on long side) facing table center,
   b) input port (on short side) facing ORC–1000 laser.
2. Long edge of baseplate mounted flush with edge of table.
3. Distance from table's short edge to baseplate is approx. 40.5″.

Note: The TRA–1000 is placed to the right of the ORC–1000 with the two separated by a gap of ~ 6 inches, so that the nitrogen flow valve can be easily accessed. and the argon-ion laser's umbilical cord can pass through.

Note: The position of the YAG beam input port on the TRA–1000's left side panel dictates the position of the ORC YAG laser.

Reposition the ORC–1000 if these two ports are not aligned.

3.2.7.1 TRA–1000 Remote Control

The operating controls for the ORC laser shutter and the TRA injection shutter are located on the *TRA–1000 Remote* box.
Turning the ON/OFF keyswitch clockwise enables control via the cable connected to the 7-pin DIN connector on the rear panel of the TRA–1000.

1. Connect the BNC terminal labeled YAG SHUTTER REMOTE on the TRA–1000 end panel (near the flow valve) to the REMOTE SHUTTER PORT on the back panel of the ORC power supply.

The YAG shutter is operated via this BNC cable.

Two push buttons control the shutter:
YAG SHUTTER OPEN and YAG SHUTTER CLOSED.

The state of the YAG shutter is indicated by which button is lit.

The TRA injection shutter can be manually controlled with the INJECTION SHUTTER knob.

3.2.8 ORC–1000 Initial Positioning

The position of the ORC–1000 laser is shown in Fig. 3–6.

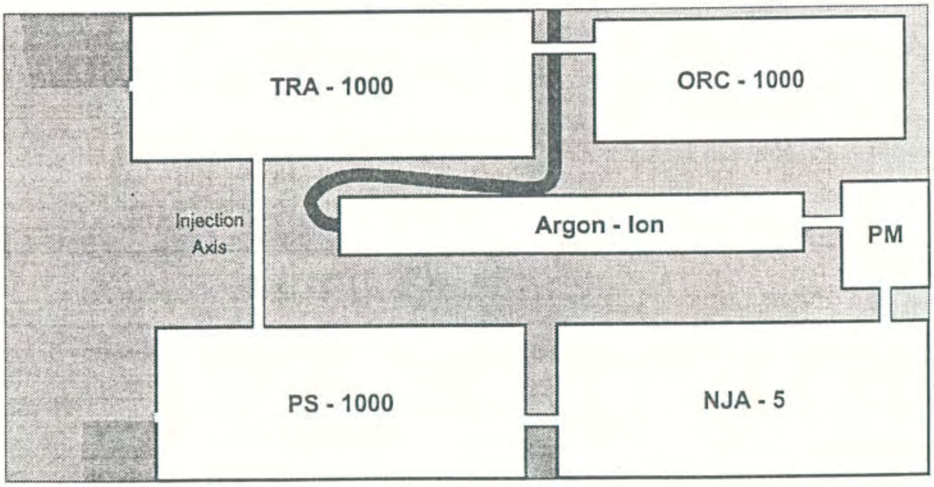


Fig. 3-6

ORC-1000 Position

The ORC pump laser is placed on the optical table in the corner opposite the NJA-5.

The output axis of the ORC and pump beam input axis of the TRA must be aligned.

A useful separation between the ORC and TRA is about 6".

The ORC–1000 is placed parallel to the table's main axis, with the output facing towards the most distant table edge. The water-cooling hoses and power umbilical cord should hang over the edge of the table.

1. Temporarily lock the ORC–1000 using the foot clamps provided with the unit.

Power Supply Position

If the power supply fits in under the optical table, place it under the table so that the front panel (control panel) faces away from the argon-ion laser.

If the power supply does not fit under the optical table, place it along the long axis of the table by the corner closest to the ORC–1000. The power supply front panel (control panel) should face away from that corner.

3.2.9 PC–1000 Initial Positioning

Before placing the PC–1000 on the optical table as in Fig. 3–7, we need to determine the correct orientation for the enclosure.

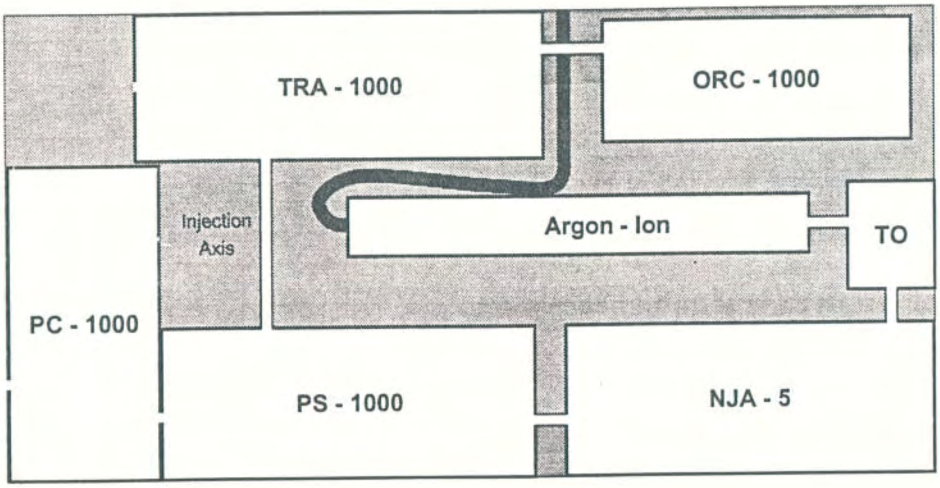


Fig. 3-7

Pulse Compressor Position

The PC-1000 is placed just after the output port of the PS-1000. The output port on the enclosure faces the short edge of the optical table.

Note:
No beam tube is used between the PC-1000 and PS-1000.

Place the PC–1000 on the table so that:

1. Short axis of PC–1000 parallel to long axis of table with
   a) output port (on long side) facing table's short edge,
   b) input port (on long side) in line with PS–1000 output port.
2. Short edge of baseplate mounted flush with edge of table.

Note: The PC–1000 is placed to the left of the PS–1000 with the two units separated by only 1 mm or 2 mm.

3.2.10 Water Cooling Connections

For general water service requirements, see the subsections on *water connections* in Sec. 2.2: Utility Requirements.

The argon-ion laser, the ORC–1000 Nd:YAG laser, the NJA–5 oscillator laser, and the TRA–1000 regenerative amplifier must be water cooled.

The argon-ion laser's power supply module should be connected directly to the main water line. Water flows into this module and is directed to the laser head via the supply hose in the umbilical cord.

user's manual

Fig. 3-8

Water Connections for the CPA-1000 System

There are three flow paths:
1) argon-ion laser,
2) ORC-1000 laser,
3) laser rod cooling.

Note:

Since the flow rate required by the argon-ion laser is much larger than the rod/Pockels cell cooling loop, the small flow to the NJA-5 may be "T-ed" off the argon loop without any noticeable loss in performance.

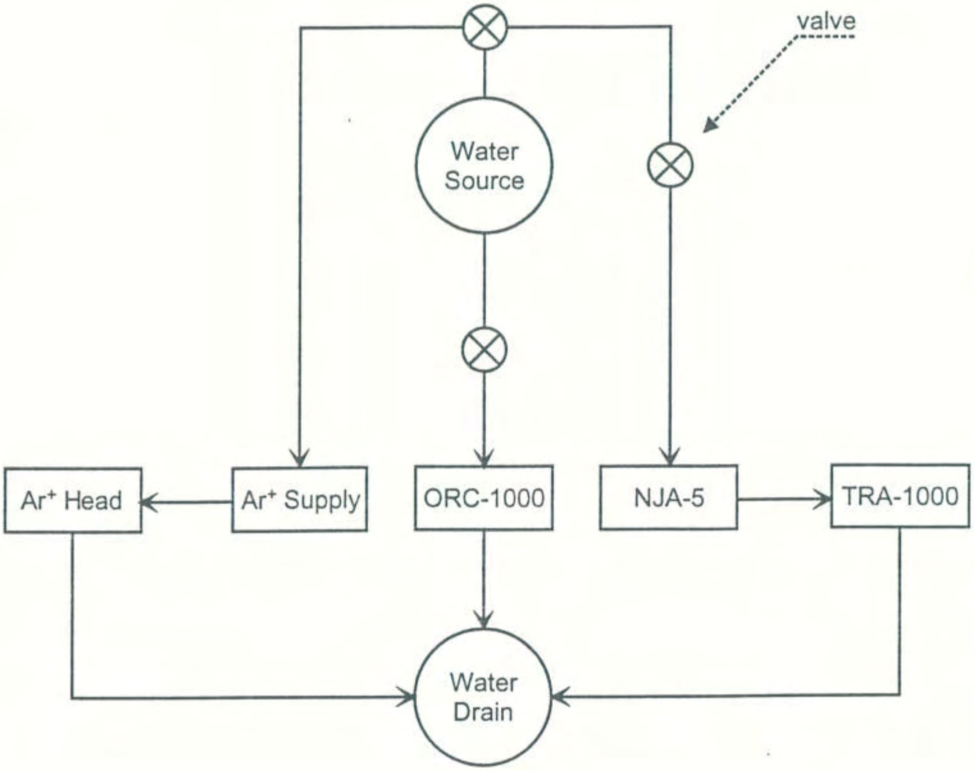
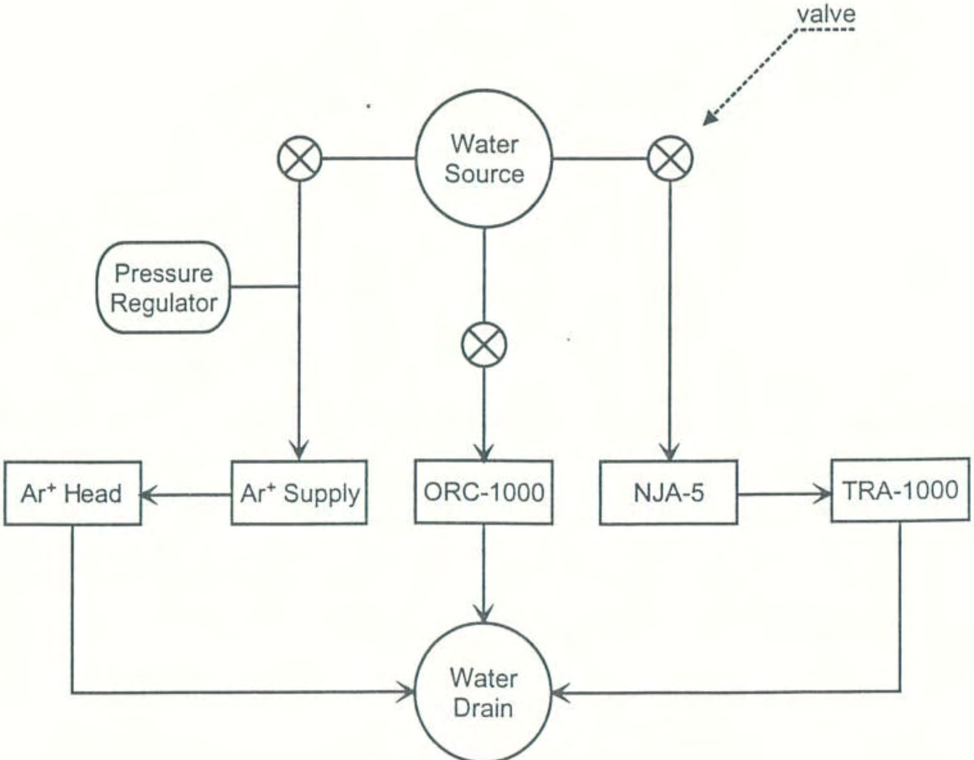


Fig. 3-9

Alternate Water Connection Scheme

All three water loops have a direct connection to the source in this scheme.

A water pressure regulator tank is also included to improve the stability of the argon-ion laser.



The return path (in a parallel flow tube) retraces the route from the laser head to the power supply, but then flows directly into the drain or the closed-loop reservoir.

The ORC–1000 power supply/cooling station should be connected directly to the main water line. A valve regulating the water flow is mounted inside the ORC's power supply. The amount of flow is controlled by a thermostat which senses the temperature of the closed-circuit, primary water cooling loop.

Note:
Water does not flow when the ORC's power supply is not in operation.

The NJA–5 oscillator and the TRA–1000 amplifier need a very limited flow of water. This flow can "tee" off the water line going to the argon-ion laser (NOT the ORC–1000), or can come directly from the main water supply line. These two cases are illustrated in Figs. 3–4 and 3–5. Direct connection of the NJA–5/TRA–1000 loop to the main line, shown in Fig. 3–5, is preferred.

Water Pressure Fluctuations

If your water supply is subject to pressure changes, we recommend installing a pressure regulating tank upstream from the argon-ion laser, as illustrated in Fig. 3–5.

Note: Water pressure fluctuations can drastically affect the stability of the argon-ion laser and the NJA oscillator.

3.3 System Alignment Sequence

We recommend that you start with the alignment of the NJA–5 oscillator and spend some time becoming familiar with its operation and characteristics. A properly running, stably mode-locked oscillator is essential for accurate system alignment and, of course, high quality output from the CPA–1000.

Alignment Sequence

We suggest aligning the subsystems of the CPA–1000 system in the following order:

1) NJA–5	Femtosecond Oscillator,
2) PS–1000	Pulse Stretcher,
3) TRA–1000	Regenerative Amplifier,
4) ORC–1000	Nd:YAG Pump Laser,
5) PC–1000	Pulse Compressor.

4. NJA–5 Installation and Alignment

4.1 Positioning

The NJA–5 Ti:Sapphire oscillator was fully tested before shipping.

Read the NJA–5 oscillator manual thoroughly, then install the oscillator before proceeding with the other modules of the CPA–1000.

Attention !

Special attention must be paid to the safety warnings posted at various steps of the alignment.

Install the argon-ion laser and the NJA–5 oscillator on the optical table as indicated in the Sec. 3.1: System Layout, on page 3–1.

Fasten both the argon-ion laser and the NJA–5 securely to the optical table using the brackets supplied with the argon-ion laser and the round, slotted "random" clamps supplied with the NJA–5.

4.2 Electrical and Water Connections

At this stage of the installation the required electrical and water service should be properly installed and functioning for the argon-ion lasers.

The user must be thoroughly familiar with the operation of the argon-ion laser using the manufacturer's manual(s) supplied with the laser.

Follow the instructions in Sec. 3.2.10 for connecting the cooling water to the NJA–5 oscillator.

4.3 Transport Optics

To perform the instructions provided in this section, you need the following parts:

- one periscope assembly (model TO–1),
- two beamtubes,
- one alignment tool.

Periscope

The functions of the periscope assembly are to:

1. deliver pump power to the Ti:Sapphire rod inside the NJA–5,
2. rotate the plane of polarization of the argon-ion laser from vertical to horizontal,
3. change the beam height to the standard 4.75″ (10.8 cm) above the tabletop, that is maintained as much as possible throughout the system.

Note: To reduce angular fluctuations in the argon-ion output beam (pointing stability), the periscope can be fitted with an optional active mirror. (*PointMaster* option TO–4)

1. Place the periscope assembly on the table as shown in Fig. ~~4–1~~ 3-3.

   transport optics (TO)

2. With the argon-ion laser running at very low power, adjust the height of the upper periscope mirror holder so that the argon beam strikes approximately on the center of the upper mirror.

Note:
~~If your system is equipped with a Clark-MXR PointMaster, the dimensions of the~~

The dimensions of the transport optics shown in Fig 3-2 and Fig 3-3 match the Clark MXR PointMaster

For a simple periscope assembly, the position correct lies at the intersection of the argon-ion pump beam and NJA-5 input axis

3. Adjust the lower mirror mount so that the exiting beam is at a constant height of 4.25″ (10.8 cm) above the table.
4. Use the alignment tool (see Fig. 3–2) to make sure that the beam is at the correct height.
5. Direct the beam into the NJA–5 oscillator entrance aperture, and adjust the position and angle of the periscope stage until the argon-ion beam passes through the two factory-set irises, which define the pump beam axis.

   Note: At this time the position of the argon-ion laser and the periscope will look similar to that shown in Fig. 4–2.

6. Install the periscope cover.
7. Install a beamtube between the argon-ion laser and the periscope cover, and a beamtube between the periscope cover and the NJA–5.

   Note: Beamtubes are necessary for eye safety and for the system to meet its performance specifications.

   Note: Any air turbulence will significantly affect the pointing stability of the argon-ion beam. It is critically important that the two beamtubes designed to cover the argon-ion beampath be installed at all times.

   The NJA–5's long-term stability specification cannot be met if the beamtubes are NOT fully in place.

At this point in the installation you have completed setup and alignment of the argon-ion laser and the transport optics. The argon-ion beam is now positioned to pump the laser rod in the NJA–5.

From here on you will perform the alignment of the NJA–5 femtosecond oscillator. Refer to the discussion and instructions in the NJA–5 manual.

After completing the oscillator alignment, return to Chapter 5 of this manual to start the PS–1000 pulse stretcher alignment.

5. PS–1000 Pulse Stretcher & Isolator Stage

(Femtosecond version)

Safety

Warning !

In this chapter, you will be aligning the PS–1000 using the Ti:Sapphire oscillator output beam.

The IR wavelengths emitted by the Ti:Sapphire oscillator are almost beyond the range of human vision. What appears as a low intensity beam is, in fact, a very high intensity beam!

5.1 Positioning

The functions of the PS–1000 pulse stretcher and isolator module are to:

- stretch the optical pulses,
- provide isolation between the oscillator and the rest of the CPA–1000,
- act as a "switch yard" for the entire CPA–1000 system. The inputs and/or outputs of every subsystem forming the CPA–1000 ensemble are routed through the PS–1000 module.

Note: The PS–1000 pulse stretcher/isolator is supplied with most hardware pre-mounted (but not fully aligned).

Note: You need the alignment tool provided with each system, in order to perform the instructions in this section.

The PS–1000 module is located directly after the NJA–5, as shown in Fig. 3–4. A layout of the PS–1000 and nomenclature for the components are given in Fig. 5–1.

5.2 Alignment through the Isolator

Delete

Caution !

Be very careful when handling the diffraction grating.

Wear protective gloves to avoid contaminating the grating with skin oil and other debris.

The grating may become worthless if you touch it directly!

The alignment of the PS–1000 is performed using the output of the NJA–5. The oscillator should be mode-locked and stable.

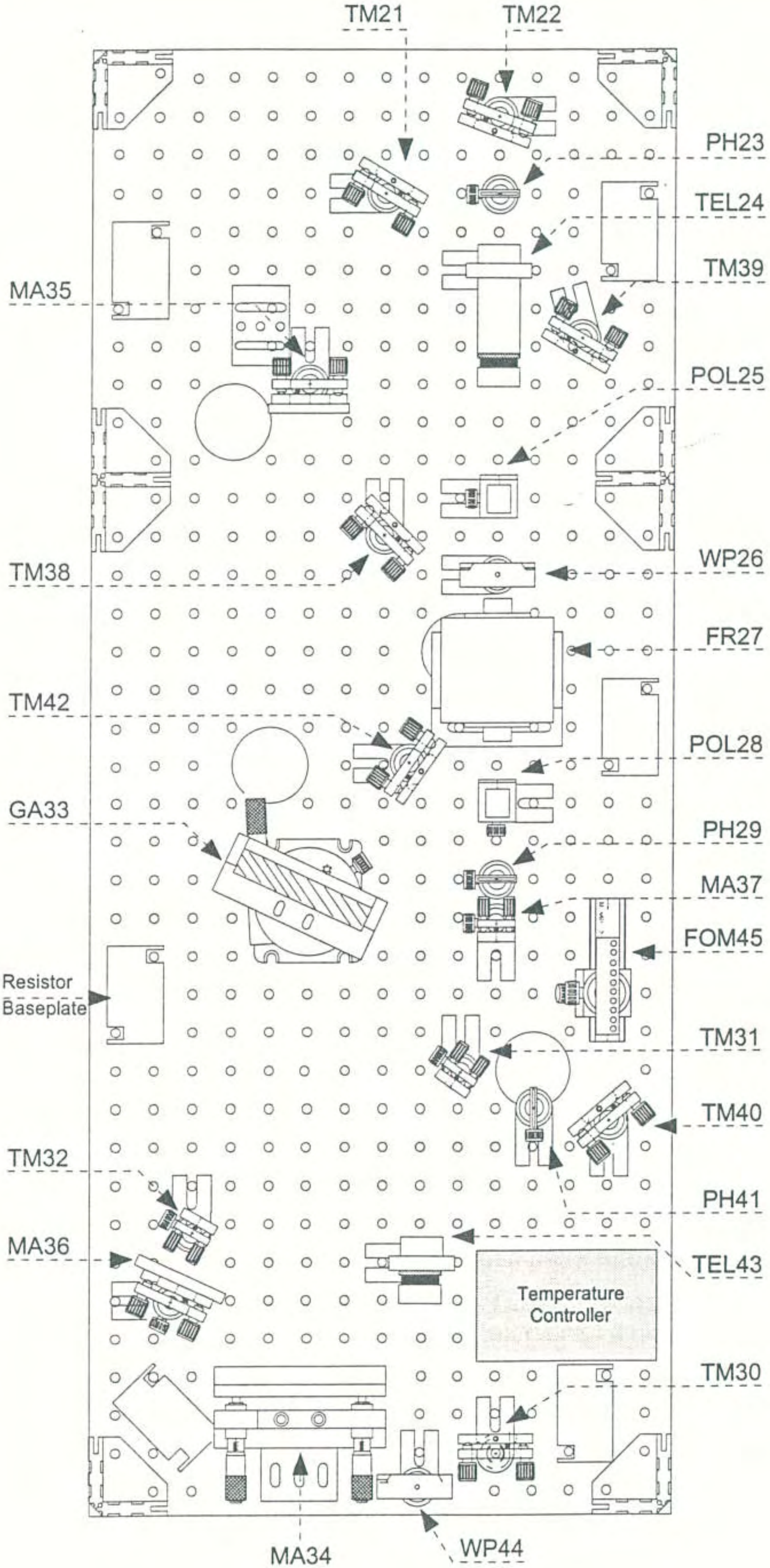


Fig. 5-1

PS-1000 Schematic Layout and Component Nomenclature

The schematic is an approximate layout of the PS-1000. Actual installations may vary slightly.

Input Port
Top of diagram near TM21

Isolator Axis
5th column of holes from right
(PH23 to PH29)

Stretcher Axis
10th column from right
(MA34 to MA35)

Injection Axis
~ 10.5 row from bottom
(TM40 through PH41)

Output Axis
7th column from right
(TM42 to WP44)

PS–1000 Positioning on Optical Table (as in Sec. 3.2.6)

1. Place the PS–1000 stage on the optical table so that the NJA–5 beam is centered on the input aperture of the enclosure, as indicated in Fig. 3–4.
2. Leave approximately 3″ (7.6 cm) between the NJA–5 and the PS–1000 (see Fig. 3–1).
3. Insert a beamtube between the NJA–5 and the PS–1000.
   Note: Installing beamtubes is necessary for eye safety and for the system to meet its performance specifications.
4. Secure the baseplate to the optical table using the clamps provided.
   Note: It should be possible to locate at least one mounting hole on the optical table by rotating each *random clamp* plate.

Mirrors TM21 and TM22 form a "dog leg" whose function is to couple the optical output beam from the NJA–5 to the input axis of the PS–1000. (See Sec. 3.2.1 for a description.)

Attention !

Apertures PH23, PH29, and PH41 have been factory adjusted. Do NOT move them under any conditions.

Polarizers POL25 and POL28 have been factory adjusted. Do NOT move them.

The beam first propagates through the isolation section of the PS–1000.

5. Using mirror TM21, accurately position the NJA–5 beam at the center of PH23.
6. Follow by positioning the beam at the center of PH29 using mirror TM22. (Do NOT use mirror TM21 for this step.)
7. Repeat the previous two steps until the beam passes precisely through the center of both apertures simultaneously.
8. Once this is done, fully open the apertures PH23 and PH29.

The beam should now propagate through the centers of POL25, WP26, FR27, and POL28 before reaching the center of PH29.

The entire isolation stage beampath is shown in Fig. 5-2

5.3 Alignment through the Stretcher

After PH29, the beam propagates through the stretcher section of the PS–1000 (see Fig. 5–3).

1. Using TM30, adjust the incoming beam so that it is redirected to TM31.
2. The beam height should be lowered from the standard height of 3.75″ (as found at the TM30 location) to a height of 3.5″ (at the TM31 location).

Note: Using the alignment tool and measuring inside the PS–1000 enclosure, the beam incident on TM30 should pass through the middle row of holes.
(See *Standard Height above Baseplate* in Fig. 3–2.)

The beam is directed downward by tilting TM30 so that the beam strikes TM31 at the reduced height.

The beam should leave TM31 at that same height, passing through the bottom row of holes on the alignment tool.
(See *Auxiliary Height* in Fig. 3–2.)

3. Using TM31, adjust the incoming beam so that it is redirected to MA32 and propagates at the 3.5″ height. The beam should strike MA32 just below the top edge of the mirror.
4. Using MA32, adjust the beam so that it is directed to the center of the grating holder GA33.
5. Check that the beam propagates at a constant height of 3.5″.

Caution !

Be very careful when handling the diffraction grating.

Wear protective gloves to avoid contaminating the grating with skin oil and other debris.

The grating may become worthless if you touch it directly!

6. Center the grating in the grating holder.
Tighten the set screws to secure the grating into position.

At this point, it is necessary to have the oscillator operating in the mode-locked regime. Although it is possible to align the stretcher without the oscillator mode-locked, the center wavelength is likely to slightly shift between cw oscillation and mode-locked oscillation. This wavelength shift would require minor readjustment of the stretcher.

Note: An IR viewer may be required to proceed with the alignment.

Fig. 5-2

PS-1000 Isolation Stage

The oscillator input beam is matched to the isolator axis by a two-mirror periscope combination.

The first pass through the isolator section collimates the beam before passing it on to the stretcher stage.

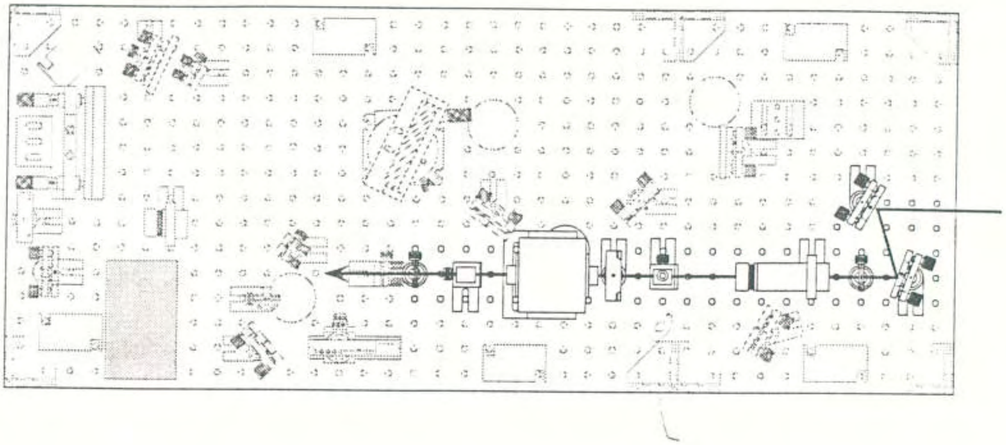


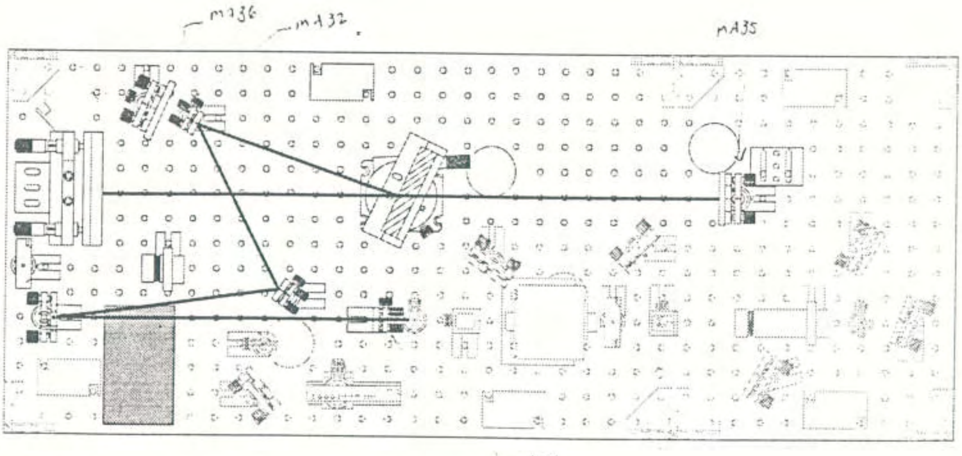
Fig. 5-3

PS-1000 Stretcher Stage

The beam enters the stretcher section as it passes over mirror MA37.

After reflection off the large mirror, the beam passes above the grating and on to mirror MA35.

Mirror MA35 reflects the beam back into the stretcher stage, eventually passing above MA32 to meet MA36.



Note: If your grating looks like the figure, Good Luck!

Grating Surface Positioning

The next step is to place the grating surface on the rotation axis.

7. Rotate the grating and make sure that the incoming beam hits a fixed point on the grating. If this is not so, loosen the two screws in the floorplate of the grating holder and slide the grating holder forward or backward until you meet the above requirement.

Grating Groove Orientation

The next step is to set the grating grooves perpendicular to the table.

8. Place the alignment tool in the beampath between the center of mirror MA34 and the grating assembly GA33.
9. Rotate the grating holder to the normal position.
   [The grating acts as a mirror (zero-order reflection).]
10. Center the reflection off the grating onto the alignment tool using the tilt adjustment screw on the grating stage.
    Note: The grating surface tilt is controlled by the rear knob on the grating mount's tilt table.
11. Rotate the grating to the first-order diffraction position (that is, the first-order is reflected back to the alignment tool), and use the grating groove angle adjusting screw on the grating stage to center the spectrum onto the alignment tool.
    Note: Grating groove rotation is controlled by the front knob on the grating mount's tilt table.
12. Move back and forth between normal and first-order reflections until there is no vertical offset observed.

Note: Do NOT change the vertical adjustment screw setting after this initial alignment.

13. Leave the grating mount GA33 in the first-order position.
14. Make sure that the beam is maintained at a 3.5″ height.

Caution !

Wear protective gloves to avoid contaminating the surface of the large (6″), *D*-shaped mirror.

15. Install the 6″ mirror into its holder MA34.
    Note: This optic may have been factory installed.
16. Check that the mirror is locked in position.
17. Adjust GA33 to center the spectrum onto MA34.
    Note: Using an IR viewer greatly simplifies this task. The IR viewer compensates for the eye's lack of responsivity at longer IR wavelengths.

Note: A poor horizontal alignment will lengthen the final pulse width *obtained from the compressor module.*

18. Adjust the mirror mount MA34 to redirect the diffracted beam towards MA35. The beam should slowly increase in height (above the baseplate), pass slightly above GA33, and strike MA35 one-third up from the bottom of the mirror.

    Note: The beam is not parallel to the tabletop at this stage.
    The beam will return to MA34, but is not retroreflected.

The inbound path through the stretcher (first pass) is completed by adjusting the vertical angle of MA35 so that the beam returns to MA34 (on a different path than that of the incoming beam), reflecting off the grating GA33, and traveling in the direction of MA32.

The tilt of MA35 is chosen such that the beam (after two reflections) does not strike MA32, rather, it passes over MA32 and strikes MA36.

The beam path is then: MA35 → MA34 → GA33 → MA36.

19. Slightly adjust the vertical tilt of MA35 to send the beam above MA32 and onto MA36.

    Note: MA35 directs the beam towards MA32 but changes its height, so that it passes above MA32 and strikes MA36.

20. Adjust the mirror mount MA36 to redirect the beam onto the grating GA33 to a location with the same horizontal position but slightly higher than the previous reflection's position.

21. Slightly adjust the vertical tilt of MA36 to send the beam slightly lower in order to hit the top section of mirror mount MA37.

The beam now has accomplished a full pass through the stretcher, the beam striking the grating four (4) times.

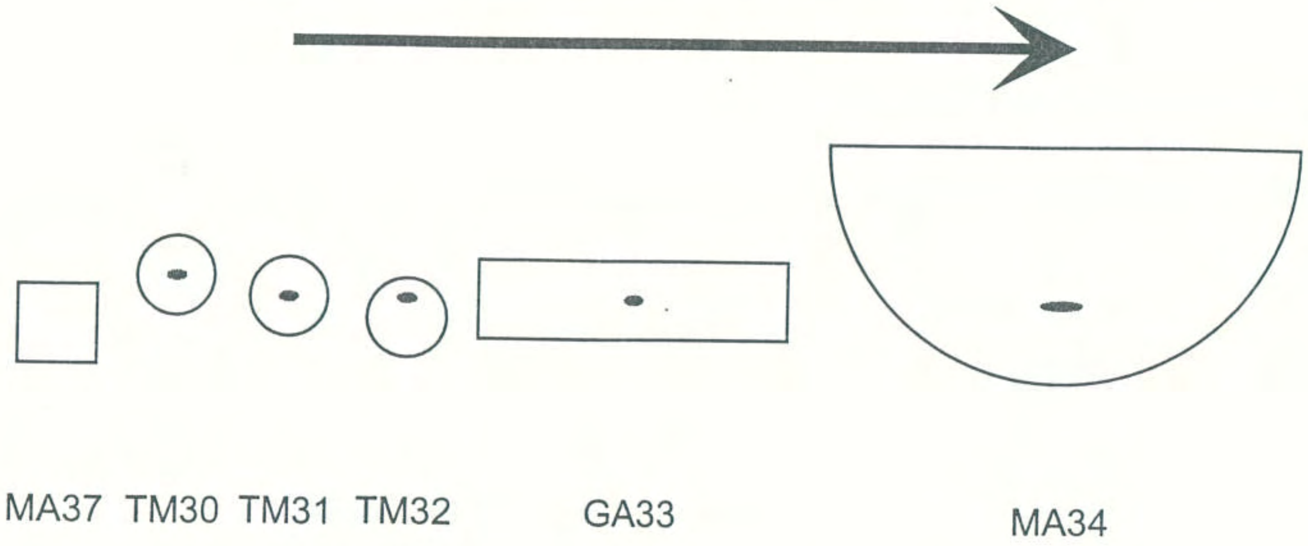
Up to this point, we have traced the oscillator beampath from the exit (PH29) of the isolation stage (passing above mirror TM37) until completing one full pass through the stretcher stage when it returns to hit near the top of TM37.

One pass through the stretcher consists of:

a) *stretcher inbound path*
TM30 → TM31 → TM32 → GA33 → MA34 →
MA35 → MA34 → GA33 → MA36,

b) *stretcher return path*
MA36 → GA33 → MA34 → MA35 → MA34 →
GA33 → MA32 → TM31 → TM30 → MA37.

Stretcher Stage: First Pass Inbound



Stretcher Stage: First Pass Return

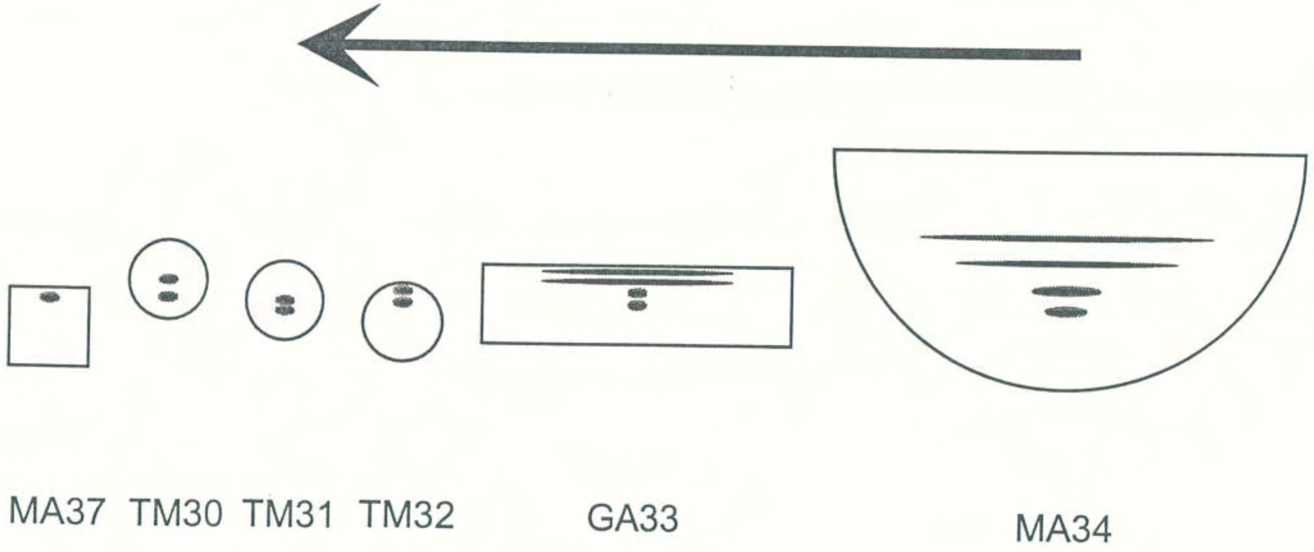
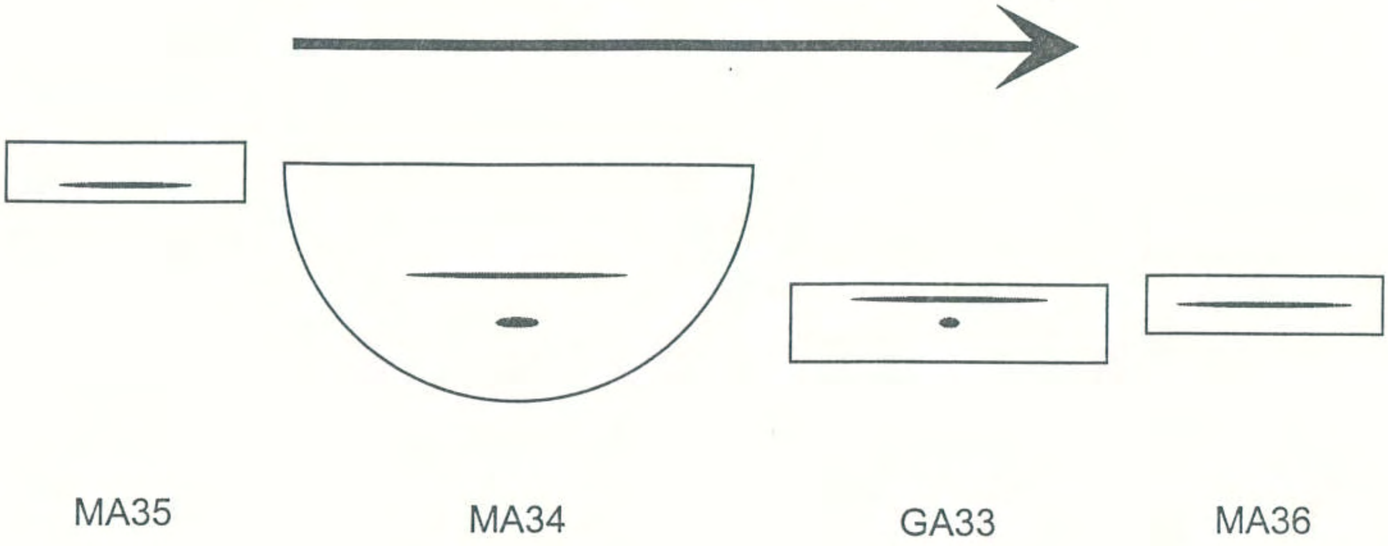


Fig. 5-4

PS-1000 Stretcher Stage Beamspots

The oscillator beam enters the stretcher section by passing over MA37 (upper figure) and returns to hit MA37 after one stretching pass (bottom figure).

Stretcher Stage: First Pass Inbound



Stretcher Stage: First Pass Return

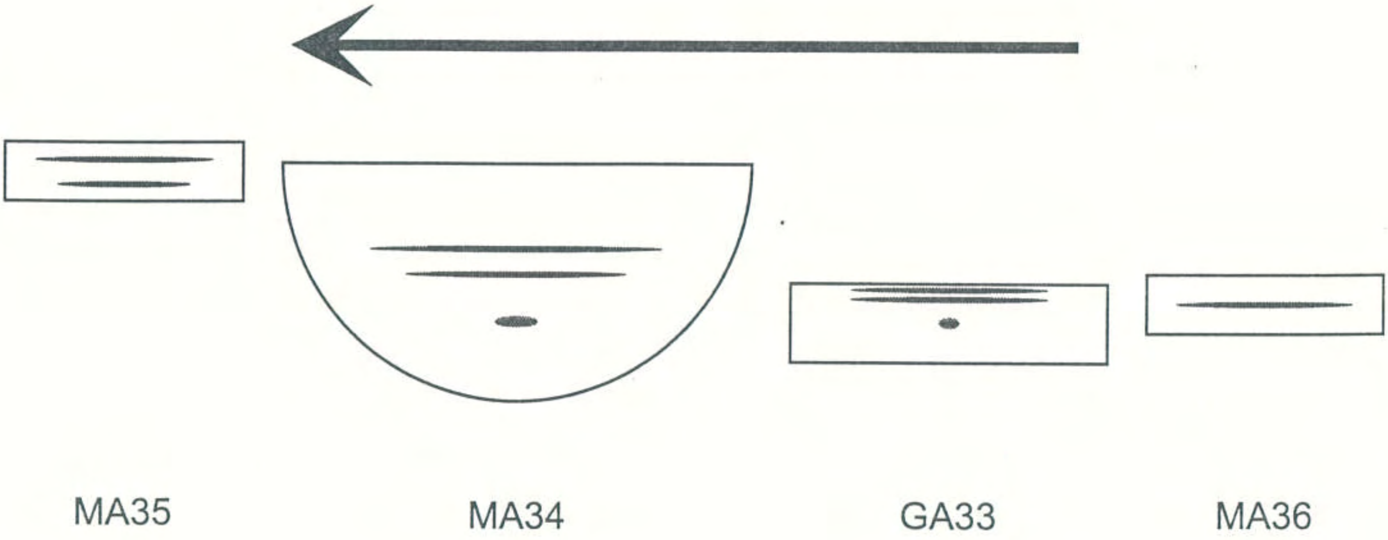


Fig. 5-4 (continued)

After reflecting from MA35 the beam proceeds to the farthest point (MA36) in the stretcher stage.

Note:
When third-order correction is applied in the stretcher, any spectra seen after reflecting from MA35 may not be horizontally centered.

It is instructive to keep track of where the beam meets the various optical surfaces in its path. During the initial alignment of the PS–1000, the beam spots on the reflecting surfaces of the optics in the stretcher stage should appear similar to those shown in Fig. 5–4 (on the previous two pages). This two-page schematic diagram has the following properties:

- ◊ beampath is from top left to top right, then from bottom right to bottom left,
- ◊ contains no information on distance traveled between components (*z*-axis), ⇒ horizontal direction only gives sequence of surfaces encountered.
- ◊ relative heights and optic crosssections are not exact but in close agreement to a scaled-down version of the actual values,
- ◊ after optimizing pulse compression, positions of the broadened spectra produced between the two reflections with MA35 typically show a different horizontal centering on the optics (see Sec. 7.3.2).

The pulse has been stretched from < 100 fs to approximately 75 ps. In order to safely extract the energy stored in the regenerative amplifier, the pulse needs to be stretched some more. This is accomplished by sending the beam one more time through the stretcher.

22. Adjust MA37 to reflect the beam back through the stretcher.

The beam will go again through the stretcher and exit passing just above MA37 and continue on towards the center of PH29.

23. Check that the beam appears on PH29, is not clipped by MA37, and is horizontally centered on PH29.
24. *Very slightly* adjust the vertical tilt of MA37 to place the beam slightly above center — roughly 1 mm higher than center.
    Note: This last step is necessary to avoid any feedback into the oscillator, without making the return beam hit high or clip on any optics in the isolation/switching stage.

The beam has now accomplished two full passes through the stretcher, the beam striking the grating eight (8) times.

25. Open the aperture PH29.

5.4 Exiting towards the TRA–1000

The retroreflected beam leaves the stretcher stage and proceeds to the isolation/switching stage, where it passes through polarizer POL28, Faraday rotator FR27, waveplate WP26, and reflects out of the input beampath onto mirror TM38. TM38 then directs the beam onto TM39. The beampath is shown in Fig. 5–5.

1. Check that the beam reaches TM39 at the standard beam height of 3.75″. Use the middle row of holes in the alignment tool.

TM39 redirects the beam towards TM40.

2. Check that the beam reaches TM40 at the standard beam height.

Waveplate WP26 Alignment

At this point you need to make sure that the waveplate WP26 is aligned correctly.

3. Place a power meter between TM39 and TM40.
4. Rotate WP26 slightly to maximize the power output.

Note: The waveplate was factory pre-aligned.
Its orientation may already be optimized.

From TM40 the beam propagates towards the regenerative amplifier. Two pinholes, PH41 (located in the PS–1000) and PH66 (located in the TRA–1000), define the injection axis. The stretched seed beam and the returned amplified beam travel along this axis.

Alignment of the seed beam to this axis is discussed in Sec. 6.8.1.

5. Before proceeding further, check that all mechanical components are fully secured, especially the post holders.

Warning !

The stretched beam may be exiting the PS–1000 and propagating in the direction of the TRA–1000.

Place a beam block to intercept this beam.

After amplification the beam will be sent back through the PS–1000. This amplified beam will be used to align TM42, TEL43, and WP44.

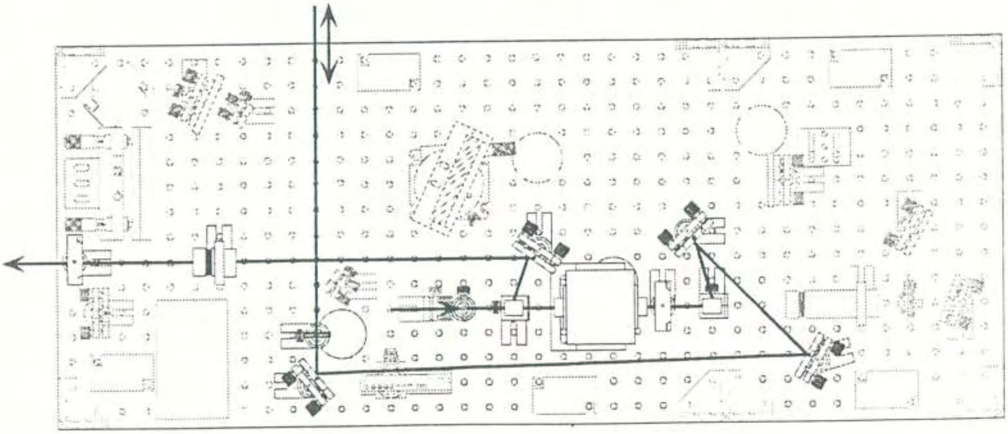
Alignment of the amplified return beam is treated in Sec. 6.8.2.

Fig. 5-5

PS-1000 Injection Stage

The beam returning from the stretcher section at PH29 is deflected by POL25 and routed out the injection axis.

The amplified beam from the TRA-1000 returns along the same path and is deflected out by POL28 and directed along the PS-1000's output axis.



5.5 Residual Spatial Chirp

The outgoing beam should appear uniform and free of spatial chirp.

1. Place the concave alignment mirror provided with the NJA–5 between the PS–1000 and the TRA–1000 (see Fig. 5–6).
2. Project the reflected beam onto a screen located one meter or more from this mirror (see Fig. 5–6).

Be extremely careful!

Block the beam at the level of the table.

At NO time should the beam be projected outside the table area.

3. Using an IR viewer, look at the image on the screen while moving a narrow object (for example, the blade of a screwdriver) back and forth in front of mirror MA35.
   (Be careful not to touch the mirror!)

The displacement of the blade across the spectrum will reduce the intensity of the image on the target.

At the level of the screen, as illustrated in Fig. 5–7, you may see a shadow of the blade moving horizontally across the image. This is a sign of residual spatial chirp, which must be eliminated.

4. Slide mirror MA35 along the axis formed by MA35 and MA34.

Moving mirror MA35 by ±1cm around its initial position is all that should be required to eliminate the lateral chirp.

The optimum distance from MA35 to MA34 is achieved when you cannot see any non-uniform change ("shadow") in the intensity pattern when moving an object in front of the mirror.

the one where you NO LONGER see the chirp on the target. This adjustment step is relatively lengthy, but it is required to obtain the shortest pulse duration.

5. Block the beam between mirrors TM39 and TM40, so that it cannot exit the PS–1000.

Note: It is necessary to keep the beam inside the PS–1000 enclosure, while you perform the alignment of the TRA–1000.

Fig. 5-6

Test for Residual Chirp

Possible lab setup to test for any residual lateral spatial chirp impressed on the oscillator beam by the pulse stretcher.

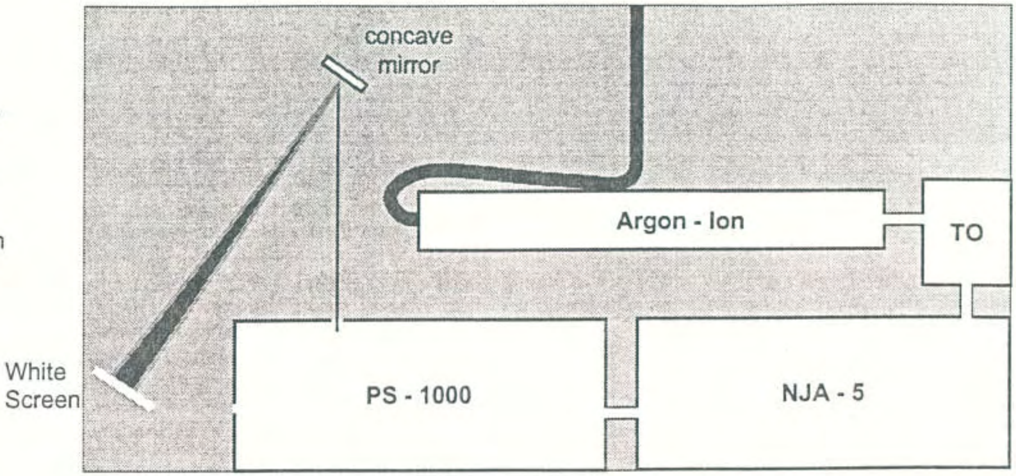
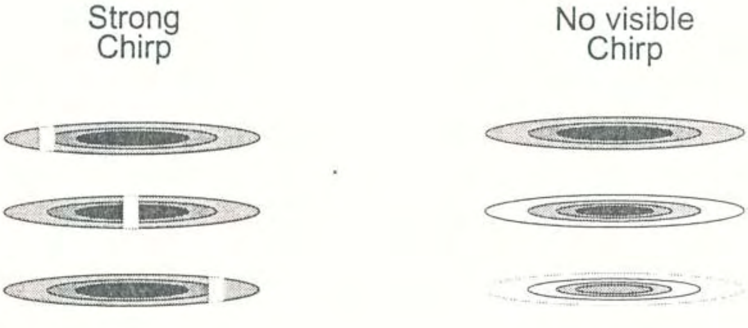


Fig. 5-7

Lateral Spatial Chirp

Two simple cases of residual lateral spatial chirp are illustrated.

The beam is chosen to be elliptical on the observing screen, with an intensity falling off uniformly from center.



For strong residual chirp the "shadow" of the object is clearly visible.

For negligible chirp no shadow appears. The intensity falls off uniformly across the beam cross-section.

6. TRA–1000 Regenerative Amplifier

(Femtosecond version)

The TRA–1000 alignment procedure is divided into six steps:

1. Positioning of the TRA–1000 baseplate with respect to the table's edge and the injection output port of the PS–1000.
2. Alignment of the ORC–1000's output to the TRA–1000's input port.
3. Alignment of a short, linear cavity to the crystal and pump beam. (The short-cavity consists of an end cavity mirror assembly, a Ti:Sapphire rod assembly, and an output coupler mirror assembly.)
4. Lasing and optimization of the short-cavity.
5. Alignment of a long, folded cavity using the output of the short-cavity (two folding mirror assemblies, a polarizer, and a Pockels cell).
6. Lasing and optimization of the long-cavity.

Note: Steps 1 – 5 do not require the NJA–5 oscillator. Step 6 requires the NJA–5 to be mode-locked and stable, and the stretched pulses must have a duration > 200 ps.

Caution !

Injection of unstretched seed pulses into the amplifier results in immediate catastrophic failure.

Safety

Warning !

The output of the regenerative amplifier is extremely powerful.

The near IR emission appears as a low intensity beam to the eye, but is actually a very high intensity beam.

6.1 Support Equipment

The following user-supplied equipment is necessary to align the regenerative amplifier:

1. power meter (reading up to 15 watts),
2. oscilloscope (bandwidth ≥ 300 MHz),
3. infrared viewer.

Included with the Clark–MXR regenerative amplifier package are a fast photodiode, an alignment tool, a polarizing sheet, and a filter for blocking the green pump and transmitting the 800nm Ti:Sapphire output.

6.2 Regenerative Amplifier Positioning

You must become familiar with the ORC–1000. See the ORC–1000 owner's manual before proceeding with the regenerative amplifier installation.

In a standard CPA–1000 setting, the ORC–1000 pump laser is positioned at the end of the table, next to the argon-ion laser, with its output directed along the main axis of the table, as shown in Fig. 6–1. 3-6

The ORC–1000 must be secured to the table using the four foot clamps provided with each unit. The base platform (baseplate for cavity) must be level with the table.

After mating the ORC–1000 laser head to its power supply, it is recommended that you familiarize yourself with its full range of operation. The ORC–1000 emission is extremely intense. The average power may reach 60 watts.

We urge you to read the safety notes that are part of the ORC–1000 manual very carefully. Proceed with extreme caution. Always place a large beam block in front of the output. Be careful: the beam block may become very hot!

See the ORC–1000 manual for additional safety information.

Once you are familiar with the ORC–1000 operation you may proceed with the installation of the regenerative amplifier.

Warning !

Use of controls or adjustments, or performance of procedures other than those specified herein may result in hazardous radiation exposure.

1. Place the regenerative amplifier parallel to the long axis of the table, with its input port lined up with the output port of the ORC–1000. The edge of the TRA–1000 enclosure should be flush with the table edge.

   The spacing between the ORC–1000 and the TRA–1000 is approximately 6″. The exact longitudinal position is obtained by lining up the injection seeding port on the rear side of the TRA–1000 with the stretched-pulse output port of the PS–1000 (see Fig. 3–5).

2. Insert the short beam tube provided with each unit between the ORC–1000 and the regenerative amplifier.

   Note: This beam tube should be parallel with the table's main axis. If it is not, check that the TRA–1000 is flush with the table's edge. Then reposition the ORC–1000 if necessary.

3. Insert the long beam tube provided with each unit between the regenerative amplifier and the stretcher/isolation stage PS–1000.

4. Secure the regenerative amplifier's baseplate by fixing the four random clamps to the optical table.

   Note: Do NOT move the TRA–1000 after this initial positioning.

6.3 Pump Beam Alignment

The alignment of the pump beam starts with the ORC–1000 operating in the cw-mode (Q-switch turned OFF) at the lowest power level possible (current knob turned fully counterclockwise).

Figure 6–1 shows the internal layout of the TRA–1000.

Warning !

In order to avoid dangerous back reflections, the periscope assembly PA51 must have its safety shield installed on top of the upper mirror holder at all times.

1. Set the ORC–1000 for
   a) lowest power (current knob turned fully counterclockwise),
   b) cw-mode (Q-switch driver turned OFF).

   Turn on the ORC–1000 power supply (turn keyswitch clockwise).

Caution !

Even with the current turned all the way down, the output power on some units may reach several watts.

2. Remove the cover of the TRA–1000 enclosure.

3. Defeat the safety interlock switch by pulling up on the sensing rod near the emission indicator lamp.

Check that the safety shield is secured to the top of the periscope assembly before executing the next step. The ORC–1000 beam is extremely intense.

The periscope assembly should redirect the ORC–1000 output beam from its approximately 6″ height to the standard 3.75″ height above the baseplate.

3. Place a beam stop where you expect the redirected beam to emerge.

Caution !

In the next step be extremely careful to avoid reflections.

Wear appropriate safety glasses.

In the following steps, do NOT move the alignment pinholes PH52 and PH53. These pinholes are critical for the alignment of the regenerative amplifier.

4. Open the ORC's intracavity shutter and increase the lamp current until the green pump beam becomes visible.

5. Adjust the periscope mirrors so that the outgoing beam passes through the alignment pinholes PH52 and PH53.

   Note: The pinholes are set for the standard 3.75″ above the baseplate. Check the beam using the middle row of holes in the alignment tool.

6. Fully open pinholes PH52 and PH53 after this initial alignment.

The beam should be at a constant height of 3.75″ above the baseplate, roughly parallel to the long edge of the baseplate, and pass through the centers of the lens assembly LA54 and the end cavity mirror CM55.

Note: The curved side of the lens must be facing the incoming beam.

Note: The distance between the center of lens mount LA54 and mirror assembly CM55 has been factory adjusted. Do not change.

Note: The pump-through dichroic mirror ($R = 0.5$ m) is mounted with its HR-coated side facing away from the incoming pump beam.

To avoid the effects of stress birefringence induced by standard mirror mounts, CM55 uses a telescope tube.

The Brewster-cut Ti:Sapphire rod has been oriented so that a beam aligned to the pump beam axis pinholes is incident at the Brewster angle. The beam will then travel parallel to the long edge of the rod while inside the rod.

7. Center the pump beam on the near face of the Ti:Sapphire rod.
   Note: The beam should exit through the center of the rod's output face.

This ends the ORC–1000 pump beam alignment procedure.

Make sure that all mounts and posts are fastened.

6.4 Short-Cavity Alignment

The goal of this section is to create a shortened version of the regenerative amplifier cavity by placing a temporary mirror just after the gain medium.

The laser beam resulting from this cavity will be used to align the elements of the full regenerative amplifier cavity.

Warning !

The interaction of the intense pump beam with any dust particles landing on a rod face may cause surface burns.

Nitrogen Flow System

To avoid surface damage the TRA–1000 regenerative amplifier is provided with a nitrogen flow system. A weak nitrogen flow (overpressure) at the end faces of the Ti:Sapphire rod reduces the chance of dust adhering to a rod face.

Note: Clean nitrogen should flow over the Ti:Sapphire rod faces at all times when operating the regenerative amplifier.

Note: Visually inspect the rod faces before operating the amplifier. Clean the entrance and exit surfaces if needed.

A flow meter is attached to the pump beam input side of the TRA–1000's enclosure, as shown in Fig. 6–2. Use this meter to set the flow at approximately 3 SCFH (standard cubic feet per hour).

1. Inspect the rod faces and clean if necessary with the pump laser and oscillator turned OFF.
2. Install the nitrogen flow cap on the rod assembly and turn on the nitrogen flow.
   Note: From now on, nitrogen must be flowing whenever the green pump beam of the ORC–1000 is incident on the Ti:Sapphire rod.
3. Check that pinholes PH52 and PH53 are fully opened.
4. Check that the pump beam (still in cw-mode) strikes the rod's entrance face on center.
5. Place the mirror assembly CM57 as shown in Fig. 6–1.
   Note: The HR-coated side must be facing the rod assembly RA56.
6. Center the pump beam on CM57 by adjusting the mount's position.
7. Align the tilt of CM57 so that the reflection from its HR-coated face is centered on the output face of the rod assembly.

Q-switched Pump-Laser Operation

8. Close the ORC–1000's intracavity shutter.
9. Turn the excitation lamp current to minimum (fully counterclockwise).
10. Connect an external source to provide a 1kHz clock signal.
    Note: Use an auxiliary pulse generator or the DT–505 Pockels cell driver.

    The BNC cable connections for the DT–505 are:
    NJA photodiode signal → DT–505 RF Input,
    DT–505 Audio 1 → ORC–1000 EXT MOD (rear panel),
    DT–505 Sync 1 (or Sync 3) → oscilloscope EXT TRIG.

At this time it is convenient to measure the relationship between the lamp excitation current (I_L in amperes) and the Q-switched pump power (P_p in watts).

Note: Since the ORC–1000's output varies with laser head and operating conditions. This information may change slightly from day to day.

11. Set the Q-switch triggering to *external.*
12. Set the modulation frequency meter scale to the 10kHz position.
13. Turn ON the power to the Q-switch driver on the front of the ORC power supply.
    Note: If the external clock signal is properly connected, the frequency meter indicates a value close to the chosen 1kHz repetition rate.

    It is recommended to fine tune this using a reliable oscilloscope.
14. Place the head of a suitable power meter after the iris PH52 and before the pump beam focusing lens LA54.
15. Choosing a suitable set of pump power levels (such as 1W, 3W, 5W, 7.5W, and 8W), measure the corresponding lamp currents.
    Note: These measurements can serve as a short-term reference—
    the lamp current indicating the approximate pump power level.

16. Set the lamp current to its minimum.
17. Close the ORC's intracavity shutter.
18. Remove the detector head from the regenerative amplifier cavity.

Warning !

In the next step the regenerative amplifier will lase.

The output of the regenerative amplifier is extremely powerful.

However, the near IR wavelength emitted is almost beyond the range of human vision. What appears as a low intensity beam is in fact a very high intensity beam.

The pump beam must be centered on the Ti:Sapphire rod face.
Fumes and solid debris may be generated if the beam is misaligned and hits the rod assembly instead of the rod itself.

If the focused pump beam hits any surface other than the Ti:Sapphire rod face, *immediately close the ORC shutter* and clean the rod faces.

Restart the alignment at low power making sure that the pump beam goes through the Ti:Sapphire rod.

19. Progressively increase the Q-switched output to 1W.

Caution !

Do NOT exceed 1 watt for the short-cavity alignment.

Be careful. The regenerative amplifier may lase immediately.

Note: The red laser oscillation output may be difficult to see in the presence of the residual green pump.

20. To monitor the near-IR lasing, place the short wavelength cutoff filter (provided with the TRA–1000) after the mirror assembly CM57.
21. Place a white target after the short wavelength cutoff filter. The red output should become clearly visible on the white target surface.
22. If lasing is not visible, scan mirror CM57 right and left, up and down, until lasing can be seen on the target surface.
    Note: Use an IR viewer to detect the onset of lasing.
    This will increase your sensitivity to the near-IR output and enable you see lasing over a wider angular range of CM57 mirror tilt.
23. Make the mode TEM_{00} using mirror CM57.
    Note: Adjust the pump-through end mirror CM55 only if necessary.
23. Turn down the power to reduce the near IR beam intensity.
24. Remove the white target.

The alignment of the short-cavity is now complete.
This beam will be used to align the full regenerative amplifier cavity next.

6.5 Pockels Cell Alignment

Note: Before proceeding with this step, you need to read the Pockels cell (DT–505) system manual.

Note: The distance between the center of the Ti:Sapphire rod and mirror mount CM58 has been adjusted at the factory.
It should NOT be modified.

The beam reflected by CM58 should propagate toward CM60, then on to CM61. A small fraction of the light will "leak" through the end mirror CM61. This leakage will be used to monitor the oscillating mode in the regenerative amplifier.

1. Check that the beam leaving CM60 travels at the standard height of 3.75″ parallel to the baseplate
2. Align the horizontal tilt of CM60 so that the beam passes through the center of the TRA–1000's output port (in enclosure's right end panel).
3. Place the alignment tool just after mirror CM60 and center the small hole for the standard height on the beam.
4. Insert the polarizing beamsplitter POL62 so that it is well centered on the beam.
5. Rotate the assembly until two weak, back-reflected spots appear on the alignment tool.
   Note: These spots form a diagonal line segment.
6. Adjust the rotation and tilt of the beamsplitter assembly until the midpoint of this line segment falls on the hole in the alignment tool.
7. Install the Pockels cell assembly PCA63 as shown in Fig. 6–1.
   Note: The Pockels cell may already be factory installed.
8. Position the Pockels cell so that the beam goes through the center of both windows.
   Note: The lateral adjustment of the cell with respect to the beam is performed by loosening the two screws in the slots on the side of the mount closer to the end mirror CM61.

   Note: Since the crystal inside the Pockels cell is centered on the same axis as the input and output windows, the Maltese Cross pattern may be used to center the beam through the Pockels cell windows.
   The position of the Maltese Cross in the apertured scatter pattern before CM61 should be centered. (see Fig. 6–)
9. Secure the Pockels cell mount in the lateral direction by tightening these screws, and in the longitudinal direction by tightening the hex screws in the slots just above the baseplate.
10. Insert cavity end mirror CM61 so that it is well centered on the beam.
11. Place the high voltage switching unit (HV–505) near the Pockels cell assembly in the front right corner of the TRA–1000 enclosure, as shown in Fig. 6–1.

12. Connect the cell's short HV-BNC connectors to HV-BNC connectors of the switching unit (see the DT–505 manual).
    Note: Since space inside the enclosure is minimal, be sure to use the high voltage BNC *elbow connectors*, so the switching unit can be placed very close to the Pockels cell assembly.
13. Connect the water cooling tubing to the switching unit at the base.
    Note: Since the switching unit does not generate excessive heat, it is recommended to place these water lines in series with the Ti:Sapphire rod cooling lines.
14. Connect the switching unit to the Pockels cell driver control unit CU–505 (see the DT–505 manual).

6.5.1 Pockels Cell Driver Initial Check

1. Connect the Pockels cell driver and the Pockels cell assembly with the set of cables provided with each unit.
   Note: This is the set of cables wrapped together and passed through the CM61 side (front right) of the TRA–1000's enclosure.
   Note: Carefully follow the labeling on each cable when connecting.

The input RF signal will be provided by the photodiode that monitors the oscillator. The driver will then always be synchronized with the oscillator.

Note: This is the same signal that goes to the self-starting oscillator electronic package in the NJA–3E that comes with the NJA–5.

2. Place the HV switch (on left side of DT–505) in the OFF position.
3. Turn ON the power switch.
4. Check the TTL-level signal at each of the three AUDIO outputs.
   Note: The frequency of each of these signals is adjusted by selecting the setting of the RF dividers on the right side of the front panel.
5. Adjust the digital frequency divider setting to give a 1000 Hz repetition rate signal synchronized to the broadband optical oscillator.
   Note: With the standard NJA–5 optical oscillator, a 1kHz clock signal synchronized to the NJA–5's output pulse train is obtained with a divider setting of 24.
6. Connect the output labeled AUDIO 1 to the ORC–1000 power supply input marked EXT MOD (located on the power supply's back panel).
7. On the front panel of the ORC–1000 power supply select EXTERNAL on the modulation control knob in the Q-switch driver section.
   The ORC–1000 should now operate at 1kHz, synchronized with the NJA–5. Check this using the photodiode provided with the regenerative amplifier.
8. Connect the Pockels cell driver output labeled AUDIO 2 to the Pockels cell driver input marked DELAY IN.
9. Set DELAY 1 to 160 00.
   Note: The 160 corresponds to the basic clock period (equal to four NJA–5 round-trip times), and 00 corresponds to a fine analog delay (each unit equal to a fraction of a nanosecond).

10. Set DELAY 2 to 261 00.

    Note: This is a convenient, large value which allows the intracavity pulse to decay substantially while the cavity remains in the high-Q state.

11. Set DELAY 3 to 161 00.

    Note: This value is chosen to be close to and following the *Delay 1* setting. *Sync 3* then gives a nicely timed trigger signal for an oscilloscope.

The stretched seed pulse and the amplifier beam should now be collinear, but counter-propagating (see Sec. 6.8: Alignment to Injection Axis).

6.5.2 Pockels Cell Crystal Axis Alignment

The ability to switch in stretched seed pulses from the oscillator and switch out stable, amplified stretched pulses from the amplifier cavity is determined mainly by the Pockels cell's polarization rotation accuracy and the extinction ratio of the polarization splitter. The process takes place as follows:

Choose a stretched oscillator pulse from the injected pulse train.

Important factors

Synchronization to oscillator pulse train	(DT–505 RF divider)
Timing adjustment	(DT–505 Delay 1)

Trap the chosen pulse while rejecting earlier and later pulses.

Important factors

Extinction ratio of optical field polarization selector	(POL62)
Modulation efficiency of optical field's polarization state	(PCA63)
Cavity-Q modulation timing	(DT–505 Delay 1 and Delay 2)

After the trapped pulse has grown to sufficient amplitude and stability, eject it from the regenerative amplifier's cavity.

Important factors

Extinction ratio of optical field polarization selector	(POL62)
Modulation efficiency of optical field's polarization state	(PCA63)
Cavity-Q modulation timing	(DT–505 Delay 2)

The Pockels cell's tilt angles have a strong effect on the modulation of the regenerative amplifier's cavity Q. The ability to switch from a high-Q resonator lasing state to a low-Q cavity dumping state is essential to achieving a good contrast ratio between the main pulse, and its accompanying pre- and post-pulses.

With the high voltage switched off, the Pockels cell behaves as a quarter-wave plate. The cavity-Q seen by the horizontally polarized Ti:Sapphire oscillation regenerative amplifier's cavity-Q is designed to be at its lowest value.

The Pockels cell will now be aligned at act as a static quarter-wave plate (half-wave in double-pass).

This is done using the seed pulse train from the oscillator ***after stretching***!

1. Check that the short-cavity beam is aligned through the polarizing beamsplitter and the Pockels cell.

The first step in aligning the Pockels cell crystal axis is performed using the short-cavity laser beam. There are two simple methods discussed below. If the crystal axis is not grossly misaligned at the start of the procedure, the method of minimizing the return beam may be easier. Using the Maltese cross pattern allows one to readily see a wider range of misalignment and indicates the proper direction to tilt the crystal in order to reach the quarter-wave alignment condition.

6.5.2.1 Method 1: Return Beam Minimization

Since the alignment of the Pockels cell's tilt angles are to be optimized for injection-seeded regenerative amplification, it is sufficient to perform a coarse alignment at this stage using a simple method.

The static (HV = 0) state of the Pockels cell changes the incident *P-polarization* state of the short-cavity beam to an *S-polarization* state after being returned by CM61 through the Pockels cell. The polarizing beamsplitter then deflects the beam out of the long-cavity path. The residual IR beam returning toward mirror CM60 should be weak.

1. Adjust the end mirror CM61 so that the short-cavity beam is reflected back toward the pinhole placed near CM60 (see Sec. 6.5, step 3).
2. Move the back-reflected beam spot so that it is just outside (horizontally) the hole in the alignment tool through which the incoming beam passes.
3. Adjust the vertical micrometer screw of the Pockels cell assembly's tilt stage until the back-reflected spot is minimized.
4. Using the horizontal knob of CM61 center the spot on the hole in the alignment tool (retro-reflection).
5. Minimize the IR scattering (halo) around the reference pinhole.

When the correct high voltage is applied, the Pockels cell behaves as a full-wave plate in double-pass. The *S-polarization* state component deflected out of the beam path should reach a minimum.

6. Turn ON the high voltage switch on the Pockels cell driver.
   Note: A white card placed in front of mirror TM64 will show a set of three spots. Only one of these reflections is sensitive to the Pockels cell alignment. Use this spot (the left-most spot, closest to the injection port) to fine adjust the Pockels cell alignment.
7. Adjust the horizontal and vertical micrometer screws of the Pockels cell tilt stage to minimize the intensity of this spot.
   Note: Often, the state of minimum intensity appears as a weak spot with a broad, dark line running through it.

6.5.2.2 Method 2: Maltese Cross

For the following alignment steps you may have to remove the end mirror CM61 from its mount.

Caution !

If the CM61 end mirror is removed, the intense laser beam from the short-cavity will exit the enclosure, unless blocked by the output port shutter on the end panel behind CM61.

1. Place the alignment polarizing sheet after the mirror CM61 assembly, as shown in Fig. 6–3.
   Note: The linear polarizing sheet is provided with the TRA–1000 system.
2. Orient the polarizing sheet so that its transmission direction is orthogonal to the polarizing beamsplitter POL62.
3. Place a weak scatter on the input side of the Pockels cell assembly PCA63 as in Fig. 6–3.
   Note: Lens cleaning tissue scatters quite well.
4. Place a white screen after the polarizing sheet.
5. Using an infrared viewer, observe the so-called "Maltese Cross" pattern projected onto the white target as shown in Fig. 6–4.
   Note: You should be able to see the main beam (probably close to the center of the Maltese cross) and at least one full ring.
6. Using the two micrometer screws of the Pockels cell assembly's tilt stage, adjust the screws to position the main beam on one of the angle bisectors (diagonals), quarter-way between the central dot and the first ring of the secondary dots (see Fig. 6–4).
   Note: For an ideal crystal the four diagonal positions are equivalent, but the effects of window wedges and crystal cut may make some diagonal positions ineffective.
7. Remove the scatterer, the polarizing sheet, and the white screen.
8. Replace the end mirror assembly CM61.
9. Turn ON the high voltage of the DT–505 Pockels cell driver.

6.6 Long-Cavity Alignment

1. Place the white target and the short wavelength cutoff filter outside the TRA–1000 enclosure, after the exit port.
2. Place the photodiode provided with the TRA–1000 so that it monitors scattering from the white target surface.
3. Optimize the photodiode alignment to obtain a signal of approximately 500mV into a 50Ω termination.
   Note: The photodiode output will saturate at around 2.0 volts.
4. Position the alignment tool between CM60 and POL62. Center the large diameter hole located at the 3.75″ height on the amplifier beam.
   Note: The small hole introduces too much loss the next steps.
5. Align CM61 so that the laser beam from the short-cavity is retroreflected towards the alignment pinhole.
6. Close the ORC–1000 shutter.

7. Remove the temporary mirror CM57 of the short-cavity.
   Note: If the long cavity is well aligned, it will lase for 1W pump.
8. If lasing is seen, adjust CM61 to maximize the output.

   If no lasing is seen, recheck the alignment using the position of the back reflected beam using PH53.

   Increase the ORC–1000 pump power to 2W.
   Note: The regenerative amplifier cavity should start lasing.
   If not, slight adjustment of mirror CM61 will make the cavity lase.
9. Increase the ORC–1000 pump power to 5W.
10. Observe the laser beam spot on the white target and optimize the mode for TEM_{00}.
11. Use a white target surface to check the exit port of the intracavity polarizing beamsplitter. Adjust the Pockels cell micrometer screws to minimize the leakage intensity.
    Note: For convenience, place the white target on the injection axis and observe the beam deflected out of the TRA–1000 enclosure.
12. Maximize the output power with the help of a power meter.
    Note: Small adjustments of the end mirror CM61 (and possibly CM55) may improve the mode structure and output power.
13. Verify that the laser is operating in the TEM_{00} mode.

Note: Do NOT alter the cavity mirrors CM58 and CM60, or lens LA54.

6.7 High-Energy Operation

You will now increase the pump energy to check a few operating parameters. Note that the various distances separating the components of the regenerative amplifier have been carefully optimized. Modifying these parameters may result in lower efficiency. Also, the outgoing beam collimation is critically dependent on these parameters.

Check that your system meets the following benchmark:
The output power (measured behind CM61) should be > 300mW when the ORC–1000 operates at 5W and 1kHz repetition rate.

Note: If the TRA–1000 falls significantly short of this benchmark, check the optics for any dust and clean accordingly.

Warning !

Do NOT extract more than 1.6mJ (as measured BEFORE the entrance of the pulse compressor).

It is quite easy to extract more energy from the regenerative amplifier, but this is likely to damage the cavity mirrors and/or transport optics.

The beam must be TEM_{00} when operating in the high end of the energy range. Operating the amplifier in a multi-transverse mode may result in damage to the cavity elements.

In order to simplify the alignment of the regenerative amplifier and to insure that it operates in the TEM_{00} mode, we are using an output coupler instead of a high-reflector in the end mirror position CM61. Use the leakage light from that output coupler to verify that the mode is TEM_{00}.

Note: Do NOT replace the output coupler CM61 by a high reflector. The output energy differential is not significant.

6.8 Alignment to Injection Axis

6.8.1 Stretched Pulse Beam Alignment

The Q-switched beam from the regenerative amplifier (long-cavity) will now be made collinear with the seed injection beam.

1. Center TM64 on the beam rejected by POL62.

   Note: There are two, sometimes three, beams coming from POL62. Only one of these beams will show change as the Pockels cell is tilted. This beam, one closest to the injection port, is the one to use.

   This beam may be very weak or not visible if the Pockels cell and polarizing beamsplitter are well aligned. You may have to slightly misalign the Pockels cell to see it.

   The polarization of this beam should be vertical. You may want to check this.

2. Set the angular adjustment of TM64 to send the beam onto the center of TM65.
3. Adjust TM65 to send the beam through the injection axis pinhole PH66 and out through the injection axis port in the rear side of the TRA–1000's enclosure, and roughly center it on aperture PH41 in the pulse stretcher.

   Note: Keep PH66 open when aligning the beam to PH41 using TM65. The opening in PH41 may be kept small during alignment.

4. Close down PH66 and use TM64 to center the beam on the aperture.
5. Open PH66 and use TM65 to re-center the beam on PH41.
6. Repeat steps 4 and 5 until the rejected (cavity-dumped) amplifier beam goes through the centers of both PH41 and PH66.

The amplified beampath is now well defined by the injection axis pinholes.

For the following steps, turn OFF the pump beam and unblock the oscillator beam and the stretcher in the PS–1000.

7. Using TM39 center the *seed* beam (oscillator beam) onto PH41.
8. Using TM40 center the *seed* beam onto PH66.
9. Repeat steps 7 and 8 until the beam goes through the centers of both PH41 and PH66.

The stretched seed pulse direction is now well defined by the pinholes.

The stretched seed beam and the regenerative amplifier's return beam are now collinear with the injection axis, but counter-propagating.

10. Place a long beam tube covering the injection axis between the PS–1000 module and the TRA–1000.

> **Warning !**
>
> Absence of this beam tube will degrade the system stability and create a safety risk to the user.

11. Fully open the injection axis apertures PH41 and PH66.

6.8.2 Amplified, Stretched Pulse Beam Alignment

The amplified, stretched pulse leaving the TRA–1000 and returning to the PS–1000 through the injection axis port is routed through the isolation/switching stage and passed onto the PC–1000 pulse compressor (see Fig. 5–5).

The final alignment of the PS–1000 can now be performed.

As shown in Fig. 5–5, the pulse train coming from the regenerative amplifier enters the pulse stretcher and isolator module centered on PH41. The beam then goes on to TM40, TM39, TM38 and POL25. The polarizer routes the beam through the Faraday rotator. POL28 then deflects the beam to TM42, which directs the beam along the output axis towards the pulse compressor.

1. Turn ON the ORC–1000 pump laser.
2. Check that the amplified beam follows the path described above and in Fig. 6–1.
3. Check that the beam is not clipped by any optical components.
4. Adjust mirror TM42 to direct the beam along the output axis.
   Note: The beam should travel at a constant height of 3.75″ above the baseplate and pass though the centers of the telescope and waveplate before exiting the enclosure.

   Note: If the beam does not pass through the centers of the components, you may have to slightly translate/rotate TEL43 to center the beam on the telescope's input face and optical axis.
5. Check that the beam coming out of the telescope is collimated and round.
   Note: If it is not, the beam is not traveling coincident with the optical axis of the telescope. Adjust the position and/or angle of TEL43 if necessary.

   Note: Do **NOT** change the spacing between the lenses forming the TEL43. This is a critical parameter that has been factory adjusted.

The PS–1000 is now fully aligned.

6. Check that all pinholes are fully opened (PH23, PH29, and PH41).

6.9 Pockels Cell Timing

6.9.1 Injection Beam OFF

1. Block the seed laser.

   Note: It is important to block either the oscillator pulse or the stretched pulse leaving the stretcher so no pulse is injected into the amplifier.

2. Turn ON the high voltage switch on the Pockels cell driver.

   Note: The HV will come on after a short warm-up period.

   Note: The regenerative amplifier should lase after the HV comes on.

3. Using a photodiode with a fast oscilloscope, observe the green YAG pulse and the red Ti:Sapphire pulse scattered off of a convenient surface placed just behind the output port (outside the enclosure).

   Note: It is not necessary to carefully align the photodiode—a simple scattered reflection should be sufficient to register on most detectors.

   Note: The Ti:Sapphire pulse will appear after the green pulse peaks, and should be much sharper as shown in Fig. 6–9A.

4. Progressively reduce DELAY 1 in order to maximize the Ti:Sapphire pulse energy.

   Note: The Ti:Sapphire pulse peaks shortly after the green pump maximum.

   Note: Do NOT move the Ti:Sapphire pulse ahead of the pump's peak or you will lose control of the injection (see Fig. 6–9A).

   Note: If the trace on the oscilloscope shows weak modulation of the laser pulse and the rise of the pulse shows considerable jitter, then you are switching in too early (DELAY 1 too small).

5. Set DELAY 2 large so the entire decay of the pulse in the cavity can be seen on the oscilloscope.

6. Use a slower time sweep to compress the pulse train and make changes in the peak pulse easier to see as DELAY 1 is scanned.

7. Scan DELAY 1 and look for the setting yielding:
   a) largest amplitude of the peak pulse in the train,
   b) fastest rise time from the signal floor to this peak.

8. Optimize the cavity and Pockels cell alignments to maximize the energy in the Ti:Sapphire pulse.

   Note: At an ORC–1000 pump power of 5W it is usually safe to adjust both cavity end mirrors CM61 and CM55.

   When operating above 5W pump power, it is best to adjust only the end mirror CM61. Adjusting both CM61 and CM55 is not recommended, since the beam walks across the crystal faces and has a greater probability of damaging the surfaces.

   Note: Only slight changes in Pockels cell alignment should be required.

9. Observe the mode shape on the target and make certain it is TEM$_{00}$.

10. Adjust the focusing lens LA54 to maximize the peaks on the oscilloscope trace.

    Note: This adjustment increases the conversion efficiency and green light power density on the rod face. The closer the system is operated to maximum efficiency, the more sensitive the rod faces are to damage.

A continuous flow of clean, dry nitrogen gas over the rod faces will reduce the chance of damage.

11. Re-adjust CM61 and check that the mode is still TEM_{00}.
12. Turn OFF the high voltage to check that lasing is prevented when no fire order is sent to the Pockels cell. If this condition is satisfied, turn ON the HV again.

    Note: Place a white card on the injection axis outside the TRA–1000's enclosure. By switching the HV on and off you should see:

    HV ON ⇒ high-Q cavity, pulse withheld ⇒ pulse not seen,
    HV OFF ⇒ low-Q cavity, pulse dumped ⇒ pulse seen.
13. Place a power meter on the injection axis between the PS–1000 and TRA–1000 to monitor the cavity-dumped pulse from the amplifier.
14. Progressively reduce DELAY 2 while maximizing the average power displayed by the detector.

    Note: Small adjustments to CM61 may also increase the average power.

    Note: For a pump power of 5W, a benchmark value of 1W average power is expected. If your system is below this value, recheck the pump power level and the pump mode. The pump mode should look approximately like an elliptical "TEM_{00}" mode with a horizontal to vertical aspect ratio of 1.5.

    The setting of DELAY 1 may also be too small so that the energy deposited by the YAG pump pulse is inefficiently extracted.

    Note: When the power has been properly maximized, the values of DELAY 1 and DELAY 2 are set for the given pump power level.

    The difference between these delays defines the time window for injecting a stretched oscillator pulse and trapping the YAG-pumped amplifier oscillation.
15. Increase the ORC–1000 output power to 7.5W.
16. Adjust mirror CM61 to increase the energy and improve the mode quality of the output beam.
17. Adjust the time window to maximize the cavity-dumped power out the injection axis.

    Note: Since the time it takes the gain in the cavity to reach a given value depends on the pumping rate, the peak of the gain pulse occurs at an earlier time. To optimize the energy extraction, the time window must occur earlier (lower delay settings).

    Note: For a pump power of 7.5W, a benchmark value of 1.75W average power is expected. If your system is below this value, recheck the pump power level and the pump mode. The pump mode should look approximately like an elliptical "TEM_{00}" mode with a horizontal to vertical aspect ratio of 1.5.

    Note: After maximizing the output power, the setting of DELAY 2 typically dumps the pulse shortly after it has completed one stable (saturated) round-trip. The previous (earlier) peaks, also seen in the leakage at the output of the amplifier cavity, show considerable jitter since these peaks correspond to times when the cavity pulse was not strong enough to saturate the available gain.

The unsaturated peaks in the output pulse train are very sensitive to the alignment of the amplifier cavity, and therefore very useful for optimizing the alignment.

At this stage, the TRA–1000 has been optimized for unseeded operation at 7.5W pump. The beam can be used to align the pulse compressor, but it is too intense for safety. By switching out the pulse before the energy has time to buildup, a low power beam suitable for alignment results. (Reduce DELAY 2 to the point that only the first weak pulse on the rising edge of the pulse train is left on the oscilloscope.)

If you would like to begin the alignment of the pulse compressor now, switch the pulse out early as described above and proceed to sections 7.1 through 7.3 of Chapter 7 on the pulse compressor. Before continuing on with Sec. 7.4 on pulse compression, return to the following section on seed pulse injection.

6.9.2 Injection Beam ON

After the stretched seed beam of the oscillator is injected into the regenerative amplifier, a strong modulation of the Ti:Sapphire pulse results, as shown in Fig. 6–9B. The period of this modulation matches the round-trip time of the regenerative amplifier cavity. The oscilloscope trace of the cavity output signal will show two or three unstable spikes. These spikes appear on the leading edge of the output pulse train and result from leakage of the oscillating pulse at times when it was not strong enough to saturate the gain. The spikes appearing later in time show little jitter and indicate that the pulse has saturated the available gain.

The buildup time should be reduced as lasing now starts from a seed pulse instead of noise. The seed pulse leads to a more rapidly growing amplifier cavity mode that can saturate the gain at an earlier time. Since more energy can be stably extracted by switching in at an earlier time, the Pockels cell time window needs to be re-optimized for maximum energy extraction from the regenerative amplifier cavity.

1. Double check that the seed pulse is stretched in time.
   If so, unblock the seed laser and allow it to enter the amplifier.
2. Place a power meter inside the pulse compressor just after the first turning mirror TM81.
   Note: The power meter will not only measure the average power injected into the pulse compressor, but also act as a beam block to avoid the risk of damage to the compressor module's optics during amplifier optimization.
3. Optimize the cavity alignment by adjusting the end mirror CM61 while observing the sensitive, unstable peaks on the leading edge of the pulse train to:
   a) maximize the peaks,
   b) move the peaks as early in time as possible (rapid ramp-up).
4. Adjust the Pockels cell's tilt stage to maximize the modulation depth.
   Note: Only minor adjustments should be needed.

Note: To perform this step accurately, focus in on the largest peak and its adjacent peaks by expanding the timebase of the oscilloscope's sweep. For increased modulation, adjust the Pockels cell's micrometer tilt screws so that:
 a) the dips before the peaks are deepest,
 b) the rising edges of the pulses are steepest, and
 c) any residual, weak post-pulse peaks are minimized.

5. Adjust TM64 and TM65 to optimize the injection alignment (reduce the buildup time) and to further maximize the modulation depth.
   Note: If the Q-switched envelope is not smooth, the laser is not running in a single transverse mode.
   Slightly realign the amplifier cavity by adjusting only the end mirror CM61 to achieve a smooth pulse envelope.

   Note: A slow photodiode may not be able to follow the multimode signal.

6. Progressively reduce DELAY 2 until the tail end of the Ti:Sapphire pulse train is sharply cutoff as shown in Fig. 6–9C.
   Note: If the pulse train is not cutoff sharply, the Pockels cell is not correctly aligned.

7. Place the photodiode after the exit of the PS–1000 stage.
   Note: The goal is to observe the pulse coming out of the amplifier. Placing the photodiode near the PC–1000 so that is can monitor scattering from any of its internal mirrors provides a good signal.

   If the power meter is still in position before TM81 as in step 2 above, use the scattering from its detecting surface or another part of the detector's head.

   Note: Be careful to avoid unwanted reflections that make the final adjustment difficult. You may see unusual features in the oscilloscope trace that are actually unwanted detection of multiple reflections or scattering.

8. While observing the amplified, stretched pulse with the photodiode and oscilloscope, adjust FINE DELAY 2 in order to cavity-dump a single pulse.

9. Adjust FINE DELAY 1 in order to maximize the injection of the seed pulse.

6.10 Regenerative Amplifier Optimization

After completing the initial injection and cavity dumping of your amplifier, you can often improve the performance (contrast ratio and beam quality) considerably with a few simple steps. In general, this is best done by looking at the pulse train just before it enters the pulse compressor, or before TM81 as in the last section.

1. Place a power meter at the output of the PS–1000. in front of TM83

2. Place the photodiode in front of the power meter and check that the photodiode is not saturated.
   Note: The photodiode signal into 50Ω should be less than 2.5V.

6.10.1 Contrast Ratio

When the position of the high-speed detector is suitable, the oscilloscope trace should show a main peak of 2V ~ 3V and weak secondary pulses, evenly spaced on both sides of the main peak. (Set the oscilloscope vertical scale at .5V/div and horizontal scale at 10ns/div.) The pulse spacing is equal to the TRA–1000's cavity round-trip time (~ 9ns).

Prepulses are the evenly spaced weak peaks at least 8ns in front of (earlier) than the main pulse. The pulses are clearly observed on the low noise baseline. In contrast, the *post-pulses* are difficult to locate on the back side of the trace, where electrical noise and cable reflections give a noisy baseline. With the correct alignment, you should be able to obtain:

a) main-pulse to prepulse contrast ratio > 500:1,
b) main-pulse to post-pulse contrast ratio > 100:1.

Measuring the main-pulse to post-pulse contrast ratio is made difficult by the presence of numerous electrical reflections from the cables, oscilloscope and photodiode. The most effective way to improve the contrast is to align the system to obtain the highest main-pulse to prepulse contrast, and then to adjust the cavity dumping timing fire DELAY 2 to reduce the presence of post-pulse.

The following procedure gives a systematic method to optimize the contrast ratio.

1. Check that the photodiode, cable(s), and the oscilloscope used are not affected by the small amounts of electrical noise generated by the Pockels cell and its driver.
   Note: Be aware that non-shielded coaxial cables may act as antennae.

800ps-Shifted ~~Pulse~~ Peak

2. Increase the vertical sensitivity of the oscilloscope trace until the prepulse features become clearly visible.
   Note: The main pulse is now far off the top of the display.
3. Locate the peak about 0.8ns in front of the main peak.
   Note: If you slightly adjust the Pockels cell tilt, changes in the peak are easily visible.
4. Maximize the dip ("shoulder") between the 800ps-shifted peak and the main peak by adjusting both Pockels cell tilt adjustments.
   Note: This adjustment also reduces the leakage of prepulse.

   Note: Only very slight adjustments should be needed.
   The vertical adjustment is generally more sensitive.

   Note: This step completes the alignment of the Pockels cell.
   If the system is to be wavelength-tuned, adjustment will be needed at that time.
5. Minimize the 800ps-shifted pulse using the *fine control* of DELAY 1.
   Note: Typically, this adjustment yields only a small reduction in the peak, but may allow post-pulse to increase.

   Note: Each digit of fine timing control is about 0.4ns for a standard NJA–5 cavity.

Secondary Pulses

6. Focus attention on the first prepulse and first post-pulse from the main peak.
   Note: You may want to expand the horizontal scale by increasing the sweep rate of the oscilloscope.
7. Minimize post-pulse using DELAY2 Fine. FINE DELAY2
   Note: It may happen that this adjustment also reduces the prepulse, but not usually.
8. Minimize prepulse using the high-voltage potentiometer HV1.
9. Minimize postpulse using DELAY2 FINE.
10. Minimize postpulse using the high-voltage potentiometer HV2.
    Note: Only small changes to the potentiometers may be needed, or not at all. The potentiometers are your last resource for suppressing secondary pulses.

Properties of Electrical and Optical Features

At times it may be difficult to distinguish electrical from optical signals in the oscilloscope trace. To help you determine the origin of a feature we list some properties to keep in mind.

A) Electrical noise spikes are not affected by the Pockels cell tilt or timing delays DELAY1 ~~OR~~ and DELAY2.

B) Electrical spikes often show both a positive and negative part with respect to the baseline, where(as) optical spikes remain only positive. You will, however, notice electrical spikes with no negative component.

C) When optical signals appear and grow superimposed on the noise during fine timing adjustment, they show considerable jitter. In contrast, electrical signal remain stable.

D) Optical signals are additive to the noise (not rising up out of the noise).
⇒ Measure signal strength from the local noise level, not from the floor.

When to Repeat Contrast Optimization

a) Whenever the wavelength is changed. ⇒ Reset Pockels cell tilt.

b) Whenever the pump power is changed. ⇒ Reset Pockels cell driver timing.

6.10.2 Beam Quality

The beam coming out of the regenerative amplifier should have a near perfect TEM_{00} profile. Departure from this ideal shape can generally be traced down to one of the following:

Clipping of the outgoing beam.
Check that the alignment pinholes are fully opened.
Check that the beam is centered on the various mirrors and other optical elements that are on its path.

Presence of dust on the Ti:Sapphire rod.
Clean the rod with methanol or acetone.

Use nitrogen-flow overpressure to avoid dust adhering to surface!

Presence of dust on one of the transport mirrors.

Clean with methanol or acetone.

Finally, if the pump energy exceeds 12mJ per pulse, the regenerative amplifier may be lasing in two or more transverse modes.

6.10.3 Pulse Energy

It is quite easy to extract more energy from the regenerative amplifier than the standard optics supplied with the CPA–1000 system can reliably handle. Pulse energies above 1.6mJ are likely to damage the cavity mirrors and/or transport optics.

Warning !

Do NOT extract more than 1.6mJ of energy per pulse as measured before the compressor stage.

7. PC–1000 Pulse Compressor

(Femtosecond Version)

7.1 Pulse Compressor Positioning

The pulse compressor is the last module forming the CPA–1000. The PC–1000 is a one-grating, all-reflective design which works precisely with Clark–MXR's PS–1000 pulse stretcher and isolator module. To achieve this, the grating in the pulse compression stage must match the grating in the pulse stretcher stage.

Note: The compressor is shipped with the mechanical components pre-mounted. Some of the optical components are packed separately for protection during transit.

Figure 3–7 shows the overall positioning of the compressor module within the CPA–1000 system.

1. Position the pulse compressor baseplate onto the optical table. Its main axis must be perpendicular to the optical table's main axis.

   Note: The separation between the PS–1000 pulse stretcher and the PC–1000 pulse compressor should be approximately 1mm.

   Note: The input port of the pulse compressor must be aligned with the output port of the pulse stretcher.

2. Secure the pulse compressor's baseplate using the four disc clamps.

7.2 Pulse Compressor Alignment

An internal layout of the compressor identifying the various components is presented in Fig. 7–1.

The initial alignment must be done at relatively low energy per pulse (typically 300μJ, or an average power of 300mW for 1kHz repetition rate). This energy level is best obtained by cavity-dumping the pulse out of the regenerative amplifier early. Five round-trips or so before the highest peak gives a good result.

Warning !

Remember that the IR wavelengths emitted by the Ti:S oscillator and greatly amplified by the regenerative amplifier are almost beyond the range of vision.

What appears as a low intensity red beam is in fact a very high intensity beam!

Be aware of all beam paths!

1. Using TM81 direct the incoming beam at the standard height towards TM82 and then on to MA83.

   Note: The beam height must be at a constant 3.75″ above the baseplate.

   Note: Place the beam spot on the top left edge (as seen from the front) of

MA83 so that the spectrum going from GA84 to MA86 is not clipped by part of MA83.

The next step involves installing the grating used for compressing the stretched pulse. The following procedures are important for obtaining the proper compression, which is designed to compensate for material dispersion in the beam path and the stretching produced by the PS–1000 module.

Caution !

Be careful when handling the grating.

Wear protective gloves to avoid contaminating the grating with skin oil and other debris.

The grating surface cannot be cleaned except with a gentle wash of dry nitrogen or other similar low pressure dusting gases.

2. Install the diffraction grating in the grating holder GA84.
   Use the soft-tip set screws provided with the grating holder.
   Note: The grating should not be centered in the mount, but its left side should be extend ~1cm outside the grating holder (see Fig. 7–1).
3. Using MA83, direct the beam onto the point on the grating surface which lies on the vertical rotation axis of the underlying grating rotation stage.
   Note: The beam should remain at the standard height.
   Note: As seen from the front of the grating this point is about 1cm from the left edge of the grating.
4. Place the alignment tool close to but just off to one side of mirror MA83.
5. Rotate the grating holder to the near-normal position (zero-order reflection) so that the beam (spectrum) is reflected onto the tool.
6. Center this reflection onto the holes at the standard height in the alignment tool using the tilt knob on the <u>back</u> of the stage.
   Note: Since the incident beam travels parallel to the baseplate and the beam is now reflected parallel to the baseplate, the grating surface is normal to the baseplate.
   Note: Do not use a true retro-reflection geometry since the beam will feedback into the oscillator and destabilize it.
7. Rotate the grating holder to the near-Littrow position so that the first-order reflection (spectrum) is reflected onto the tool.
8. Center this reflection onto the holes at the standard height in the alignment tool using the tilt knob on the <u>front</u> of the stage.
   Note: Since the incident beam travels parallel to the baseplate and the beam is again reflected parallel to the baseplate, the grating groove orientation is normal to the baseplate.
   Note: Again, avoid optical feedback by not using retro-reflection.

9. Repeat steps 5 to 8 until no vertical offset in the reflections relative to the middle row of holes in the alignment tool is observed.
   Note: Do NOT adjust the grating tilt stage after this initial alignment.

10. Orient the grating mount GA84 to direct the diffracted beam towards the center of the left (output port side) mirror of assembly MA85.
    Note: The beam remains at the standard height.

    Note: The spectrum should be centered on the left mirror of the pair.

    Note: Mount MA85 and its two mirrors have been factory adjusted. Do NOT change the alignment of these two mirrors.

The mirror pair MA85 redirects the beam back to the grating. The beam must be parallel to the baseplate and the spectrum must be perfectly horizontal (not tilted with respect to the baseplate). The knobs under the tilt stage of MA85 are used to perform this alignment.

11. Place the alignment tool in front of the grating with the incident spectrum centered on the slit in the tool.

12. Using the front knob under MA85's tilt stage, adjust the spectrum for the standard height.

13. Using the rear knob under MA85's tilt stage, adjust the spectrum so that it is horizontal (parallel to the baseplate).
    Note: Check that the width of the spectrum is well aligned with both holes in the middle row of the alignment tool.

    Note: Failure to align this mirror correctly could result in back-reflection into the PS–1000 (possibly causing damage) or poor output beam quality from the CPA–1000.

The beam is diffracted again by the grating and then sent on to mirror MA86.

14. By adjusting mirror mount MA86, center the reflection from the grating onto the rectangular mirror of MA86.

15. Adjust mirror MA86 to redirect the beam back into the grating.

Warning !

Sending the compressed pulse back along its incident path can cause severe damage to the optics of the PS–1000 and oscillator.

Avoid retro-reflecting the beam when passing it over TM37!

16. Adjust the vertical tilt of MA86 until the beam, now returning through the entire compression stage, hits very near the top of the "pick-off" mirror MA87.
    Note: It is very important that you do NOT retro-reflect the beam while scanning the vertical tilt knob of MA86. Start the final angular alignment by setting the vertical tilt of MA86 very low, and then carefully scan the knob while watching the spot move upward on the mirrors, particularly on the low "pick-off" mirror TM87.

    Note: The smaller the angle the return beam makes with the forward beam, the more efficient the pulse compression (near retro-reflection) and the smaller the residual vertical chirp.

17. Check that the beam is not clipped by any of the PC–1000 components.

The beam can exit the pulse compressor through the main Port A, located on the left panel of the compressor as shown in Fig. 7–1.

Note: If your system has the optional white-light stage, refer to Chapter 9 and Fig. 9–1 for the final beam path.

You can now safely increase the average power to the specified values.

7.3 Optimum Compression

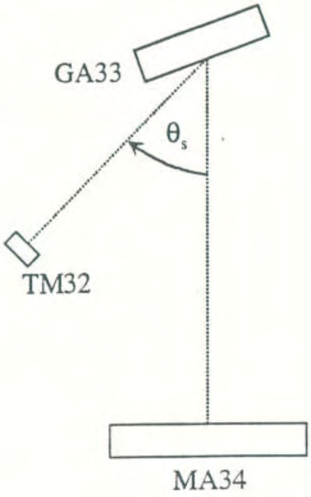
The maximum degree of pulse recompression depends on the ability of the compressor to compensate for the stretching of the pulse (wavelength versus time) before amplification, and any additional sources of dispersion introduced into the beam by materials through which the beam passes. As we saw in Sec. 5–3, the important part of the beam path in the outgoing stretcher beam is

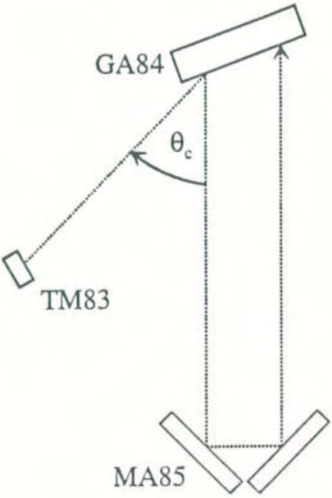
TM32 → GA33 → MA34 → MA35 → MA34 → GA33 → MA36.

The first parameter determining the amount of stretching is the angle between the beam incident on the grating and the beam leaving the grating—the angle formed by the first three components listed in the above beam path. Let us call this angle θ_s as shown in the left side diagram in Fig. 7–2. The reference axis for the stretcher stage is chosen to be screw hole row six from the top (injection port side) of the baseplate. The stretcher angle θ_s is therefore the angle formed by the incident beam direction and the stretcher axis.

The corresponding beam path in the compressor is between mirror MA83, grating GA84, and the left mirror of MA85. The angle formed by these components, designated as θ_c in the right side diagram in Fig. 7–2, affects the amount of compression in the pulse compressor. The reference axis for the compressor stage is chosen to be midway between rows seven and eight of screw holes from the right (input) side of the baseplate. The beam spot on the grating and the center of the left mirror of MA85 should be aligned with this axis. The compressor angle θ_c is therefore the angle formed by the direction of the beam incident on the grating and the compressor axis.

When using the CPA–1000 system, compression can be improved by setting the compressor angle θ_c relative to the stretcher angle θ_s so that dispersion compensation can be achieved. At this stage, the important factors are the number of lines per millimeter of the grating and the number of passes used in both the stretcher and compressor. For the standard double-pass configuration Table 7–1 shows the recommended difference in the incident angles ($\theta_c - \theta_s$) for a given grating dispersion. For the single-pass case these angles should be doubled.





Grating (# lines/mm)	$\theta_c - \theta_s$ (degrees)
1200	5°
1400	3°
2000	1°

Note: For single-pass configuration multiply angle by two.

Making sure that the compressor is in good agreement with the above values is the first step to optimizing the compression of the CPA–1000's output beam. Note also that these values are affected by the number of round-trips in the TRA–1000 before the beam is switched out. We assume the standard switch-out peak is the first peak after the main (maximum) peak as discussed in Sec. 6.9.1, step 17, note 3.

There are two additional operations that can further improve the final temporal width and shape of the output pulse.

7.3.1 Final Pulse Width (FWHM)

In order to generate the shortest pulses, the final pulse width can be improved by optimizing the distance between GA84 and MA85. This procedure requires the use of a good autocorrelator.

1. Measure the autocorrelation pulse width.
2. Increase the spacing between the grating GA84 and retro-reflector MA85 by a few millimeters.
   Note: The control knob closer to the output port of the PC–1000 is used to adjust this distance. (Two turns equals one millimeter.)
3. Measure the autocorrelation pulsewidth again and compare.

If the pulse duration is shorter than the original measurement, repeat the above procedure. If not, decrease the spacing.

Note: When you are close to the optimum value, the distance required for maximum compression changes by only a fraction of a millimeter.

7.3.2 Final Pulse Shape (wings)

If you have a good autocorrelator, you will be able to detect the presence of "wings" under the pulse. It is generally desirable to minimize this feature. Fine tuning the angle θ_c formed by MA83, GA84, and MA85 will reduce the intensity of the pulse "wings."

1. Measure the autocorrelation of the pulse and determine if the pulse shows any sign of slowly falling off wings or asymmetrical features.

   Note: The pulse may look like it falls off quickly away from the peak, but make sure that the scan range is not too narrow. On a wider delay range the pulse appears sharper, but wings become more apparent.

   Note: Asymmetrical features can be a sign of higher order residual chirp or a poorly aligned autocorrelator.

   Note: If you see no signs of poor pulse shape, your CPA–1000 is well aligned and you are finished with the standard system.
2. Very slightly adjust the angle formed by MA83, GA84 and MA85 by changing the pointing direction of TM82. Translate the beam spot on mirror MA83 a few millimeters to its left.
3. Adjust the horizontal tilt of MA83 (upper knob) to reposition the beam back onto the rotation axis of the grating stage.
4. Adjust the rotation angle of GA84 to redirect the beam towards MA85.

   Note: The control knob for the grating rotation stage is the knob further away on the output side of the PC–1000.

   Note: This procedure changes the angle of incidence on the grating without changing the position or direction of the exiting beam (along the compressor's reference axis).
5. Measure the autocorrelation pulse shape again.

   If the pulse duration is shorter, or the wings and/or asymmetry are reduced compared to the original measurement, repeat the above procedure. If not, decrease the angle and repeat the process.

   When you are close to the optimum value, the change in the beam spot position on MA83 is hardly noticeable.

Note: You will have to re-optimize the pulse compressor if the number of round-trips in the regenerative amplifier changes.

A. PS–1000 Wavelength Tuning

The stretcher section of the PS–1000 module consists of the path (see Fig. 5–3)

TM32 → GA33 → MA34 → MA35 → MA34 → GA33 → MA36,

and its return path. The stretcher axis is chosen to be along the sixth row of holes from the top (injection port side) of the enclosure. The beam incident on the grating comes from mirror TM32. The central wavelength component of the beam reflected from the grating is set to travel along the stretcher axis. Our goal in this section is to present a convenient relationship between the wavelength component traveling along the stretcher axis and the angle given by the grating's rotation stage.

A.1 Relationship between Wavelength and Grating Angle

The most common method for determining the wavelength of an incident beam is to use the so-called Littrow condition, in which the angle of incidence on the grating is set so that the first-order reflection is sent back along the incident beam direction. Since the geometry used in the PS–1000 is not true-Littrow, we will generalize the Littrow condition somewhat.

DEFINITIONS

a ≡ grating constant

λ ≡ wavelength of light

$\mathbf{k}_i$ ≡ incident wave direction

θ_i ≡ angle between $\mathbf{k}_i$ and $\mathbf{n}$

θ_s ≡ angle between $\mathbf{k}_i$ and $\mathbf{k}_r$

$\Theta_R^{(m)}$ ≡ grating stage angle for retroreflection of order m

$\mathbf{n}$ ≡ normal to grating surface

m ≡ diffraction order

$\mathbf{k}_r$ ≡ reflected wave direction

$\theta_r^{(m)}$ ≡ angle between $\mathbf{k}_r$ and $\mathbf{n}$ for order m

$\Theta(\lambda)$ ≡ grating stage reading for λ-component on $\mathbf{k}_r$ axis

The grating equation is: $\sin\theta_r^{(m)}(\lambda) - \sin\theta_i = m\lambda/a$. (1)

For the condition that the reflected beam is along the stretcher axis we find

$$\sin(\theta_i - \tfrac{1}{2}\theta_s) = \lambda/(2a\cos\tfrac{1}{2}\theta_s), \tag{2}$$

$$\boxed{\Theta(\lambda) = \Theta_R^{(0)} - \tfrac{1}{2}\theta_s - \sin^{-1}[\lambda/(2a\cos\tfrac{1}{2}\theta_s)].} \tag{3}$$

Equation (2) relates the angle of incidence on the grating to the wavelength of light that is directed along the stretcher axis. The second equation transforms this into values that can be read from the grating rotation stage. Note that for $\theta_s = 0$ the beam is retroreflected and the standard Littrow condition is recovered.

Since there is freedom in how we may set the grating holder in the rotation stage, we may choose $\Theta_R^{(0)}$ to be some convenient value, such as

$$\Theta_R^{(0)} = \sin^{-1}[\lambda_0/(2a\cos\tfrac{1}{2}\theta_s)] + \tfrac{1}{2}\theta_s, \tag{4}$$

where λ_0 is to the wavelength at the peak of the Ti:Sapphire gain curve. We then can rewrite the second equation as

$$\Theta(\lambda) = \sin^{-1}[\lambda_0/(2a\cos\tfrac{1}{2}\theta_s)] - \sin^{-1}[\lambda/(2a\cos\tfrac{1}{2}\theta_s)]. \tag{5}$$

Note that $\Theta(\lambda_0) = 0$ implies that when the grating rotation stage reads zero, the peak wavelength of the Ti:Sapphire emission is directed on the stretcher axis.

If these values have not been determined, the following procedure describes how to do this if you wish to do so.

A.2 Measuring the Pulse Stretcher Angle

Since the pulse stretcher is already aligned, the beam from TM32 hits grating GA33 on the rotation axis. The beam height before and after reflection is 3.5″ (bottom row of holes in the alignment tool). Ideally, we would like to measure angles in retroreflection but this would destabilize the oscillator. Let us work slightly off retroreflection by sending the back reflection a little high.

1. Close down the PS–1000 input axis pinholes PH23 and PH29.
2. Turn **back** knob of grating rotation stage about 1/4 turn screw-in.
3. Release the stage clamp so the assembly turns freely.
4. Rotate the stage to bring the zero-order diffracted beam in line with the incident beam.

   Note: You will notice the first-order spectrum pass over TM32 before the zero-order spot arrives at TM32.

   Note: Look for the retroreflected beam spot on the back of PH29.
   If the spot is too high, rotate the back knob in the screw-out direction until the back reflection is close to (but above) the hole in PH29.
5. Read the angle $\Theta_R^{(0)}$ off the grating rotation stage scale.

   Note: This angle is the stage reading when the $m = 0$ zero-order is retroreflected. ⇒ Incident beam is normal to grating surface.

6. Place the alignment tool just in front of mirror MA34 with its slot centered on the stretcher axis.

   Note: The stretcher axis coincides with the sixth row of holes from the top of the baseplate.

7. Read the angle $\Theta^{(0)}$ off the grating rotation stage scale.

8. Calculate and note the angle $\theta_s = 2\,|\Theta^{(0)} - \Theta_R^{(0)}|$.

If you wish to set $\Theta_R^{(0)}$ as in Eq. (4), follow steps 9 – 13, otherwise go to step 15.

A.3 Setting a Particular Stage Offset Angle

9. Calculate and note $\Theta_R^{(0)}$ using Eq. (4) and your value for θ_s.

   Note: The peak in the Ti:Sapphire is typically near 790nm, but you may want to define it more accurately for your system by running the oscillator in cw-mode without any wavelength control and maximizing the output power. Use a spectrometer to obtain an accurate reading of λ_0. This will give a value optimized to your system.

10. Set the stage reading to the value for $\Theta_R^{(0)}$ and clamp the stage.

11. Loosen the brass screw in the post holder and rotate the grating for zero-order retroreflection.

12. Fine tune the angle by lining the back reflected spot to the pinhole on the back of PH29.

13. Tighten the brass screw in the post holder and release the stage clamp.

    Note: If the set screw does not twist the post during tightening, your grating stage is set to obey Eq. (5) above, which can be written as

$$\Theta(\lambda) = c_2 - \sin^{-1}(\lambda/c_1), \tag{6}$$

    where $c_1 = 2a \cos \tfrac{1}{2}\theta_s$ and $c_2 = \sin^{-1}(\lambda_0/c_1)$.

    Note: If the oscillator is run cw without wavelength control and the grating stage is set to the zero position, the λ_0 wavelength component of the first diffraction order should be centered on the slot in the alignment tool on the stretcher axis.

14. Reset the tilt of the grating back to reflecting the beam parallel to the baseplate.

    Note: To aviod optical feedback position the beam spot off to the left side of TM32. Turn the back knob of the grating mount in the screw-out direction.

    Note: Be careful to avoid back reflecting the beam when passing the first diffraction order back across TM32. Before placing the spectrum on the stretcher axis, check that the first-order spectrum is also properly aligned to the lowest row of holes in the alignment tool.

15. Open PH23 and PH29.

A.4 Bandwidth Estimation (visual)

To obtain a quick and easy estimate of the bandwidth we will develop a procedure using only the results of the previous section and an IR viewer.

We have the relationship between wavelength and grating angle as

$$\lambda = 2a \cos \tfrac{1}{2}\theta_s \sin[\Theta(\lambda) - \Theta_R^{(0)} + \tfrac{1}{2}\theta_s]\,.$$

DEFINITIONS

λ_1 ≡ long wavelength limit of "visible" spectrum
λ_2 ≡ short wavelength limit of "visible" spectrum
Θ_1 ≡ stage reading for λ_1 on stretcher axis
Θ_2 ≡ stage reading for λ_2 on stretcher axis
$\Theta_+ \equiv \tfrac{1}{2}(\Theta_2 + \Theta_1)$
$\Theta_- \equiv \tfrac{1}{2}(\Theta_2 - \Theta_1)$
$c_1 \equiv 2a \cos \tfrac{1}{2}\theta_s$

The bandwidth can be calculated from the expression

$$\boxed{\Delta\lambda = 2c_1 \cos(\Theta_R^{(0)} - \Theta_+) \sin \Theta_-\,.} \tag{7}$$

1. Place the alignment tool just in front of mirror MA34 with its slot centered on the stretcher axis.
2. Release the stage clamp so the assembly turns freely.
3. Rotate the stage to bring the long wavelength end of the spectrum in line with the center of the slot in the alignment tool and read the angle Θ_1 off the grating rotation stage.
4. Rotate the stage to bring the short wavelength end of the spectrum in line with the center of the slot in the alignment tool and read the angle Θ_2 off the grating rotation stage.
5. Calculate $\Delta\lambda$ using Eq.(7) above.

   Note: Θ_1 and Θ_2 are not symmetric with respect to the center wavelength due to the angular dependence of the diffraction as

   $$d\theta/d\lambda = 1/(a\cos\theta).$$