The Fundamentals of . . .

Medical Laser Technology

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Laser systems are electro-optical devices that convert electricity into intense beams of pure colored light. There are many different types and classes of medical lasers available today that are used in various forms in most medical/surgical specialties. Each application may utilize a different characteristic of the light or the delivery system to benefit the patient.

Laser surgery.

Medical lasers work on tissues by heat, acoustical shock waves, photochemistry, photodisassociation, or biostimulation. Surgical lasers are generally considered "hot knives" that hemostatically dissect or ablate tissues with the beam of light directly, or through intermediate contact devices. Most dermatological and ophthalmic lasers are also "hot" but induce only coagulation of tissue to some degree, without causing its surgical removal. Some lasers, like the Q-switched Nd:Yag laser in ophthalmology, or a laser for lithotripsy, actually work by creating acoustical shock waves in tissue induced by optical breakdown.

Q-switched is a term that means 'quality switching' a resonator. By momentarily interrupting the optical gain in the resonator, usually by sending an electrical signal to an electro-optical crystal that turns opaque, the population inversion of the active medium increases, thereby causing a higher power burst of laser light to be emitted when the opacity is removed. This makes a Q-switch work like an optical capacitor in a laser head.

A photosensitizing drug that is activated by low-level red light is used in the treatment of cancer and several other diseases. This photochemical process is called Photodynamic Therapy, or PDT, using argon or KTP pumped Dye lasers. The Argon:Fluoride Excimer lasers, which are used to reshape the cornea of the eye to eliminate the need for glasses, works by a unique process called photodisassociation. The energy of the photons actually creates an electronic breakdown of the carbon molecule in the tissue resulting in a nonthermal type of ablation. Finally, a non-surgical use of the laser is called biostimulation. Very low levels of laser light (like laser pointers) are used to treat chronic pain, reduce inflammation in carpal tunnel syndrome, and speed hair growth.

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Technical Aspects of Design & Function

Lasers can be classified into 4 types of systems as outlined below:

Laser Type	Examples
Gas	CO_2, Argon, Krypton, Argon Fluoride, Metal Vapor
Liquid	Pulsed & Continuous Wave Dye
Solid (Crystal)	Erbium Yttrium Aluminum Garnet (Er:Yag), Neodymium Yttrium Aluminum Garnet (Nd:Yag), Holmium Yttrium Aluminum Garnet (Ho:Yag), Potassium Titanyl Phosphate (KTP), Alexandrite, and Ruby Lasers
Electronic	Semiconductor Diode Lasers

This classification is important for biomedical engineers because the maintenance and repair requirements in each class are very similar, if not identical. For example, once you know how to perform preventive maintenance (PM) on one solid state laser, you can likely do it on all lasers in that class (for instance changing flow tubes or deionizers). There are some differences within a class such as the CO_2 or Argon. However, unlike most medical equipment, there is a high degree of similarity in both the design and maintenance of most laser systems. Once you've learned to work on one CO_2 laser, you are well equipped to work on most CO_2 lasers.

Emission of light from a laser requires several components/systems:

Active Medium—is the material that actually emits the light from its atoms or molecules, such as Argon ions. The laser is named after this active medium. For instance, the CO_2 laser contains the gases CO_2, He and N_2, but it's the CO_2 molecule that emits the light.

Optical Resonator—are the front and rear mirrors that create optical gain in the active medium. The space between them is called the optical cavity, and is part of the laser head.

Output Coupler—is the front mirror of the laser, sometimes called the partially transmissive mirror. It allows a portion of the beam generated in the optical cavity to be released into the delivery system optics.

Excitation Source—is sometimes called "pump" source, or pumping the laser medium. This is what puts energy into the active medium to create the light. More atoms/molecules must be pumped into an excited state than are in the resting state. This condition is known as "population inversion," a requisite for the lasing action of the medium. The gas lasers are usually excited by a direct current (DC) or radio frequency (RF) discharge within the laser tube, while solid state and some dye lasers use high powered krypton lamps for optical pumping.

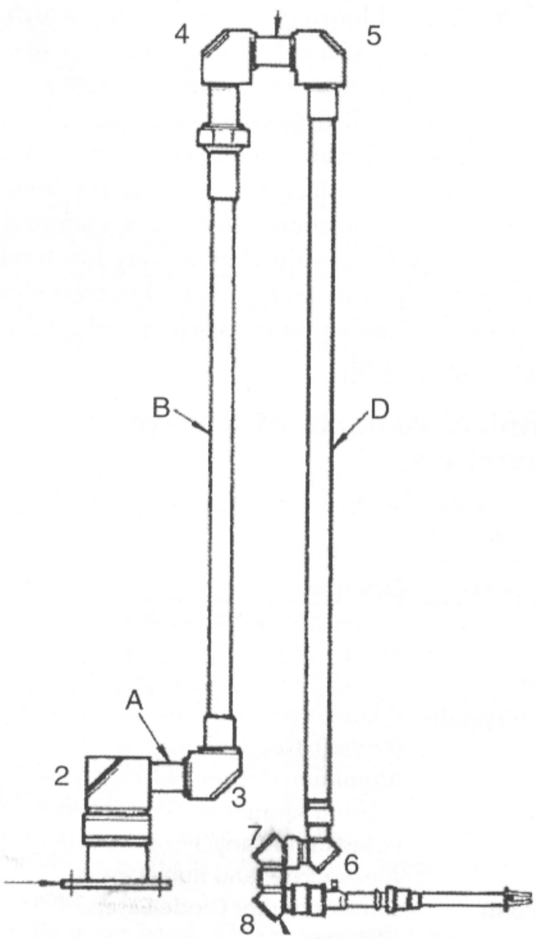

Figure 1. *Articulated arm. The letters and numbers illustrate the sequence of hollow tubes and the mirrors at arm joints, respectively.*

Of course there are all the systems required to support these primary ones, including cooling systems, safety interlocks, power and energy controls and measurement, and system logic.

Once the beam is emitted, it must be delivered to the operative site. Many lasers can be delivered through some type of fiber, but some such as the CO_2, Er:Yag, or Ar:Fl lasers are not. These latter types use hollow articulated arms (Figure 1) or are reflected directly from the laser output to the output site. Lenses are utilized to either focus the laser beam into the proximal end of the fiber (the launch optics) and/or at the output end to focus the beam onto the tissues. The intensity of the beam is manipulated through the focused spot size, power output (rate of energy delivery), and time of exposure (total delivered energy in joules).

When the beam is focused down to small spots (as with CO_2 laser handpieces), it also will defocus with distance from the lens (Figure 2). The intensity of the beam is primarily determined by the size of spot to which it is focused. A large spot will become harmless and ineffective (see the eye hazards below). Spot size can then increase the surgical intensity when very small, and also create a high margin of safety when it's very large.

Managing the Device

There are 2 aspects of managing health care laser systems within an institution. One is the day-to-day operation and power checks (not calibrations) of the unit and the other are the routine PMs (including calibrations) and repairs.

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Because of the myriad of optics and delicate alignments in lasers, they are more susceptible to performance problems than other medical equipment. The more the laser is moved, jostled, or subjected to airborne contaminants, the more often it will go down. Most laser problems are simply alignments and cleaning of optics, rather than actual part failures.

A dedicated laser operator is your first line of defense to ensure dependability of the laser. They know how to work the equipment and attachments, will properly care for them, and will report small performance problems early on. Catching a small alignment problem early can save thousands of dollars in optics replacements, which results when the problem progresses.

A routine PM program is essential to keep the laser operating properly and prevent the premature breakdown of optics and other parts. The internal power or energy meter is required to be calibrated once every 6 months, so 2 PMs per year should be the minimum. As with most pieces of equipment, maintenance may be conducted by the manufacturer, independent laser service, or in-house engineer.

Regulations

American National Standards Institute (ANSI) provides recommendations on the safe use of lasers in health care facilities. (ANSI Z136.3 Safe Use of Lasers in Health Care Facilities, 2000), Occupational Safety & Health Administration (OSHA), and Joint Commission on Accreditation of Healthcare Organization (JCAHO) have been using the ANSI standards as the basis for enforcement. They require the institution to appoint a Laser Safety Officer (LSO) who manages and administers the safety program. This may be in the biomedical engineering department. LSOs may or may not also function as a laser operator. The safety program must incorporate detailed safety policies and procedures, require documented training for all related personnel, provisions for safety eyewear and warning signs for laser rooms, and monitoring of periodic maintenance on the lasers. The 174-page manual, *Lasers in Medicine and Surgery*, has more details about the regulations and is available free at www.lasertraining.org.

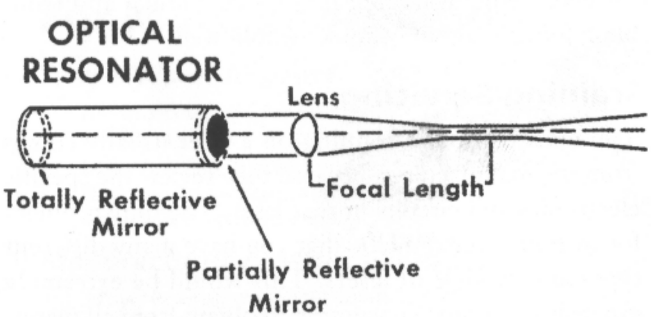

Figure 2. *Once the collimated laser beam is focused to a small spot by the lens, the spot continues to diverge and get larger as it moves away from the focal point. This increases the safety margin for burns at a distance because the spot is not intense enough to burn when it is far away.*

Risk Management Issues

Rather than discuss the risk-related issues of the entire laser safety program, comments here will be confined to those aspects of the laser that present physical risks to the biomedical engineer.

Your risk of physical injury from lasers boil down to 3 areas:

- Electrocution or burns from power supplies and electronics
- Burns to skin/clothing/room furnishings from laser beams
- Eye hazards

Electrical hazards from laser power supplies present the most serious risk of injury to engineers working on the units. Some lasers like DC excited CO_2 systems use non-lethal power supplies—typically about 15–20ma at 15–18 KV. It's enough to get your attention and possibly cause injury, but are generally not considered lethal. Some lasers use 3-phase 220v current at 50a to drive pumps. These are a serious hazard and all precautions should be taken. Ion lasers (argon/krypton) and these 3 phase lasers (like older Nd:Yag and KTP lasers) present the greatest risk.

ANSI establishes eye and skin burn hazards as their criteria for establishing the Nominal Hazard Zone (NHZ). This is the area surrounding the laser output where damage can occur, and where everyone is required to wear their safety glasses and comply with other policies. This area is determined by the LSO and may or may not be the entire laser room (Laser Treatment Controlled Area, or LTCA).

The CO_2 laser can set fire to flammable materials across the room when used without the focusing lens in the handpiece. Care must be taken when working on these systems. When the lens is in place it defocuses rapidly, which has minimal to no risk at a distance. The greatest hazard is to the engineer who has the protective covers removed. The beam is invisible and not yet combined with its red aiming light. Feel around the laser head area with your hand while the laser is firing at low powers to detect any stray deflections before putting your face there to work on it. The laser output from fibers can't burn anything more than an inch or two away from its tip, but it can set surgical drapes on fire if left in the drape when fired.

Eye hazards get the most attention in laser safety. This is as much of an emotional issue as it a technical one. No one wants to lose their eyesight, and don't be mistaken—lasers can do this if you're looking right into the output! Lasers are bright lights. Safety glasses are meant to provide safety when viewing the indirect or diffusely reflected beam. They are NOT designed for direct intrabeam viewing. This is very important and many laser operators and laser nurses are unaware of this. If someone points the beam in the direction of your face you are NOT guaranteed protection by these glasses. (As the sign says, do NOT stare into the laser beam with your one remaining eye!)

Lasers such as the CO_2, Ar:FL and Er:Yag laser do not transmit through fluid, and will not transmit back to the retina. These lasers present only surface burn hazards to the front of the eye. The spot size must be small enough (close to the laser lens) to create this intensity before it is a hazard. Therefore, a 60-watt CO_2 laser focused through a 125mm handpiece, which can cut through tissues at its focal point, will present no hazard whatsoever if aimed directly at someone's unprotected eyes across the room at 15 feet distance. The Ho:Yag laser is even safer. It does not transmit all the way to the retina, but since it is fiber delivered, it's difficult to deliver a focused spot to burn the surface of the eye unless you touch the fiber to the eye.

Lasers such as Nd:Yag, Dye, KTP, Argon, Krypton, and diode lasers present retinal hazards. Even though the beam diverges from the fiber and would not burn at a distance, the lens of your own eye would refocus these spots on the retina causing retinal burns (like welder's burns). Your safety glasses will be marked according to the wavelength (laser type) and Optical Density (OD or darkness) for which the glasses offer protection.

Troubleshooting

Service calls are requested on lasers because of:

- Operator error or unrealistic expectations
- Optics and alignments
- Electronic components and power supplies

Operator error seems to be more of a problem with lasers than other pieces of medical equipment, perhaps because they're not as automated and exhibit complex beam-tissue interactions. This is the reason why the dedicated laser operator becomes so important.

Optics and their alignments are the most common cause of malfunction. The front and rear mirrors are responsible for the peak power outputs of the laser head. They must be aligned perfectly parallel to one another and perpendicular to the optical cavity. Infrared lasers usually are combined with a red Helium Neon (HeNe) laser so you can see where the beam's going. This involves a combiner assembly with a near and far alignment mirror.

When your burn spot isn't with the red dot, it's usually this combiner. Once the beam is emitted it must be launched into either a laser fiber or articulated arm. The fiber requires a launch optic and 3 axis alignment into the fiber. The articulated arm involves a series of 7 mirrors within a jointed hollow arm, and an entire series of alignments. It is recommended that when performing an arm alignment you perform a burn on a piece of tape that shows the run out of the arm in all positions. This can be taped to your service report as documentation of the alignment.

If a laser head has no output at all (and doesn't use an expendable gas or dye supply) you should usually check the output of the power supply. Of particular concern are the passbank power supplies for ion lasers. The electronics controlling the logic of operation are different for every type of laser. The service manual and troubleshooting diagrams should be followed.

Training/Servicing

The most thorough training on a laser usually comes from the manufacturer, because they review the specific electronics and circuits in that laser. The only problem for in-house personnel is that you have many different types and models of lasers. This would be extremely expensive and time consuming to obtain from all manufacturers.

The comprehensive types of hands-on laser courses cover many different systems because they don't dwell on the specific non-laser electronics in each system. Most biomedical engineers already know how to perform basic electronic troubleshooting and follow the block diagrams in the manuals. It's only the optics and alignments that are new. By concentrating on these specific components that are unique to lasers, you can become reasonably adept at basic PM's and front line troubleshooting on many lasers. The service procedures on the optics and alignments are very similar if not identical from one laser to the next.

Everyone will need some backup or outside help at some point. Once you complete an initial laser training program, you should be able to perform all normal PMs and calibrations on the equipment.

You do need one power meter and the service manual for each laser. A power meter consists of both the meter and heads that attach for different types of lasers. It will cost between $2500–$3500 for a meter and 2 or 3 heads. There are many specialty tools available from manufacturers, though almost all of these are "nice to have" rather than "need to have" tools.

You will also need the service manual for your specific laser. Manufacturers are required to include the specific alignment and calibration procedures for that laser. The Food and Drug Administration is very specific about this requirement, and the *complete* manual must be provided to anyone upon request, at the reasonable cost of reproduction. Most companies are fairly cooperative about complying with this requirement. The requirements are in the Code of Federal Regulations (CFR) at 21CFR 1040.10 H2II, and 21CFR 1040.11 A2. If you need step-by-step guidance on contacting the FDA to obtain service manuals, you can find it on our Web site along with links to the actual CFR.

For More Information . . .

Web Sites of Interest

- **American Society for Laser Medicine & Surgery,** www.ASLMS.org
- **Laser Training Institute,** www.LaserTraining.org
- **National Council on Laser Excellence,** www.LaserCertification.org

Manufacturer & Service Web Sites

- **Altus Medical,** www.altusmedical.com
- **Candela Laser,** www.clzr.com/candelalaser/
- **Continuum Lasers,** www.continuumlasers.com
- **Lumenis (Incorporates ESC, Sharplan, Coherent and HGM),** www.lumenis.com
- **National Laser Parts & Service,** www.National-Laser.com
- **Palomar,** www.palmed.com/
- **PLC Lasers,** www.plcmed.com/home.stm