SURGICAL CO_2 LASER SYSTEM DEVELOPED AT CAT

Lasers are being widely used in medicine for various surgical modalities. Laser surgery due to its several advantages viz. non-contact nature, minimal blood loss, reduction in trauma, selective irradiation, sterilization etc., has been found to be a better choice compared to conventional surgical procedures in many cases. Further, the ability to direct the laser beam into the interior of the body by means of optical fibres or other suitable attachments eliminates the need of major incisions. This converts major surgeries into outpatient procedures consequently reducing the hospitalization time. This aspect is particularly important in the Indian context where hospital beds are in a short supply.

The CO_2 laser is one of the most widely used surgical lasers. A major reason for this is the fact that the CO_2 laser radiation is strongly absorbed in water which is a major constituent of all tissues. The CO_2 laser interaction is therefore, not tissue specific and the laser can be used as a general purpose surgical tool. Further, the strong absorption coefficient ensures deposition of energy in very small depths (15-20 μm) leading to precise incisions and minimal thermal damage to the surrounding tissue. Table 1 lists some of the areas where the CO_2 laser is used along with typical conditions of use. From Table 1, it can be seen that power levels of about 20 W and exposure durations ranging from 0.05 seconds to several seconds are common. Further, in certain cases, pulsed operation of the laser (about 500 W peak power, few hundred μs pulsewidth, 10-15 W average power) is required. Keeping these requirements in view, the model C-40 surgical CO_2 laser system was developed at CAT. Two units of this model are already in use, one at Choithram Hospital and Research Centre, Indore and the other at Centre for Biomedical Engineering, All India Institute of Medical Sciences, New Delhi.

In this article, we first provide a brief overview of the mechanism of interaction of CO_2 laser radiation with tissues and how it is exploited for various surgical procedures. We then describe the model C-40 CO_2 laser system in detail.

Mechanism of interaction of CO_2 laser radiation with tissues

The primary mechanism of interaction of the CO_2 laser radiation with tissues is thermal. The laser beam falling on the tissue gets absorbed in the tissue and heats it up. The rise of tissue temperature will depend on the rate of deposition of energy and the volume into which it is deposited. For moderate increase in temperature of the tissue, the damage is through denaturation. The denaturation temperatures can vary from few degrees above the body temperature to 85°C depending on the tissue under consideration. The denaturation can be used for welding of tissue thus dispensing with sutures. At above 65°C, coagulation of the tissue occurs leading to cell necrosis. The coagulation of the tissue also results in sealing of blood vessels and pain nerves cut during surgery and thus helps in minimizing blood loss and reducing pain. When the temperature exceeds 100°C, vaporization of the tissue water occurs. A 1670 fold volume expansion occurs when the tissue is vaporized isobarically leading to physical separation and cutting. Tissues heated beyond vaporization temperature of water are ablated and carbonized. At these elevated temperatures generated in the thermal cutting process, bacteria and virus are sterilized, minimizing chances of infection. At very high intensities and short pulse durations, the extremely large temperature gradients produced can also lead to athermal non-linear effects like shock wave generation. The three basic processes viz., coagulation, cutting and ablation produced by the CO_2 laser are exploited by surgeons for various therapeutic modalities indicated in Table 1.

Model C-40 CO_2 laser system.

The model C-40 CO_2 laser is shown in Fig.1. The laser system consists of a CW CO_2 laser head that can deliver more than 60 W power, a rotary vacuum pump and gas

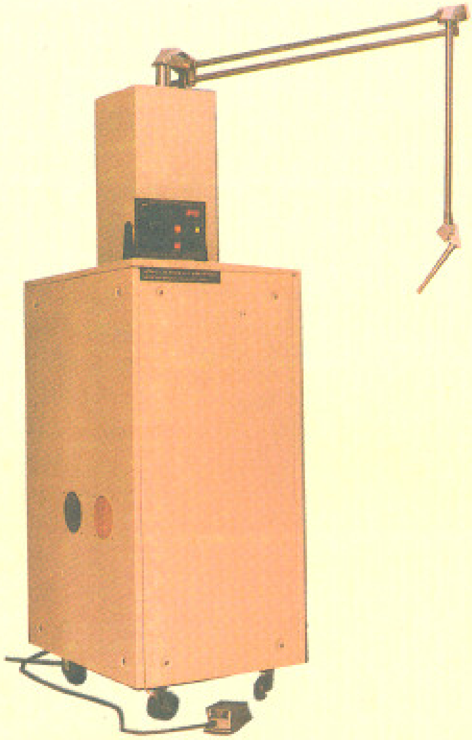

Fig.1. The model C - 40 CO_2 laser system.

supply unit to create vacuum and fill gas in the proportion of $CO_2 : N_2 : He :: 1:2.5:12$ at a pressure of 40 mbar and a flow rate of 0.3 lpm at STP. The high frequency power supply creates the initial discharge into which dc power is pumped. As the CO_2 laser beam is invisible, a 2 mW red He-Ne laser beam is combined with it coaxially to locate the site of operation. A shutter controlled by a pedal switch controls the CO_2 laser beam exposure at the site of operation. When the beam is blocked by the shutter, it is deflected into a power meter developed by us for measurement applications.

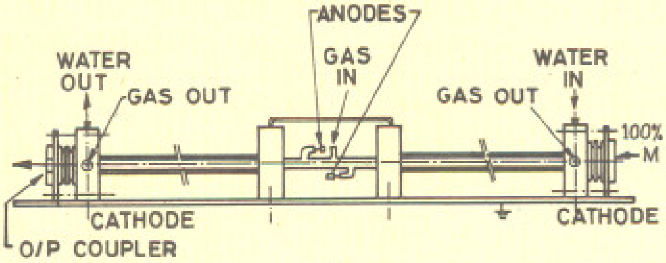

Fig.2. A schematic diagram of the laser head of model C - 40 CO_2 laser system.

Fig.2 shows the diagram of the laser head. The laser is a slow flow diffusion cooled longitudinal laser. To operate the laser at lower voltages and for ease of alignment, a two limb discharge structure is adapted. The advantage of this structure is that the discharge length is reduced to half as electrical power is pumped into two discharge limbs which are electrically in parallel but optically in series. Further, both mirrors are attached to cathodes which are at ground potential and alignment can be done safely even during operation of the laser. The HF power supply generates high voltage (5 kV, 10-20 μs pulse width) and high frequency (5 kHz) pulses which create the initial discharge. The dc power is then pumped into the discharge. This scheme has two advantages over the conventional scheme of pure dc discharge pumping. First, if one uses a pure dc supply, the voltage has to be increased beyond the breakdown voltage to create the discharge and then reduced to maintain optimum current. By the use of the HF supply, discharge is already created and dc power can be pumped into the discharge at low voltage levels also. Secondly, by varying the dc voltage from zero to maximum value, a smooth variation of output power is obtained from few mW to maximum power. In a pure dc discharge operated laser, the ballast resistance limits the value of the minimum current below which the discharge gets quenched. Hence min-

Table 1 : Major areas and conditions for use of CO_2 laser in medicine

Area	Power (W)	Power Density (W/cm^2)	Pulse duration
Cutting (General):			
soft tissue	~5		
hard tissue	15 - 20	-	-
Welding	0.1 - 2	<200	-
Otolaryngology	10 - 15	2000	0.05 - 1s
Neurosurgery	60 - 80	5000	<0.1 CW
	10 - 20 (500 W peak)	10^6	10^{-4} s >200Hz rep. rate
Dermatology, Plastic Surgery & Podiatry	5 - 15	1000	-
Gynaecology	10 - 20	2000	CW
Dentistry	10 - 20	250 - 2000	0.1s - CW
Oncology	10 - 20	2000	-

Table 2 : Specifications of model C-40 system

Parameter	Value
Laser	CO_2 laser, multimode
Wavelength	~10.6 μm
Focussability	350 μm
Modes of operation	CW, Chopped, Superpulse
CW and chopped mode:	
a. Power output	Few mW - 30 W
b. Exposure duration	0.1, 0.2, 0.4, 0.8, and 1.0 sec
Super pulse mode:	
a. Maximum average power	20 W at laser head
b. Energy/ pulse	100 mJ
c. Pulse repetition rate	200 Hz
Aiming beam	2 mW He Ne red laser
Beam delivery system	7 joint, light weight, spring balanced articulated arm
Cooling	self contained chiller
Controls	Sequential, automatic
Weight	~350 kg
Dimensions	~70 x 80 x 90 cm (main cabinet) about 180 cm mast height.

Accessories : Micro manipulator attachment for coupling with surgical microscope of 40 cm working distance.

imum power below say 20% of the peak value cannot be practically obtained in pure dc discharge operated lasers. In some medical applications, operation of the laser at very low power levels is essential and the above scheme developed by us accomplishes this purpose.

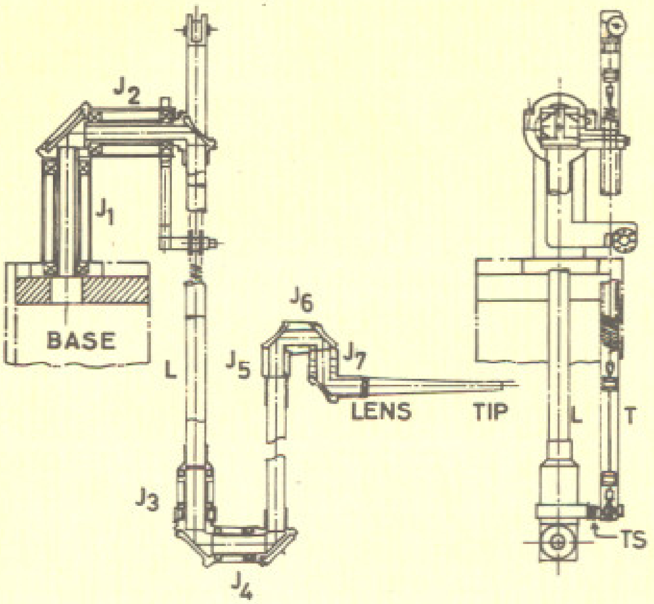

Fig.3. A schematic diagram of the articulated arm.

The laser beam emanating from the laser head should be carried to the site of operation in a flexible manner. Due to non-availability of optical fibres in the mid IR region, we have developed an articulated arm based beam delivery systems shown in fig.3. There are seven joints (J_1 to J_7) in the articulated arm to provide flexible three dimensional motion. At each joint a mirror is mounted on a bearing housing at 45° angle of incidence to the laser beam. At each joint, the laser beam can be rotated by 360° about its axis of incidence. All the joints are connected by hollow tubes through which the laser beam passes. The arm is counter balanced at joint J_2 by means of a tension spring mounted inside a long, hollow tube (T) using a rope and pulley arrangement. The tube T is mounted below the long limb (L) of the articulated arm. The long tube serves as a sacrificial arm also in the following way. The long limb (L) undergoes deflection because of cantilever loading due to its own weight and weight at its end. But it has to be straight to pass the laser beam without obstruction. The sacrificial arm is deliberately deflected by adjusting a thumb screw (T.S) in between T and L. This compensates the deflection in the long tube L and keeps it straight. To keep the diameter of the arm to a minimum, the laser beam size has to be maintained small throughout the arm. This can be achieved by the use of long focal length concave mirrors in an astigmatic-free configuration at the joints. In our case, concave mirrors of radius of curvature of 2.5 meters were used at the first four joints of the articulated arm. The beam radius was 2.5 mm at the end of the arm, whereas at the input it was 2.7 mm. At the tip of the articulated arm, a lens is attached to focus the laser beam at the site of operation. To couple the laser beam to a surgical microscope of 40 cms working distance a micro-manipulator was also made. By the use of this manipulator, laser surgery can be performed by viewing through a microscope. In the micro manipulator, a concave mirror focuses the laser beam at the site of operation. A joy-stick arrangement has been used to move the concave mirror so that laser beam can be made to fall at any point in the field of view of the microscope. This attachment is useful particularly in applications like Otolaryngology.

Table 2 describes the specifications of the model C-40 laser system. These specifications compare favorably with commercially available imported systems. Cost wise, the laser developed at CAT may cost about half of a similar imported unit. As a first step towards commercial production, two units of this model have already been given to hospitals for detailed evaluation. The first unit was handed over to Choithram Hospital and Research Centre, Indore by Dr. P K Iyengar, Chairman, AEC in May 1990. The other unit was delivered to Centre for Biomedical Engineering, All India Institute of Medical Sciences, New Delhi. The system installed at Choithram Hospital has been used in various clinical modalities. It has been particularly used in Otolaryngology to remove blockages in vocal canal (Voice therapy). The observed lack of post-operative Oedema and dry operative field make it a superior choice to conventional therapy in this case. For use in ENT, the laser system has been coupled to a Zeiss operating microscope through the micro-manipulator. So far more than 75 operations (32 in ENT, 25 in gynaecology and 18 in general surgery) have been performed using the laser system.

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