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Principal Investigator: James H. Burkhalter
Martin Company

LASERS AND THEIR EFFECTS

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ABSTRACT

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A description is given of the work performed by the Martin Company Research Laboratories for the Biological Effects of Lasers Program of the Office of the Surgeon General for the period 1 July 1963 to 1 March 1964. This includes the design and construction of a research laser and associated instrumentation for the attack on problems of interest to the biological researchers of the program. A discussion is presented of the more important problems to date of the various biological researchers, together with the approaches used.

- 7. Key words: Lasers, Q-Switch, Beam Sampling, Impulse, Shock Detectors**

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FOREWORD

This document is submitted in fulfillment of a requirement of Contract Number DA-49-193-MD-2456 between the Office of the Surgeon General and Martin Orlando, and constitutes the 1964 annual report due 1 April 1964 on that portion of the contract work accomplished to date.

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INTRODUCTION

The Office of the Surgeon General has a program of research in the biological effects of lasers, with several member biological laboratories participating in this work. These member laboratories should not and do not wish to dilute their efforts with problems of an electro-optical, instrumentation, or general physics nature. For this reason, the Office of the Surgeon General has contracted with the Martin Company to furnish general assistance to the overall program and to its individual members.

It has been determined that the Martin laboratories can be of best assistance to the member biological laboratory by following a line of effort involving a combination of long and short range problems. Much of this work is directed toward the assistance of the program as a whole, and some is directed toward attacks on specific problems of the individual member laboratories. The work described in this document represents the efforts expended on this program for the period 1 July 1963 to 1 March 1964.

1. RESEARCH LASER

A. DESIGN CRITERIA

One of the prerequisites of the work planned under this program was a research type of high power laser with the parameters controllable as much as possible and designed for the maximum of flexibility of operation. In particular, it was desired that both room temperature and cryogenic temperature operation be possible, and that the laser operate in both Q-switch and non-Q-switch modes at both temperatures.

B. CONSTRUCTION DETAILS

With these criteria in mind, an original design was conceived for this laser. An analysis was made comparing the advantages and disadvantages of a two flashtube design versus a four flashtube design. For a 6-5/8 inch long by 5/8 inch diameter ruby, under the requirement of cryogenic operation, the flashtube chosen for this operation was the type FX-47 manufactured by Edgerton, Germeshausen & Grier, Incorporated. It is a linear type of flashtube with a 6 inch arc length rated at 10,000 joules each at 3000 volts. Under these restraints, a comparison of a four elliptical lobe cavity to a two elliptical lobe cavity showed that, due to the loss of coupling efficiency in the four lobe case, the four flashtube case was only marginally better than the two flashtube case using twice the input. Since each flashtube must have a bulky, expensive, capacitor bank, the decision was made to design for the two flashtube case.

It was also noted that the expensive fabrication of elliptically cylindrical surfaces could be avoided with very little loss of efficiency if the unit is designed carefully. For the cavity design chosen (Figures 1 and 2), due to the relatively large diameter of both the ruby and the flashtube, little additional cylindrical aberration is introduced by the use of cylindrical rather than elliptical reflectors, providing that the object (flashtube) and image (ruby) positions are relatively close to the center of curvature.

Thus, within the constraint of the space required at each end of the ruby for the heat exchanger and flashtube connectors, the flashtubes should be as close as possible to the ruby. With the heat exchanger design

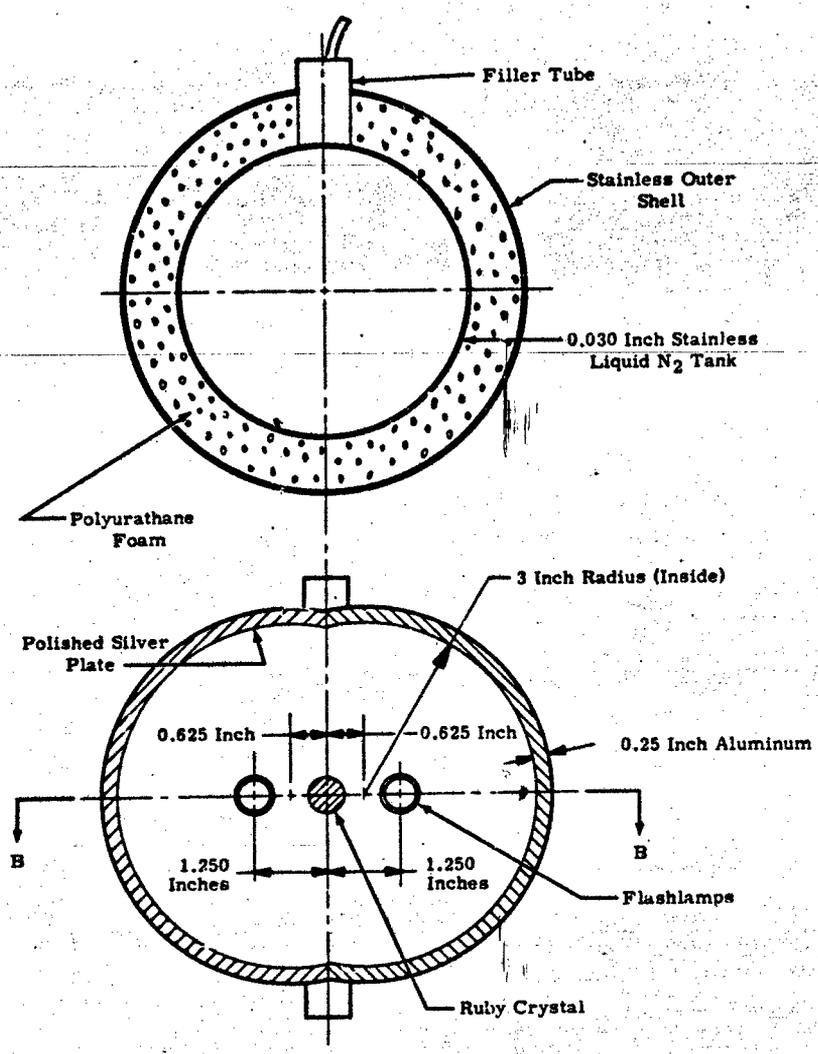
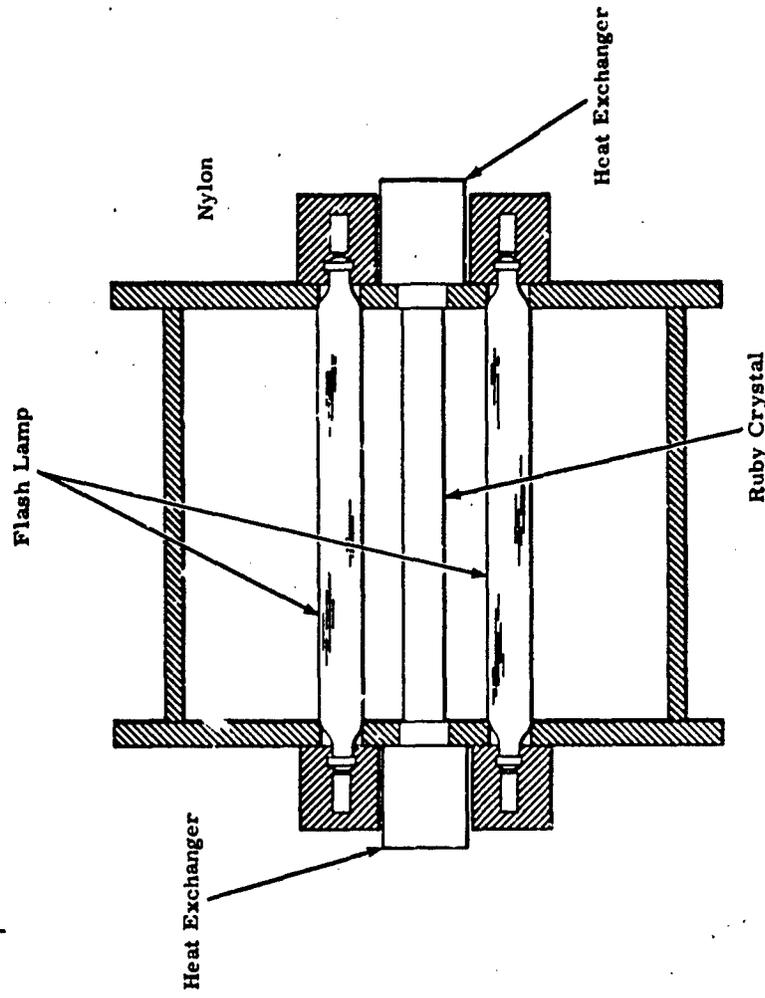


Figure 1. Laser Cross Section, Elevation



Section B-B
 Figure 2. Laser Cavity Cross Section, Plan

incorporated, the required ruby to flashtube distance was 1.25 inches. With this distance chosen, the best tradeoff between best image (infinite radius) and availability plus convenience of size was a cylinder with a 3 inch inner radius. In this manner, the geometry of the cavity is determined, and is that depicted in Figures 1 and 2.

The heat exchanger, whose outside dimensions constituted an input to the cavity design above, is shown in Figure 3. The ruby is held between copper fingers formed by milled slots in the tubular holder. Due to differential shrinkage, the hold becomes tighter as the assembly is cooled. An edge relief is incorporated to prevent edge damage to the laser rod. The tubular holder is formed into a heat exchanger by fins and an outer wall forming a tank. This tank is kept flooded with liquid nitrogen at 77°K supplied from a special Dewar above. The exhaust gases are returned to the tank, from which pressure relief gases are piped through a copper helix heat exchanger at the rear of the laser and into the laser cavity (Figures 4 and 5). This serves as a continuous drying and purging source to prevent moisture from condensing on the cold surfaces and spoiling the optics. The bleedoff of this purging dry nitrogen is both around the heat exchanger, keeping the region around the cavity-heat exchanger contact dry, and through the finger slots, keeping the end of the ruby dry. The heat exchangers proper, one at either end of the ruby, are supported by insulating polyurethane foam.

In order to maximize the coupling efficiency between the flash lamps and the laser rods, the inner cavity walls are silver plated and highly polished (Figure 5). The entire cavity assembly is mounted on an I-beam support in such a manner that it can be moved along a channel, thus controlling the distance between the laser rod and the Q-switcher described below. This I-beam also serves as an optical bench for mounting other associated components.

The Q-switching head is primarily a rotating Porro prism with associated synchronization and positioning devices. It is diagrammed in Figure 6 and illustrated with the cover removed in Figure 5. The prism itself is made of high quality optical quartz with roof angle tolerance less than 1 second of arc. This is rotated at speeds up to 30,000 rpm by an electric motor. At a given phase of each revolution, a tiny magnet passes near a magnetic pickup coil, generating a pulse. The phase of these pulses is adjustable by positioning the synchronizer disc, which is supplied with a reference scale and a clamp. A cover protects the assembly in operation. By counting the rate of such pulses, the motor speed can be accurately determined and, by using one of the pulses to trigger the flash lamp, the firing can be so phased that the ruby has been pumped to a condition of optimum population inversion at the time the prism arrives at its critical angular position.

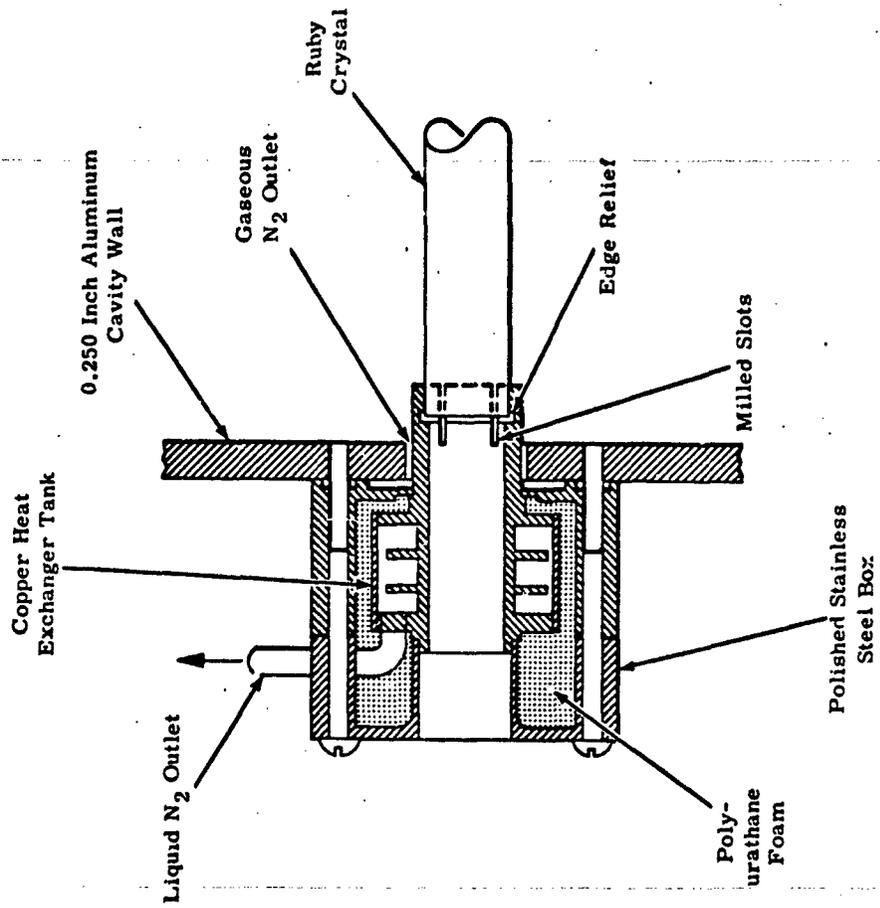


Figure 3. Heat Exchanger Assembly

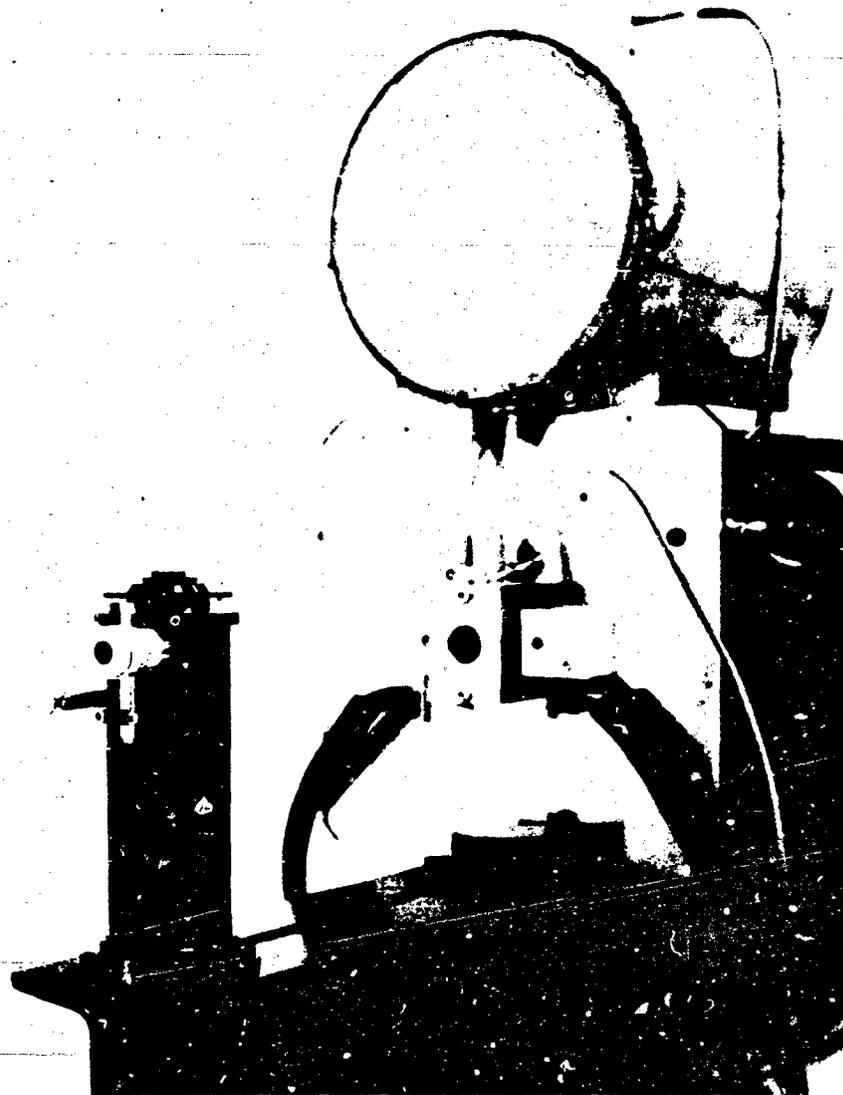


Figure 4. Q-Switch and Laser

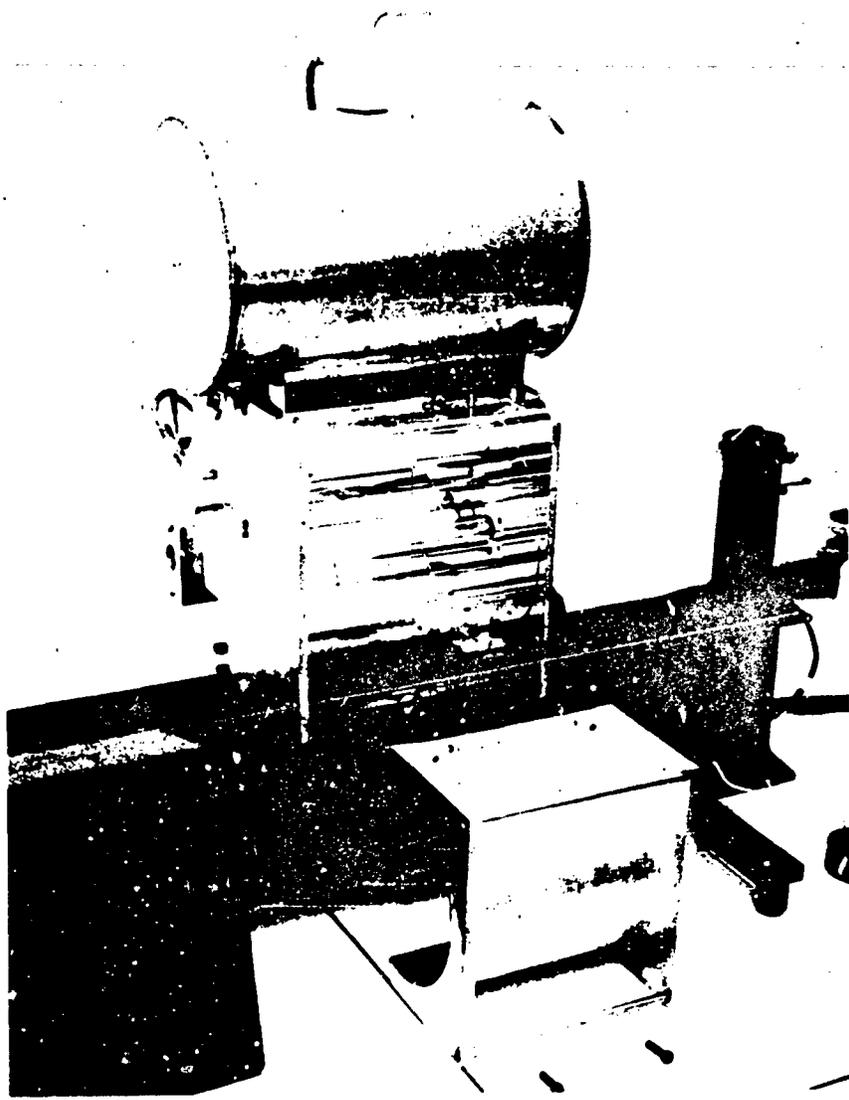


Figure 5. Laser with Cover Removed

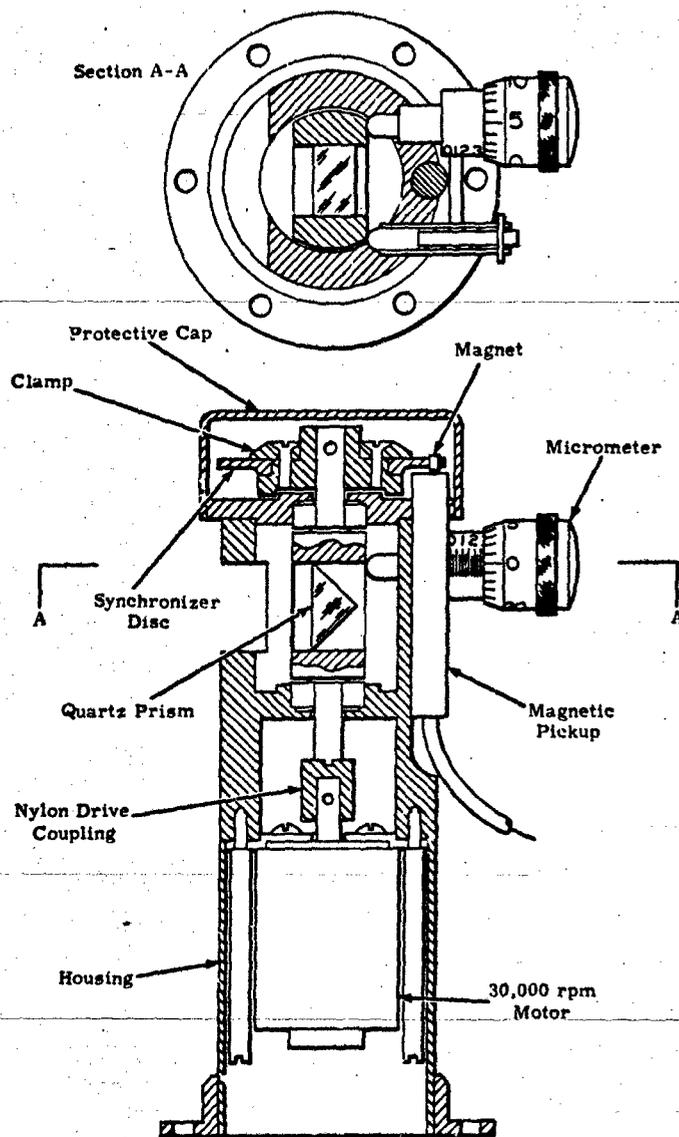


Figure 6. Q-Switch Mechanism

For non-Q-switched operation, the prism is held in an arrested position with the motor off. This position is determined by releasing a spring loaded latch which then bears against one side of the prism housing. A micrometer is then advanced to bear against the other side so that position is reproducibly characterized by the micrometer reading. (See section AA in Figure 6.)

The output of the laser is from the end of the ruby opposite the prism. Reflectors of chosen reflectivity may be mounted in front of the laser rod to adjust the Q of the optical cavity. The normal ruby-air interface, uncoated, has about 8 percent reflection and is adequate for much high power work. It has the advantage over a coated reflector of ruggedness to the extremely high power levels involved.

C. ELECTRONICS

The electronics for the research laser consist of a power supply to charge the storage capacitors, a trigger circuit to trigger the flash lamps, a power source for the Q-switch motor, and various monitoring circuits. The overall design of the laser in general, and the electronics in particular, is oriented toward maximum flexibility of operation. For example, the laser can be operated in either the Q- or non-Q-switch mode. It can also be fired from a remote point or from the electronics cabinet next to the laser itself. The Q-switch motor speed can be varied from 0 to 30,000 rpm continuously and is monitored by a tachometer.

1. Q- and Non-Q-Switching

The electronic trigger circuit which produces the high voltage trigger output to the flash lamps can be operated either in the Q-switch mode or the non-Q-switch mode. The basic block diagram for this circuit is shown in Figure 7. Here the central element is a flip-flop (bistable multivibrator). This flip-flop drives an amplifier and then a silicon controlled rectifier through the amplifier which discharges a capacitor into the primary of a step-up transformer to produce the high voltage output trigger pulse. This pulse has approximately 31 kilovolts amplitude and approximately 10 microseconds duration. Ahead of the flip-flop is the Q-/non-Q-switch. Here the switching is done by two mechanical switches. One is the Q-/non-Q-switch, the other is the firing switch. In the Q-switch mode the positive voltage (3.3v) is applied to an AND gate with the output from an amplifier from the pickup in the Q-switch motor. When both signals are present at the same time, the flip-flop is triggered if the fire button has been pressed. In the non-Q-switch mode, the fire signal goes directly to the flip-flop and causes it to trigger the high voltage transformer as before.

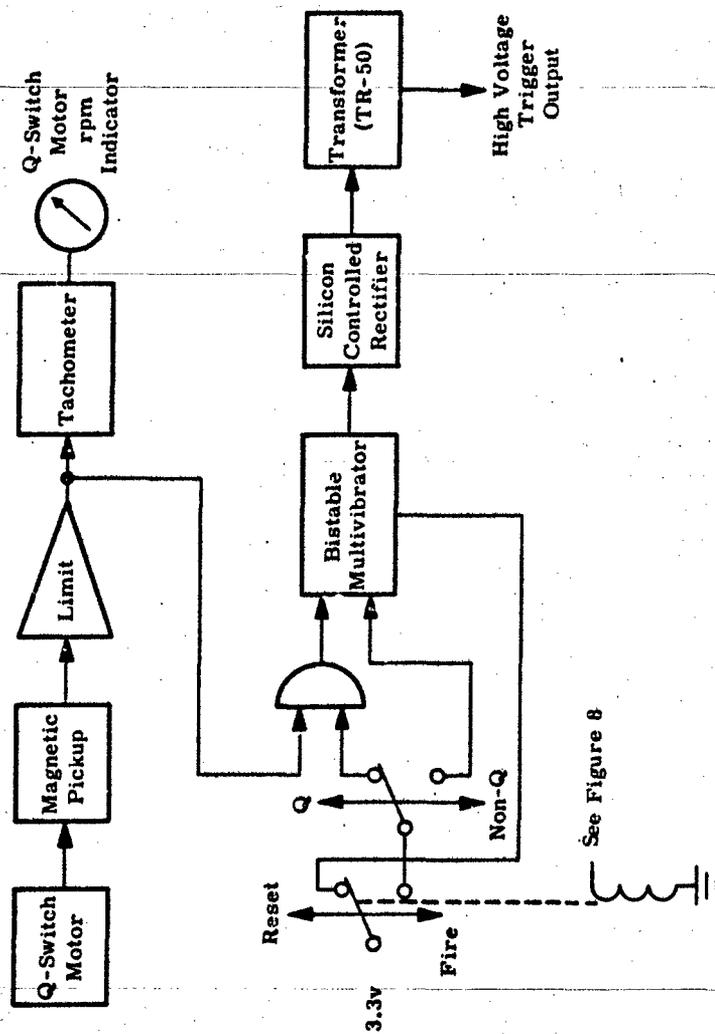


Figure 7. Trigger Generator

The Q-switch motor which drives the prism to form a rapid buildup of the Q in the optical cavity also produces an output from a magnetic pickup. The magnetic pickup is obtained from a small head and a rotating chisel-pointed magnet. The output of the magnetic pickup is amplified and sent both to the AND gate and to a tachometer circuit to indicate the speed of the Q-switch motor.

2. Q-Switch Motor Interlock

Referring to Figure 8, the Q-switch motor is interlocked with the Q-/non-Q-switch on the control panel. A relay is connected so that remote control of the Q-switch motor is possible. The Q-switch motor can operate only when the Q-switch mode of operation is selected, the Q-switch motor is turned on, and the voltage of the Q-switch motor is sufficiently high to make it rotate.

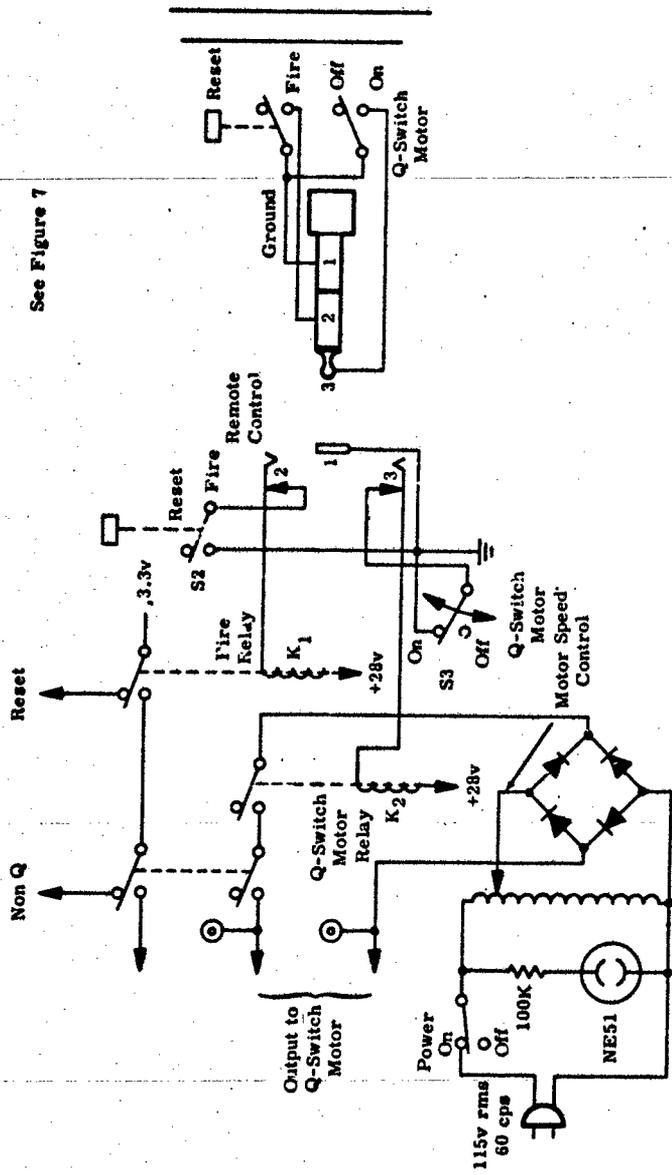
A remote control jack is provided so that the laser as well as the Q-switch motor can be operated remotely. This is accomplished by means of two relays, fire relay K_1 and Q-switch motor relay K_2 . A switch, which is controlled by a plug-in connector, switches between the panel operated fire button and the remote operated fire button and between the Q-switch motor control from the panel and the remote Q-switch motor control. In the remote control operation, the setting of the remote control switch dominates.

3. Q-Switch Motor Speed Control

The Q-switch motor is controlled by a Variac and a bridge rectifier. The output of the bridge rectifier is unfiltered and is connected to the Q-switch motor by means of the interlock device described above.

4. RPM Indicator

The rpm indicator or tachometer circuit is connected to the magnetic pickup on the Q-switch motor as described above. Basically, this unit is a one shot multivibrator (Figure 9). An output meter or current reading meter is connected into the normally-off leg of this one shot multivibrator. It is triggered from the magnetic pickup and a current pulse of constant duration and amplitude is sent through the meter. The number of these pulses of current per second determines the average current through the meter. By calibrating the amount of current in this leg it is possible to determine the rpm of the Q-switch motor accurately. This indicator is calibrated in rpm from 0 to 50,000.



See Figure 7

Figure 8. Q-Switch Motor Controls

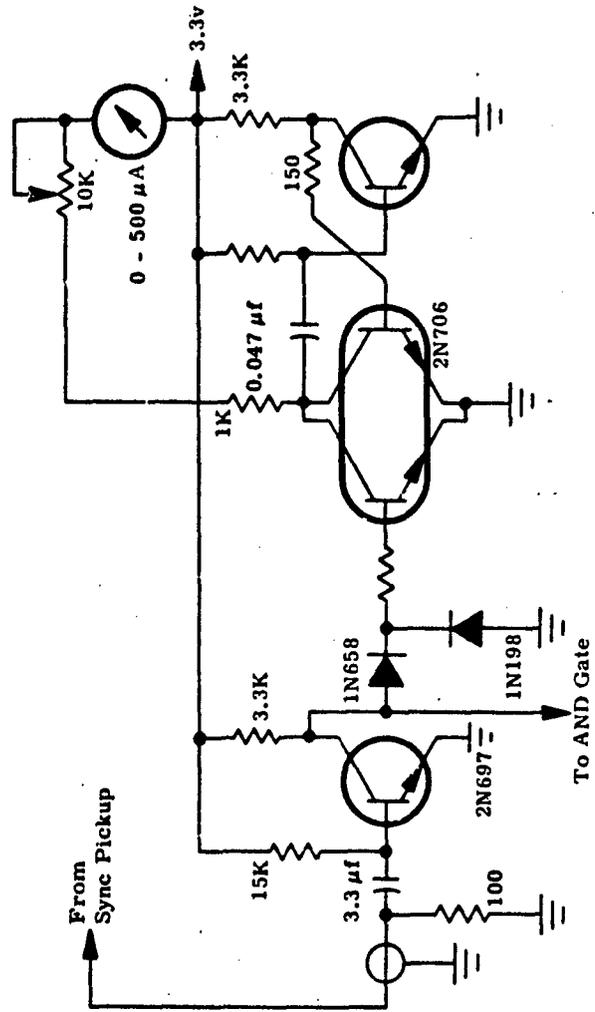


Figure 9. Tachometer Circuit

5. Impulse (Firing) Counter

The impulse counter is used to determine how many times the laser has actually been fired. This device samples the magnetic field of the current-limiting inductors and triggers an electromechanical counter to indicate the count. If for some reason the flash lamp does not fire, no count is obtained. The inductor used to limit the current in this case is a type TR-79 manufactured by Edgerton, Germeshausen & Grier, Incorporated. Three turns of number 22 wire are taped to the bottom of this coil and are connected by a coaxial cable to the counter circuit. A schematic diagram of the counter circuit is shown in Figure 10. Here the large-amplitude input signal is used to charge an 8 microfarad capacitor. The output is limited by two series forward silicon diodes and coupled through a limiting resistor to an amplifier circuit which triggers a relay. The relay in turn supplies a pulse of ac voltage to the electromechanical counter.

Without this integration device, chatter in the relay would cause erroneous counting of the electromechanical counter.

6. Power Supply and Controls

The power supply must be capable of charging two separate and equal capacitor banks. The voltage that can be obtained in each capacitor is limited by the capacitor rating of the bank itself, in this case 4000 volts. A 7000 volt center tapped transformer capable of delivering 300 milliamps is used for the primary transformer. The primary is 115 volts 60 cycles. A fuze limits the current to 8 amperes. The output of each side of the transformer goes to a charging rate indicator (a 6 volt lamp with a suitable resistor to indicate full brightness at 300 mills through the combination). From each of these lamps the output goes to a rectifier-diode combination consisting of 12 solid state diodes connected in series. From there the output goes directly to the capacitor bank with an indicating meter built into the power supply. Test points across the capacitor bank on the output of the power supply are accessible. On the primary, a Variac is used for manual control of the charging rate. The operation of this power supply is as follows: to charge the bank, the Variac is initially turned to 0, the power switch is turned on, and the voltage is slowly increased keeping the charging rate approximately 300 mills or lower, although higher values can be tolerated for short times. After the capacitor bank is charged, the Variac is turned back to zero and the charge is allowed to remain on the capacitor bank, held off from the transformer by the diode. When the flash lamp is triggered and the capacitor bank is discharged through the lamp, no voltage is developed by the power supply to recharge the bank unless the Variac is turned up again. A schematic

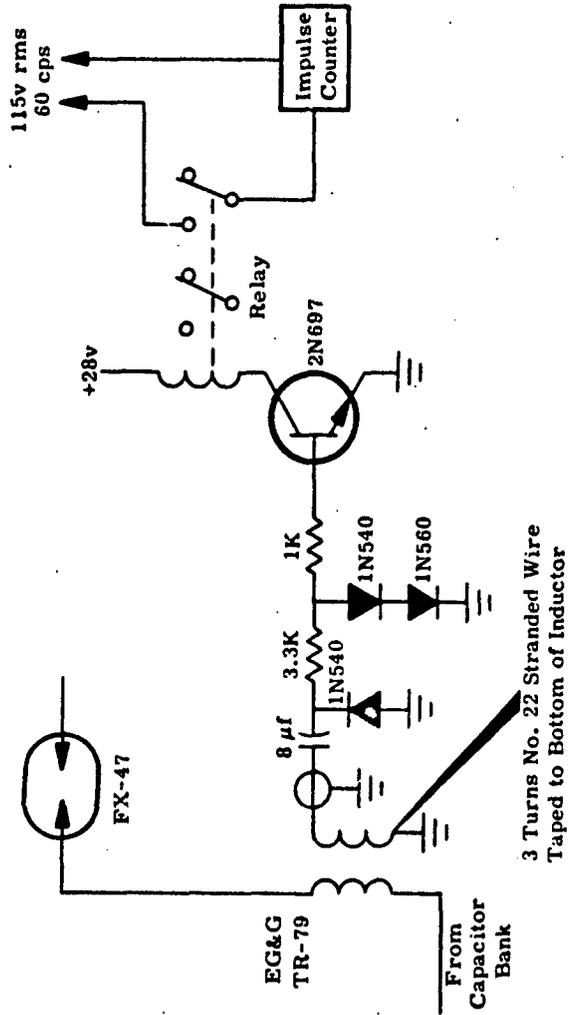


Figure 10. Counter Circuit

diagram of the power supply is shown in Figure 11. The control rack housing this power supply is shown in Figure 12.

The size of the capacitor bank is limited to the available 3400 microfarads with a voltage rating of 4000 volts. However, the flash lamps are capable of operating only to 3000 volts because of lamp flashover at higher voltages. Therefore the total energy content of the capacitor bank is less than the rating of the two flash lamps used in this laser. At 3000 volts the total energy content of the capacitor bank is 15,300 joules. Since each of the two flash lamps is rated at 3000 volts and 10,000 joules, the total energy of the capacitor bank required would be 20,000 joules which represents a capacitance of 4400 microfarads. At present each capacitor in the bank is 100 microfarads rated at 4000 volts. At least ten more capacitors are required to meet full power capabilities of the present design.

D. RESULTS TO DATE

The results of the research laser are gratifying. The efficiency is approximately 1 percent but, of course, this varies with pump level. The greater the pump level the greater the efficiency of the flash lamp and therefore of the laser. The output of the laser at liquid nitrogen temperature is in the vicinity of one percent of the pump level. At 2700 volts (12,400 joules) the output was 125 joules measured by a TRG calorimeter. This corresponds to an efficiency of 1.01 percent. At 2700 volts (13,300 joules) the measured output was 139 joules, for an efficiency of 1.045 percent. At 2900 volts, the lens on the calorimeter was severely damaged (Figures 13 and 14) so that no accurate readings could be obtained from the calorimeter. However, based on the change of the efficiency of the other data, the efficiency was estimated to be 1.081 percent corresponding to 155 joules.

At room temperature operation in the non-Q-switched mode, the laser output was 51.5 joules for an input of 12,400 joules, that is, for 2700 volts across the capacitor bank. The efficiency for this case was 0.416 percent. Data at 2400 volts on the capacitor bank (input energy of 9800 joules) gave an output energy of 36.9 joules. The efficiency in this case was down to 0.375 percent.

At room temperature in the Q-switched mode at 2400 volts on the capacitor bank (input energy of 9800 joules), the output energy was measured to be 8.91 joules, or an efficiency of 0.091 percent. At 2700 volts (12,400 joules), the output energy was 12.1 joules. The efficiency in this operation was 0.100 percent.

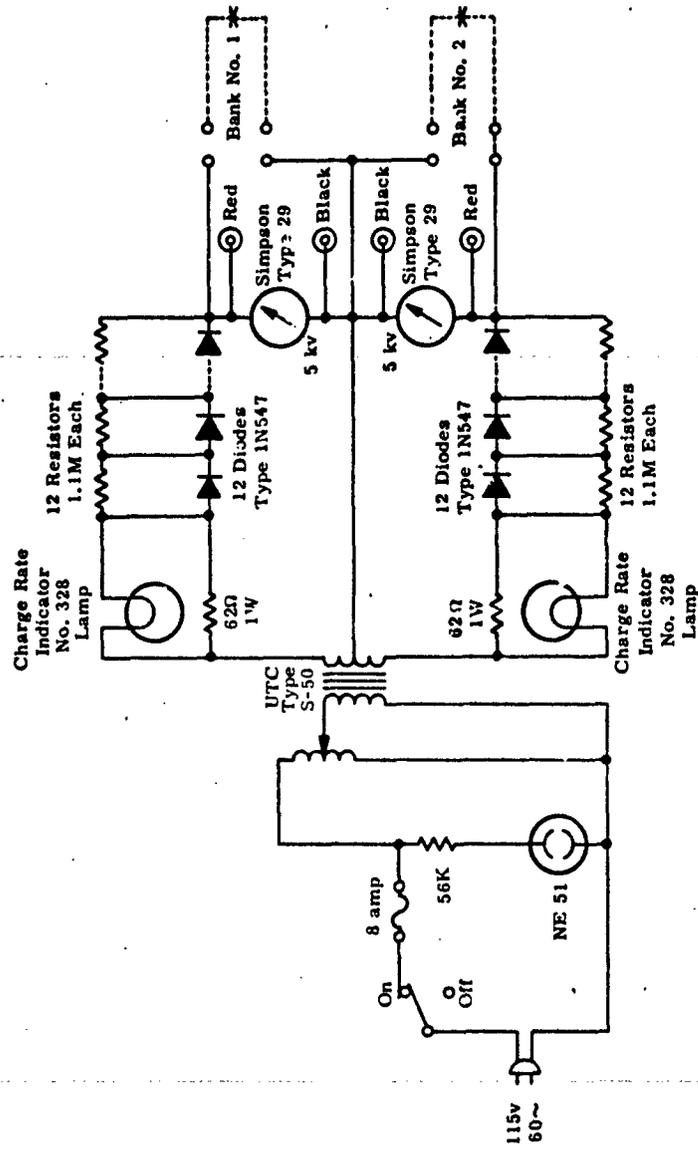


Figure 11. Laser Power Supply

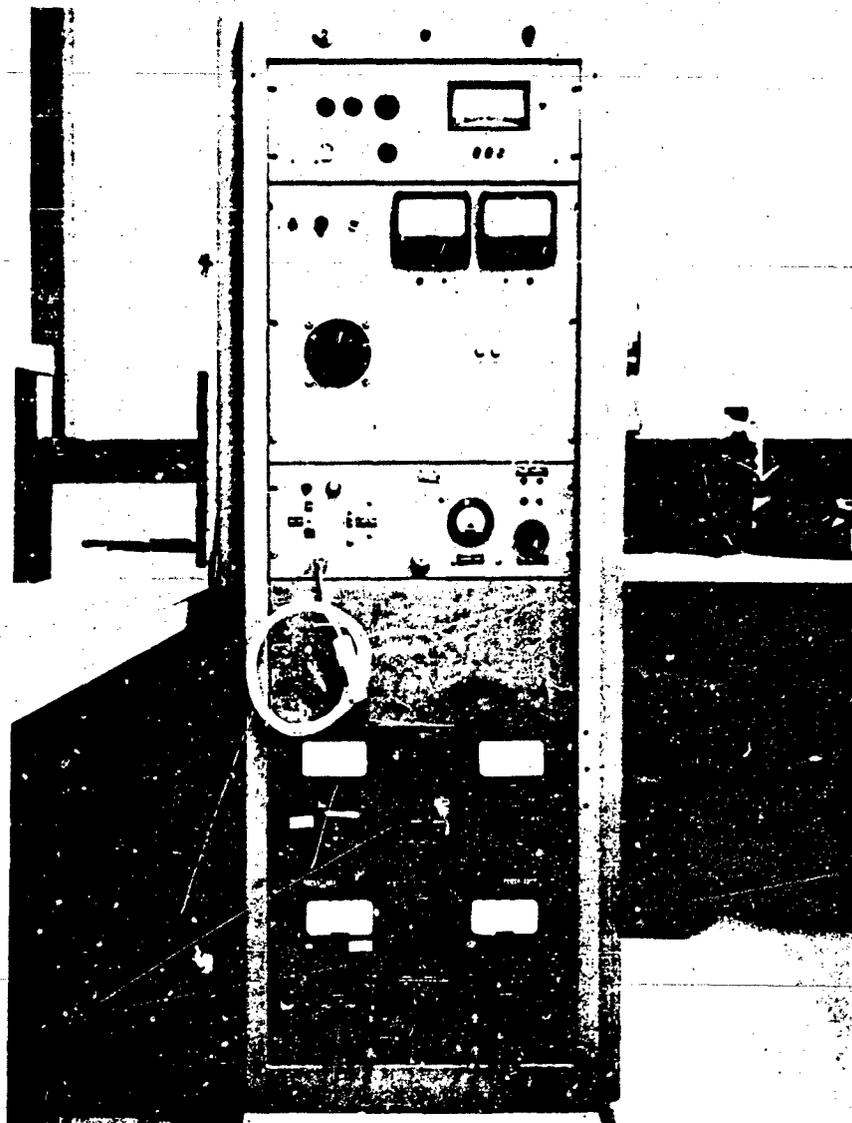


Figure 12. Laser Power Supply Rack



Figure 13. Damage to Quartz Lens

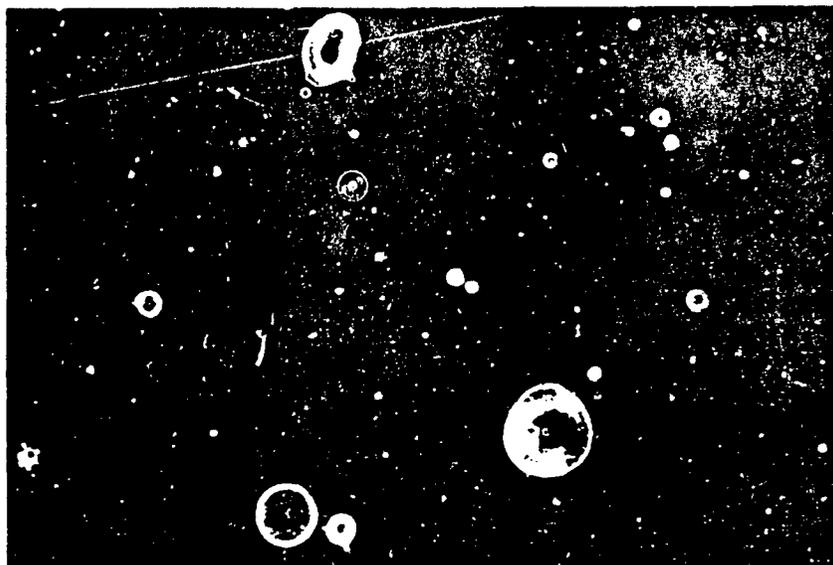


Figure 14. Damage to Quartz Lens Magnified

The quartz lenses designed and used on the TRG calorimeter proved satisfactory until the energy level reached a value high enough so that damage resulted. The damage in this case consisted of little pit marks across the surface of the first lens on the calorimeter input (Figures 13 and 14). Here the damage might have been caused by one of several things: the first is the possibility of minute particles of lint on the surface. The second is the possibility of minute absorbing centers in the quartz near the surface. The third is filamentary lasing, which can probably be ruled out. The quartz lenses in the calorimeter must be replaced by a more durable type of lens system such as sapphire to be of value for the high energy measurements. The design of a sapphire lens system has been started and will be incorporated in the equipment soon.

E. EXPANSION PLANS FOR LASER

The possibility of future expansion of the pump capability is fairly obvious. A new 13,000 joule flashtube has been marketed by Edgerton, Germeshausen & Grier, Incorporated. This flashtube has a larger diameter than the one presently used. This would possibly require a modification to the existing design but should give an input capability of 26,000 joules provided capacitors are obtained.

The Research Division of the Martin Company has recently moved into new research quarters. A high energy storage facility has been requisitioned and possibly will be added to the new quarters in the near future. The energy capacity of this system is 62,500 joules rated at 10,000 volts. This facility is to be located adjacent to the laboratory in which the research laser for this program is housed. This high energy storage facility would be readily available to this project for any use which might be required. With this system in addition to the present storage capability, all systems contemplated for the near future should have adequate storage capacity.

During the interim, additional capacitors are planned for our present storage bank. These capacitors (ten of 100 microfarads each at a voltage rating of 4,000 volts) are needed to bring our energy storage capability up to the maximum that the flashtubes are rated to stand. Each of the two flashtubes in the present research laser is rated at 10,000 joules.

One of the possibilities for a future laser is to incorporate a Brewster angle directly on the end of the ruby. Such a device would show an improved threshold in the Q-switched mode and would produce a greater output.

Another possibility is the use of a water-clad ruby, using a Pyrex tube around the ruby with water between the ruby and the Pyrex tube. A larger flashtube such as the Edgerton, Germeshausen & Grier type FX-52 (13,000 joules) can be used with this water-clad ruby. Without cladding the 13,000 joule flashtube would decrease the optical gain of the cavity because of its increased size over the type FX-47. Thus, the true output would not be appreciably greater than the present system. The possibility of such a system is intriguing for several reasons. First it provides an approach which might prevent the ruby crystal from fracturing when shocked by the flash output. Another possible advantage would be an increase in the optical efficiency of the cavity, producing a greater output because of the larger effective collecting power of the ruby-Pyrex combination. The three reasons for the water are to absorb ultraviolet radiation, to absorb the infrared radiation, and to provide an optical contact between the Pyrex and the ruby. In addition the Pyrex will also absorb ultraviolet and infrared.

Double pulsing is a possible way to improve the performance of future lasers. Referring to the data supplied above, it becomes obvious that the higher the pump level, the higher the output efficiency. For this reason, if the pump could safely be increased by a large factor, then the laser output would also be increased provided the pumping energy falls within the pump spectrum of the ruby. The double pulsing technique does just this. Double pulsing is accomplished first by initiating a small discharge to obtain an arc in the flash lamp. Then the main, high energy, very rapid arc can be increased tremendously. This requires two separate power supplies - the first a relatively slow, low energy supply for initiation of the arc; the second, a very rapid capacitor bank at high energy to produce a very short high intensity flash in the flash lamp. The present limitation of the flash lamp is in the ability of the quartz envelope to withstand the rapid expansion of the shock wave caused by the arc leading down the tube. In the double pulsing technique the shock wave is associated with a small flash starting the arc and terminates before the increased arc is started. No expansion of the shock wave with the increased arc is felt by the envelope. In this manner an increased flash of considerably greater output can be tolerated. Such a method of double pulsing is expensive and complicated, but should provide an excellent means of pumping the future laser. Efficiency is expected to go up perhaps by a factor of two by using such a method.

In the study of the laser which was built and developed for the Medical College of Virginia, and which is described below, it was found that by varying the reflection of the output end of the cavity an optimum could be

obtained for the output from the laser. For a higher energy laser such as that considered here, it is impractical to use a deposited film reflector such as was used on this laser because it will vaporize in the increased beam energy. There are methods whereby it might be possible to "walk in" the beam toward the center of the ruby and appear as a much higher reflection from the ruby end than the 8 percent presently used by the flat surface of the ruby. Such a method might be used to "tune the cavity" to provide the optimum impedance match between the ruby material and the air where the laser output is finally observed.

Thus it would appear that using a combination of the above mentioned possibilities it might be possible to improve the efficiency of a future laser considerably. Recommendations at this time are not appropriate since additional study of each method should be made.

II. OTHER INSTRUMENTATION

A. CALORIMETER

The calorimeter used for laser beam energy measurements in this work was a commercially available one manufactured by TRG, Incorporated. It consists of two platinum receiving cones of identical construction, each in contact with a thermocouple. These thermocouples are identical and connected in opposition. The device thus does not respond to changes that affect both cones alike. If a laser beam is directed into one of these, but not both, an output voltage will appear at the terminals of the device. The calorimeter has a response time of several seconds. Therefore, if the duration of the laser beam is short compared to this, the calorimeter acts as an integrator, and its peak reading is proportional to the total energy received. The output voltages are low, so that very sensitive voltage measuring equipment is required. The meter chosen for this purpose was a Keithley model 149 millimicrovoltmeter. This combination was used successfully over the range 0.002 joules to 150 joules. It has a nominal limit of 300 joules.

Since the diameter of the calorimeter opening was only $3/8$ inch and the laser beam was $5/8$ inch diameter, it was necessary to use an optical system to reduce it. For this purpose, a quartz lens system was designed and fabricated in the Martin optical shops. In spite of its high melting point relative to glass, quartz does not stand up well to beams of this intensity range, and the front lens of this system was damaged. It is planned to replace this system by a sapphire one now being fabricated.

B. TENNIS RACKET TYPE MONITOR

To perform precise experiments with laser beams in which pulse energy or peak power is important, it is necessary to monitor the actual pulses used. This requires a device capable of sampling the beam without appreciably affecting it. The sampled portion should be a small, but representative portion, and the sampling mechanism must be capable of withstanding high power beams.

The sampler under development here consists of a mesh of fine tungsten wires woven in a manner similar to a tennis racket. This is inserted in

an unfocused portion of the laser beam, and scatters a small fraction of the light, sampled across the beam. Two samples of this scattered light are used. One is detected close to the sampler and used to trigger the sweep of an oscilloscope. The other sample is directed through a 6 foot long fiber optics light guide and detected by a photomultiplier tube. The resulting transit time gives sufficient delay to allow the oscilloscope sweep to be under way in time to resolve the early portions of the response. This signal is both displayed on the oscilloscope and integrated in an appropriate circuit. The integrated result is displayed as total energy, since the response of the photomultiplier is proportional to power. The device can be calibrated in total energy by comparison to a calorimeter. From this, the power calibration can be inferred from the oscilloscope presentation knowing the time scale and the integrated signal. Figure 15 is a block diagram of the device as planned.

C. IMPULSOMETER

In the study of the interaction of laser beams with materials, a device was desired for measuring the mechanical impulse of reaction of mass blown off the target by the laser beam. Earlier devices had been built utilizing ballistic pendulums and high speed motion picture cameras; however, these devices proved unwieldy, expensive to operate, and inconvenient in regard to necessary delays for film processing. Furthermore, quantitative results were difficult to achieve. The device desired in this instance was one which would give an immediate quantitative result, preferably with low material expenditure. It needed a wide range of impulse sensitivity and a good reproducibility from shot to shot.

In a previous program at Martin, such an impulsometer was developed for this purpose. Results were sufficiently gratifying that a redesign of the device has been undertaken incorporating certain desirable improvements based on our experience with the original model.

The device consists essentially of a torsion pendulum holding a target mass and a transducer for monitoring the instantaneous position of the pendulum. In order that the position transducer not affect the pendulum, it had to have a low order of interaction with it. For this reason, an optical position transducer was devised.

The essentials of the design of this device are shown in Figure 16. Above the target, a small mirror is rigidly mounted to the target pendulum, rocking as the torsion pendulum oscillates. A photomultiplier looks into this mirror at a variable-width illuminated source, scanning a narrow slit σ' . As the target pendulum oscillates, the area scanned moves up and down the variable-width illuminated source. Thus the amount of light falling

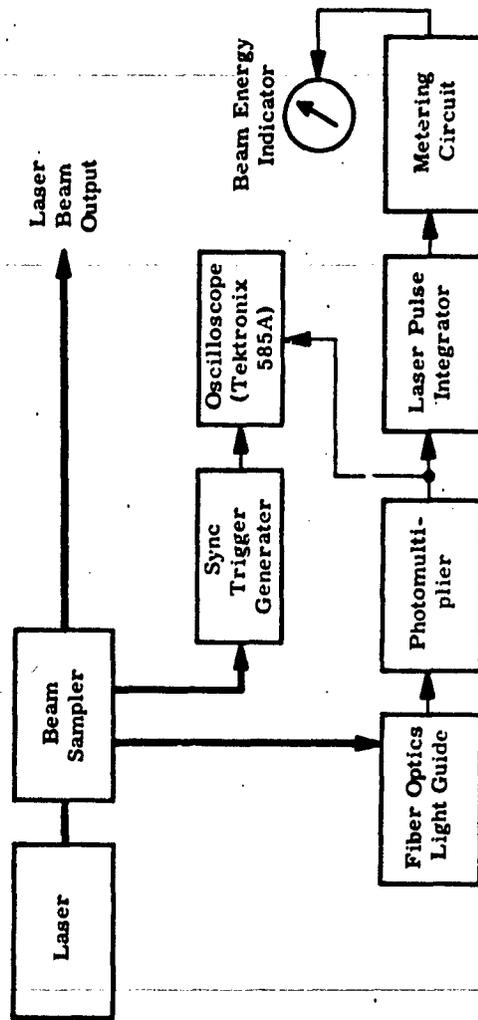


Figure 15. Beam Monitor

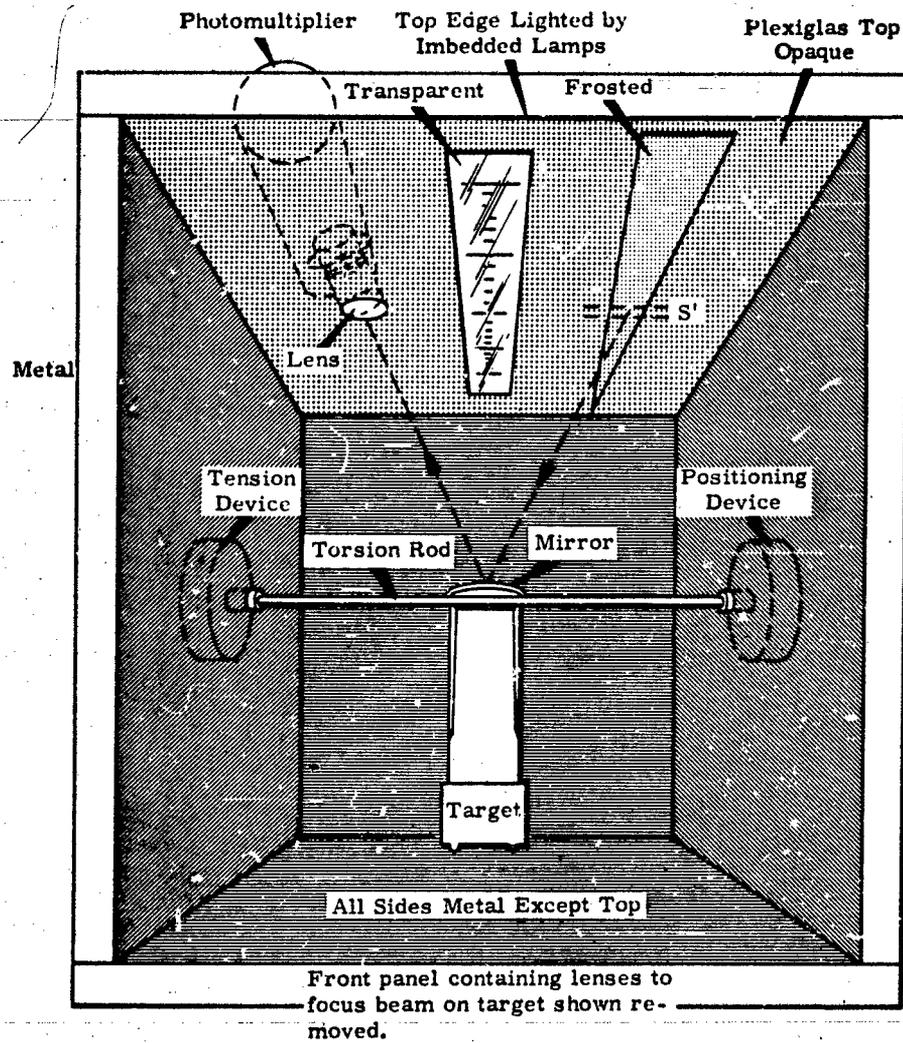


Figure 16. Impulsometer

on the photomultiplier varies in an approximately sinusoidal manner exactly in phase with the oscillation of the target pendulum. The output of this photomultiplier can be calibrated directly in terms of the angular position of the torsion pendulum by the stationary calibration. To accomplish this, a transparent window is located above the mirror and a tangent scale inscribed in it. To set the pendulum at a desired calibration angle, the pendulum is positioned so that a given angular graduation lines up with its image in the center of the mirror. The corresponding reading from the photomultiplier is then noted as an angle.

Thus the transducer records the instantaneous angular position of the torsion pendulum without loading it in any way. The output of the photomultiplier is recorded by a Sanborn recorder, for which the response time is sufficiently fast that the response time errors are negligible.

By extrapolating the oscillation to zero time (the laser firing) one can obtain the initial amplitude of the pendulum oscillation. From built in timing markers, the period of the oscillation can be determined accurately. By statically loading the pendulum with known torques and observing the angular displacement, the torque constant of the pendulum can be determined. An analysis of the mechanics of an impulse driven torsion pendulum yields the interesting result that the impulse can be deduced from these three quantities (initial amplitude, period, and torque constant) and the radius of action of the impulse, a detailed knowledge of the moment of inertia or target mass not being necessary. Thus, the device is an absolute instrument for the measurement of impulses.

By proper choice of torsion bar construction parameters, the device can be made in a wide range of sensitivities and ranges to meet the demands of particular experiments. It is so designed that replacement of torsion bars is a relatively simple procedure. Naturally, when sensitivity is high, the range is correspondingly reduced, the device is sensitive to vibration, and the torsion mechanism is fragile.

The device is built into a vacuum-tight closed cavity so that experiments can be carried out either in atmosphere or in vacuum. The focusing lenses are mounted on the removable front of the cabinet which acts as an access door. They are fashioned of sapphire for durability with high intensity laser beams.

III. PROBLEMS OF THE SURGEON GENERAL BIOLOGICAL LABORATORIES

A. PROBLEMS

The laboratories currently contributing to this program in the biological effects of lasers are listed below:

- 1 Medical College of Virginia (MCV) - Dr. William T. Ham, Jr.
- 2 Northeastern University (NU) - Dr. Samuel Fine
- 3 Roswell Park Memorial Center (RPMC) - Dr. Edmund Klein
- 4 Armed Forces Institute of Pathology (AFIP) - Dr. Jude R. Hayes
- 5 Minneapolis Honeywell Regulator Co. (MH) - Dr. Harry Sperling
- 6 Edgewood Ballistic Research Laboratory (EBRL) - Lt. Col. Janice Mendleson
- 7 Army Medical Research Laboratory (AMRL) - Capt. Alan J. McCartney

The work of these laboratories is primarily biological in nature. To relieve them of the necessity of diluting their efforts with work of a non-biological nature, the work at Martin was set up to furnish aid along these lines. Some of the problems on which Martin effort can provide assistance to the overall program are as follows.

1. Supply of Specially Designed Equipment

From time to time in the laser development program at Martin, new devices are developed that can be applied by the laboratories listed above. Furthermore, Martin is in the position to know of advances in the state-of-the-art in other laser laboratories. Under this program, a contribution is to extend the advantages of these developments in the form of copies of pieces of equipment in question.

2. Calibration Services

Another service appropriate to this type of work is cross-calibration of such items as detector equipment. To do reliable and accurate threshold experiments, for example, it is essential to have reliable methods of determining the output of a laser. As the program progresses, Martin intends to do studies aimed at increasing the reliability and accuracy of available calorimeters. In this way, Martin could serve as a standards laboratory for the entire program, so that any laboratory may have its calorimetric equipment checked against that of the other laboratories. This type of service would be of value to all the laboratories of this program.

3. Sampling and Monitoring Techniques

Research into better ways to sample and to monitor the output of a laser is a service that will be useful to all the laboratories of the program, since all these laboratories require knowledge of the input energy in their experiments with laser beams. The problems involved here are those of obtaining a representative sample of the laser beam both in total energy and in power as a function of time without either having the sampling mechanism destroyed by the laser beam or disturbing the unsampled portion of the laser beam which will be used in biological experiments. Due to the shot-to-shot variations in the parameters which characterize laser beams, such as the total power across the face of the ruby, it is important that the shot used in a particular biological experiment is itself measured. This is contrasted to a situation in which one shot is measured by some instrument such as a calorimeter, and a second shot is used in a biological experiment.

4. Depth of Penetration

Detection of the depth of penetration of laser radiation into such materials as animal tissue is a problem in which several of the laboratories mentioned above are interested. At the present state of the art it is not known if absorption of high power laser radiation is characterized by ordinary exponential decrease of intensity with penetration distance, that is, by a constant percentage per unit length of absorber, or if the absorption parameters are themselves functions of intensity. Thus an experimental determination of the penetration of laser radiation into target materials appears to be necessary.

5. Shock Wave Detectors

Evidence exists that a significant, and perhaps traumatic shock is set up when a laser beam of sufficient strength is applied to animal tissue. To study this effect, both from a biological standpoint and from a standpoint of characterizing the interaction, detectors are needed that can measure shock reproducibly. The detectors must be sufficiently small and sensitive that they do not significantly affect the shock they attempt to measure. An array of several such detectors would be desirable, so that the propagation character of the shock could be studied. This should preferably work in vivo, as well as in excised tissue samples.

6. Temperature Effects

Several researchers are interested in studying the temperature effects produced in laser-irradiated samples. Instrumentation appropriate for this type of study is also needed. The problems here are the need for rapid response, sensitivity, and miniaturization simultaneously.

7. Limitations Due to the State-of-the-Art in Lasers

Many biological experiments are impractical at present due to limitations in the state of the art in lasers. Problems confront the biological experimenter that are rooted in limitations in stability of laser pulse-to-pulse characteristics, limitations in peak power, pulse interval, pulse energy, collimation, coherence, image size and uniformity, and in control and reproducibility of these parameters.

8. Miscellaneous Services

From time to time, any given laboratory may need the services of a scientific discipline beyond its own capabilities. The considerable total scientific capability of the Martin Company is a useful reservoir that, under the present contract, can be negotiated to aid any of the above member laboratories.

Many of the problems mentioned in section A are applicable to more than one of the laboratories mentioned. The particular problems of interest to the various laboratories are listed in Table I.

TABLE I

Distribution of Problems

	MCV	NU	RPMC	AFIP	MH	EBRL	AMRL
1. Equipment	*			*	*		*
2. Calibration	*			*	*		*
3. Sampling and Monitoring Techniques	*			*	*	*	*
4. Depth of Penetration		*	*	*		*	*
5. Shock Detectors		*	*	*		*	*
6. Temperature Sensors		*	*	*		*	*
7. State-of-the-Art Improvement	*	*	*	*	*	*	*
8. Miscellaneous Services	*	*	*	*	*	*	*

MCV - Medical College of Virginia

NU - Northeastern University

RPMC - Roswell Park Memorial Center

AFIP - Armed Forces Institute of Pathology

MH - Minneapolis Honeywell Regulator Co.

EBRL - Edgewood Ballistic Research Laboratory

AMRL - Army Medical Research Laboratory

B. INVESTIGATIONS PERFORMED TO DATE

Most of the work performed under this contract and reported herein fits into one or more of the categories listed in Table I. The development of the research laser, however, is categorized as a necessary prerequisite to many of these categories instead of being itself listed. The actual investigations of these problems to date include work on sampling and mon-

itoring techniques, concept development for instrumentation for depth of penetration studies, microminiature shock detectors, laser development in preparation for work in calibration and standardization, and for use in the other studies mentioned, and in miscellaneous services, such as electron spin resonance detection of free radicals formed in laser irradiated tissue. The attacks on the limitations of the laser state-of-the-art are of course under way in all the laser projects at this laboratory as elsewhere.

Problems in the above list yet to be investigated are those of providing calibration services, which await developments in the work on beam sampling and laser stabilization, and work on instrumentation for temperature sensing. It is also expected that additional problems will arise as the program progresses. The approaches currently under study in the field of instrumentation are described in the subsequent paragraphs.

1. Needle Transducer for Shock

The requirements listed above for shock detectors can possibly be met by a device such as that diagrammed in Figure 17. In this device, a hollow tube is filled by optical fibers collected into two coaxial bundles. This assembly is ground and polished flat, then cemented to a glass cone with an inverted conical apex. This double cone connects the two fiber bundles optically by internal reflection from its conical surfaces. If this assembly is used to transmit light from a collimated source to a sensitive detector, the transmission depends on the internal reflection at the conical surface. One of these surfaces can be capped with another cone fitted to mechanical contact but not optical contact. In this configuration, a shock wave propagated through the outer cone would partially frustrate the internal reflection as it passed. Thus, by monitoring the output of the light detector, vibrational amplitudes of the order of a fraction of a wavelength of visible light would be detectable, at essentially zero delay. It appears possible to construct these devices using hypodermic needles or other tubes of comparable size, thus obtaining shock sensors less than one cubic millimeter in volume. If these detectors work at all, they can be used to determine arrival times of shock fronts, and thus determine propagation velocities, wave shapes, etc. If their response is also sufficiently reproducible, they can be calibrated relative to each other and used to measure shock decay and dissipation, as well as to supply a reference to compare shocks among different experiments.

2. Needle Transducer for Radiation Penetration

A device related to the needle transducer for shock could also be used to detect the penetration of laser radiation into a target material. In this

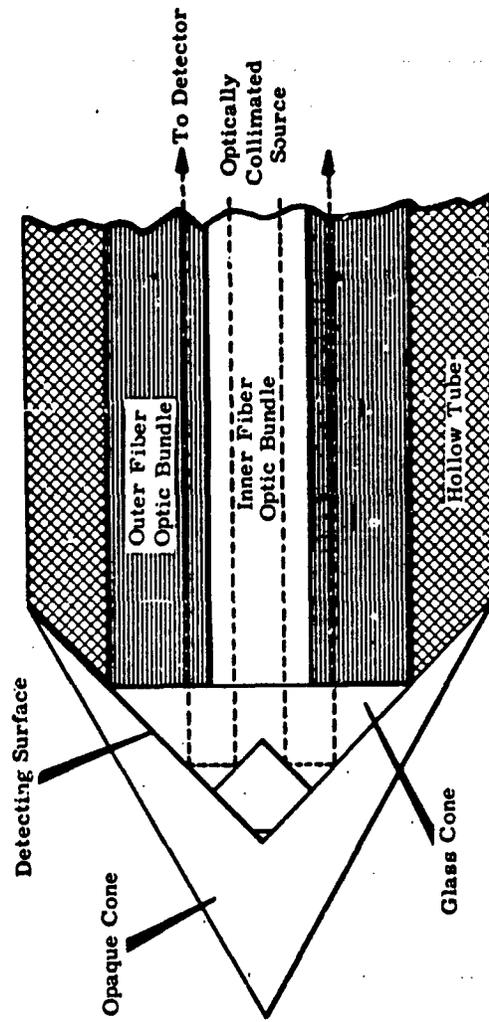


Figure 17. Fiber Optics Shock Probe

case, all that is needed is an enclosed fiber optic bundle to transmit the laser radiation to a detector. The fibers could be epoxied together into the end of the needle for ruggedness, and the assembly pointed for easy insertion into the target material. In this case, the orientation of the probe would be critical for quantitative results. If the probe described in the preceding paragraph is to be developed and techniques evolved for its construction, it may prove more economical to utilize the same configuration, replacing the outer cone with one of a transparent material and making the contact an optical one, perhaps by means of a fluid or cement.

3. Irreversible Reactions on Implants

A third approach to the detection of shock, radiation, and/or temperature has been considered, but is less attractive than these. In this method, some sort of irreversible reaction must be found that occurs at a known level, or threshold, of shock, radiation, or temperature. Small samples of the reactant are then surgically implanted in the tissue of the sample, perhaps with a protective layer to prevent reaction with the tissue, and analyzed subsequent to laser exposure. Mechanisms that suggest themselves include biological reactions (for example, death of micro-organisms), irreversible chemical reactions (detectable by chemical or spectroscopic analysis), and the production of free radicals (detectable by spin resonance spectroscopy).

IV. SERVICES PERFORMED FOR THE SURGEON GENERAL BIOLOGICAL LABORATORIES

A. LASER FOR MEDICAL COLLEGE OF VIRGINIA

In their work on the effects of laser beams on retinas, the group at Medical College of Virginia needed a laser with controllable parameters. Among the options desired were a choice of wavelength (0.6943 micron or 1.06 micron), and a choice of pulse lengths and power combinations (Q- or non-Q-switch operation). To satisfy this need, the Martin laboratory, under this contract, designed, built, and delivered such a laser. Figure 18 shows two views of the completed unit. Since large powers were not required, a design based on a 3 by 1/4 inch laser rod was chosen. The flashtube chosen was an FX-38, manufactured by Edgerton, Germeshausen & Grier, Incorporated. The output can be increased by changing to a type FX-42 flashtube, also manufactured by Edgerton, Germeshausen & Grier, and the apparatus was designed to incorporate this change. The pump cavity is a split elliptical one of Martin design. The laser rod is easily removable, and easily adjustable in orientation about its cylinder axis. Q-switching is achieved by rotating a quartz prism at 10,000 rpm. The prism used was locally fabricated to an accuracy of better than 1/2 second of arc at the right angle roof. For non-Q-switch operation, the prism is reproducibly located by a swing away yoke with a micrometer and a spring loaded anvil. The synchronization signal for Q-switch triggering is obtained from a pickup coil mounted in an adjustable collar on the motor, energized by a small magnet on the rotating prism holder. The associated electronics circuitry was also engineered and built under the contract, and is diagrammed in Figure 19.

An interesting feature of this laser was the design of the holder for the Fabry plate. The Fabry plate is a multicoated resonant reflector designed for a specific wavelength. Therefore it must be replaced when changing wavelengths (changing laser rods). Also, if the laser is overdriven, these Fabry coatings are occasionally destroyed. Since their price is more nearly by the piece than by area, it is economical to use small areas of a larger piece when possible. In this instance, a 1 inch diameter Fabry plate was positioned so that the 1/4 inch diameter area used was near one edge. If a burn occurs, it is normally much less than the full laser aper-

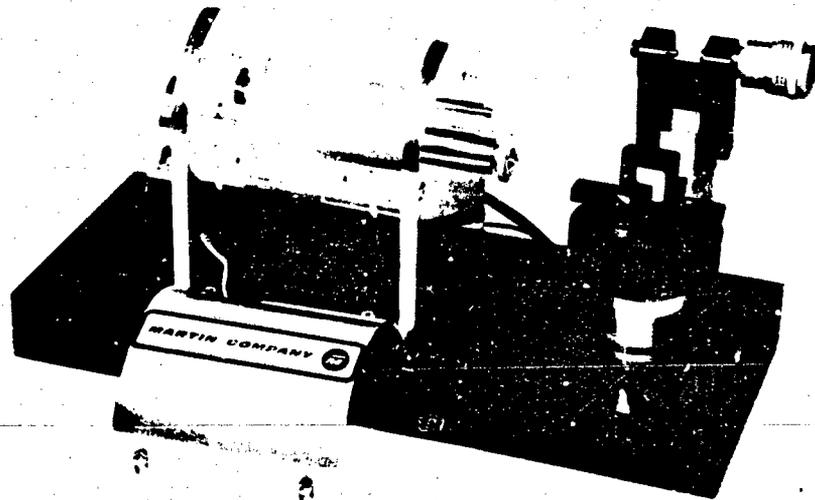
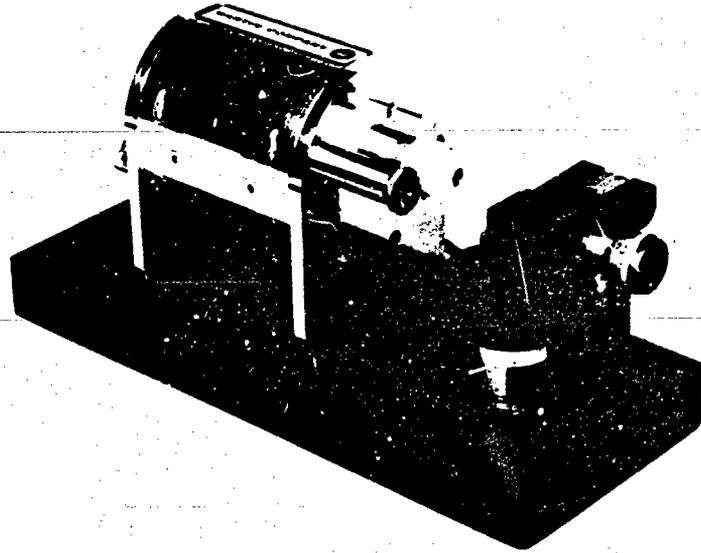


Figure 18. Laser for Medical College of Virginia

ture, so that by rotating the oversized Fabry plate, many burns could be tolerated before the plate would have to be replaced.

B. ELECTRON SPIN RESONANCE MEASUREMENTS

The Physical Sciences Laboratories of the Martin Orlando Research Department has built a 35 gc electron spin resonance spectrometer. This consists of a frequency-stabilized source at 35 gc, a cryogenically coolable sample absorption cell, a variable magnetic field about the sample, and a detector. This field must be highly uniform, variable to high values, and capable of being modulated. For field sensitive absorptions, the field modulation produces an intensity modulation of the detected signal at a known phase. Using phase-sensitive detection, the apparatus is capable of detecting extremely weak absorptions. As the dc field is varied, resonance absorption at particular field values is characteristic of particular molecular or atomic systems.

This device is capable of sensitive detection of free radicals in the form of free electrons. In certain cases, as few as 10^{10} free electrons in a sample can be detected. The test is non-destructive and the heating of a sample is negligible. By repeated or even continual observation, the decay in population of free radicals can often be observed. These rates of decay are significant data, as are the levels of activity or, in many cases, even the mere presence of free radicals.

One of the services rendered to the biologists during this program was the application of this equipment and skill to the observations of free electrons produced in laser irradiated samples. This was done on behalf of Dr. Klein of Roswell Park Memorial Center and Dr. Fine of Northeastern University, who furnished the samples.

Although the results were not absolutely conclusive, a correlation of observed spins with samples irradiated with high energy laser beams was observed with a confidence level of about 90 percent.

By modifying the existing equipment sufficiently, particularly in regard to the sample cavity, more refined measurements are possible. This work has been submitted for publication elsewhere.

C. CONSULTATIONS AND MISCELLANEOUS SERVICES

In addition to the above, a number of less formal services have been rendered. These include consultations on a variety of problems, both by

long distance telephone and by visits. In several instances, items of equipment have been furnished on a loan basis on short notice and without formality. Data and consultations from other Martin efforts have been supplied.

V. OTHER ACTIVITIES

A. VISITS AND TRIPS MADE TO DATE

All of the laboratories of the program of Biological Effects of Laser Radiation have been visited at least once. In addition, most of the biological researchers have visited the Martin Orlando laboratories. Continual contact is maintained with these researchers by telephone.

B. REPORTS AND PAPERS

The work on electron spin resonance mentioned in Section IV B was reported in a Martin Orlando report, OR 3698, dated December 1963. Copies were distributed to interested personnel. Through appropriate channels, it has also been submitted for publication in Applied Optics.

A paper is also in preparation for delivery before the First Annual Conference on the Biological Effects of Laser Radiation in Washington, D. C. April 30 - May 1, 1964.

VI. PLANS FOR FUTURE WORK

A. SERVICES TO THE BIOLOGICAL LABORATORIES

One of the principal responsibilities of this laboratory under the existing arrangement is the performance of the type of service described in Chapter IV. This work will be continued along two main themes, the attack on short range type problems as they occur and the more indirect type of aid on long range problems, usually common to more than one laboratory. An example of the latter would be the development of original instrumentation for a particular type of measurement. Particular cases are mentioned below.

B. INSTRUMENTATION NOW UNDER DEVELOPMENT

The laser beam monitor (tennis racket) is included in the instrumentation under development at the time of writing of this report. This device will allow simultaneous monitoring of the waveform of the pulse and the total pulse energy with a very low insertion loss.

Other instrumentation currently under development includes the shock detector (Figure 17) for observation of shocks in animal tissue and similar target materials, and laser radiation penetration detectors. These two types of instruments will probably be related in construction and operation. An improved model of the impulsometer is under development for observing the impulse of recoil from blown off surface material from the interaction between a laser beam and a target.

Work will also continue on improvement of the research laser. In addition to the obvious goal of obtaining peak performance from this laser with maximum versatility, it is expected that design lessons will be learned that will lead to improved future lasers. This device will probably never become a static one since continual advances in the art of lasers are a definite expectation and many of these improvements will be applicable to the work of this program.

C. MAINTENANCE OF A RAPID REACTION TO BREAKTHROUGHS

At any stage of the contract, one of the plans for the future will be to maintain a rapid reaction to breakthroughs in the state-of-the-art made either here or elsewhere. This ability is considered to be a valuable asset, and one of the goals of this program is always to be in the position not only of being able to incorporate the latest advances into a design or technique but also to initiate quickly a new approach made possible by such advances.

D. FOLLOW ON PROPOSAL

A follow on proposal for an extension and elaboration of this work has been submitted. The remaining portion of the present contract will be conducted in such a manner that, should this proposal be accepted, the work will flow smoothly and without interruption into the new contract.

SUMMARY

The Office of the Surgeon General has a program on the biological effects of laser radiation in which several member laboratories are participating. It has contracted with the Research Department of the Martin Company to furnish aid to these member laboratories in the general area of lasers, electro-optics, and instrumentation.

This effort is divided into two main parts, short range direct aid to individual researchers, and longer range, more indirect aid directed toward larger problems, often of interest to more than one of the member laboratories.

Some of the details of these problems are discussed, along with actions taken during the eight months interval beginning 1 July 1963, and action planned for the following four months.

<p>OR 3885 Martin Company, Orlando Division, LASERS AND THEIR EFFECTS, 1 April 1964 Contract No. DA-49-193-MD-2456 59 P. UNCLASSIFIED REPORT</p> <p>This annual report to the Office of the Surgeon General describes the biological effects of lasers and laser radiation. Design and construction of a research laser and associated instrumentation is included. Important problems investigated for various biological researchers and the approaches used are discussed.</p>	<p>UNCLASSIFIED</p> <p>1. Lasers - Biological Effects 2. Lasers - Radiation</p> <p>I. Contract DA-49-193-MD-2456 II. J. H. Burkhaller</p>	<p>OR 3885 Martin Company, Orlando Division LASERS AND THEIR EFFECTS, 1 April 1964 Contract No. DA-49-193-MD-2456 59 P. UNCLASSIFIED REPORT</p> <p>This annual report to the Office of the Surgeon General describes the biological effects of lasers and laser radiation. Design and construction of a research laser and associated instrumentation is included. Important problems investigated for various biological researchers and the approaches used are discussed.</p>	<p>UNCLASSIFIED</p> <p>1. Lasers - Biological Effects 2. Lasers - Radiation</p> <p>I. Contract DA-49-193-MD-2456 II. J. H. Burkhaller</p>
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