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PASSIVELY MODE-LOCKED Nd-YAG OSCILLATOR STABILITY STUDY

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13. ABSTRACT

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Passively Mode-Locked Nd-YAG
Oscillator Stability Study

I. INTRODUCTION

In operating the NRL High peak power glass laser, a prime consideration is the reliability and stability of energy content of the output pulse. Since the glass system can only be fired once every 8 minutes, it is important that the mode-locked YAG oscillator provide an output pulse reliably. Since two Pockel's cell shutters have to be opened, a low energy output would result in no output through the second shutter. Because of the low duty cycle of the entire system, a loss of only one shot in every eight would result in a loss of an hour of operating time every day. At the other extreme, a pulse of too high an energy could conceivably cause catostrophic back reflections. In order to upgrade overall performance, a study was initiated to determine the cause of the energy spread of the output of the YAG oscillator-amplifier combination.

At first, it was thought that the principal cause of trouble was in the laser-triggered spark-gap. An experiment was set up to try to determine the extent of jitter in the firing of the spark-gap, and its causes. A large jitter was found, but at the same time it was found to relate directly to the amplitude of the mode-locked oscillator train. When the train was of larger than normal amplitude, the spark-gap fired too early; when the train was smaller than normal, the spark-gap fired too late. From this it became obvious that the trouble was in the oscillator itself, and not in the spark-gap.

As a result of the above considerations, this study was initiated to determine the causes of the instability and to correct them. The information obtained led to changes in the oscillator which have been incorporated in the NRL glass laser facility.

II. EXPERIMENTAL SET-UP

The experimental set-up used is shown in Figure 1. The output of the mode-locked oscillator under test was sent through calibrated attenuators to a battery-biased PIN photodiode. The photodiode (Fig. 2) had a masked opal glass diffuser mounted on a tube attached to its front to insure proper monitoring of the beam. Also, the battery voltage was checked regularly, and the photodiode was checked against a calorimeter to see that its relative output had not changed.

The photodiode signal was shaped and amplified by a Tektronics 564B oscilloscope with a 3A9 plug-in unit before being applied to a 512 channel pulse height analyzer. Various attenuators (optical and electrical) were then inserted in the signal path between the mode-locked oscillator and the pulse height analyzer to make certain that signal changes up to 6 db (2X) would be recorded linearly. Since no more than 2 db of signal change was expected, this was felt to be accurate.

As a final check, the mechanically chopped output of an unstabilized HeNe laser was recorded to make sure the wide distributions seen were caused by the source and not the instrumentation. The FWHM obtained this way was 2.7%, about half of that finally obtained with the YAG oscillator.

The memory of the 512 Channel Analyzer was readout in three ways: by visual monitoring on a Tektronics 503 Oscilloscope, by plotting the distribution with an HP-135 X-Y recorder, and by printing out the number of events recorded in each channel with an IBM Typewriter. The first two readouts provided immediate gross features while the final readout provided numbers for data reduction.

This method may not be quite as satisfactory as analyzing one pulse at a time for pulse train build up, double pulsing, pulse amplitude, etc. On the other hand, it allows one to compare the net energy content of 40,000 pulses recorded over a period of 18 continuous hours in a few minutes rather than several months. In further defense of this method, it should be noted that when double pulsing or low amplitude pulse trains occur a drop in energy content of the whole train occurs (as measured by a calorimeter). Thus a distribution of total pulse train energies is one measure of how repeatably a mode-locked oscillator is operating.

III. ANALYSIS

Let

A = channel number for which the greatest number of pulses occurred.

N = number of pulses in channel A.

B = number of the first channel below A recording less than N/2 pulses.

C = number of the first channel above A recording less than N/2 pulses.

N_x = number of pulses in channel X.

Then, define

$$\alpha = B + \frac{N/2 - N_B}{N_{B+1} - N_B} \qquad (1)$$

$$\beta = C - 1 + \frac{N/2 - N_{C-1}}{N_C - N_{C-1}} \qquad (2)$$

Also, to locate the peak a little better (this is not a rigid derivation of the peak, but just an educated guess!), let

$$A' = A + .5 \; \frac{N_{A+1} - N_{A-1}}{2N_A - N_{A-1} - N_{A+1}}$$

This is not such a poor approximation as can be seen from the extreme cases of N_A equals N_{A+1} or N_{A-1} and the symetric case of N_{A+1} equal N_{A-1}. Finally, we characterize the distribution by its relative full width at half its maximum number of counts:

$$\text{Dist FWHM} = \frac{\beta - \alpha}{A'} \quad . \qquad (3)$$

The reason for normalizing the width is as follows: assume that an input energy of peak at 2X and half points at 2X - 2 and 2X + 2 is recorded. If that same input had been passed through 3 db somewhere before being recorded, the peak would have been at X and the half points would have been at X - 1 and X + 1. Applying (3), we see the distribution remains constant (as it should) as the average signal level is changed external to the mode-locked oscillator.

IV. RESULTS

In looking at the problem of changing output amplitude, it is obvious that the cavity gain must be changing in some manner. In the NRL YAG laser system, the output of the pump lamp is coupled to the laser rod by a tightly focused eliptical cavity. If the arc established in the pump lamp is in a different location each shot, it is reasonable to expect that its image in the laser rod would also move and that the gain distribution in the rod would change. Two methods were considered and tested for stabilizing the arc in the lamp. The first, suggested by ILC Inc. [1] in a report, was to add a simmer supply to the lamp circuit so that an arc would remain as established in the lamp between pulses. The second method was to use smaller bore lamps in the oscillator, and thereby restrict the range of paths available for arc formation.

The most obvious effect to be tested was the energy stored in the capacitor banks. Since the ILC power supply used originally was of a resonant charge type supject to some variation, a highly stable Kepco BHK-1000 constant current/constant voltage supply was substituted. Some improvement was noted, but not of the magnitude needed.

It was suggested by John McMahon that some improvement might occur by not cooling the laser rod. Since Nd-YAG operates better on the 1.064 μ line when it is warm, this seemed a reasonable subject for test. Actually stability decreased for the uncooled rod case.

The real progress come when the air conditioning went hay wire during a simmer supply test with the Kepco and ILC supplies over a two and one half hour period. As can be seen in Figure 3, the distributions so obtained were not normal distributions. Since external temperature was causing such a big effect, two 80 minute distributions were recorded and superimposed in Figure 4. Here appear two narrow distributions whose sum over a longer recording period would have been a much wider distribution. At this point the study became an attempt to locate the most temperature sensitive parts of the oscillator.

The primary results for this study for a dielectric output mirror are summarized in Table 1. It is immediately obvious from the table that the most important factor is the temperature stability of the mode-locking dye. To verify this effect, a quartz cell filled with Kodak 9740 mode-locking dye in 1-2 dichloroethane was wrapped with a heater tape connected to a Variac and placed in a dual beam Cary Model 14 spectrophotometer with a thermometer stuck through its side into the cell. Although crude, this was accurate enough to show a 10% change in the absorption coefficient of the dye at 1.064 μ when the temperature was changed by 10°C, and that the effect was reversible. That is, the change was a true dye absorption vs wavelength change and not a change of the amount of dye which remained in solution.

A second important conclusion was that there is no real advantage to using a simmer supply in mode-locked oscillator operation. Using a 3 mm bore lamp is much cheaper and a more effective way to stabilize the arc location in a lamp.

Third, below the repetition rate where operation heats the dye, stability is not sensitive to pulse repetition rate.

Table 2 summarizes the results for the output stability using a sapphire etalon resonant reflector as an output mirror. It was found that for about 18% of the pulses, no output at all was observed. By increasing the concentration of the dye, an output was obtained more than 97% of the time (less than 1 in 50 pulses missing) and the distribution of energies stabilized. This is not unreasonable, as increasing the dye concentration increases the peak intensity of the mode-locked pulse, while stretching the pulse length with an etalon decreases the peak intensity.

V. SUMMARY AND RECOMMENDATIONS

It has been found that for maximum reliability of operation of the NRL mode-locked oscillator, it is necessary to run the mode-locking dye at a constant absorption coefficient and temperature. Additional stability has been obtained by going from a 4mm bore to a 3mm bore flashlamp, and by using a stabilized power supply.

For longer pulse duration it is necessary to increase the absorption coefficient of the mode-locking dye. I recommend the use of 0.5mm teflon dye cell spacers and absorption coefficients of 20 cm^{-1}, 23 cm^{-1}, and 25 cm^{-1} for 15 psec, 200 psec, and 900 psec pulses respectively.

In addition, since the dye used has a limited shelf like, it is recommended that a 1-μ Millipore teflon filter be placed in series with the dye cell, and that the absorption coefficient be checked and corrected at least once every week.

VI. REFERENCE

1. Lowel Noble and C. B. Kretschmer, Optical Pumps for Lasers, Tri-Annual Report No. 1 - March 1972.

TABLE 1

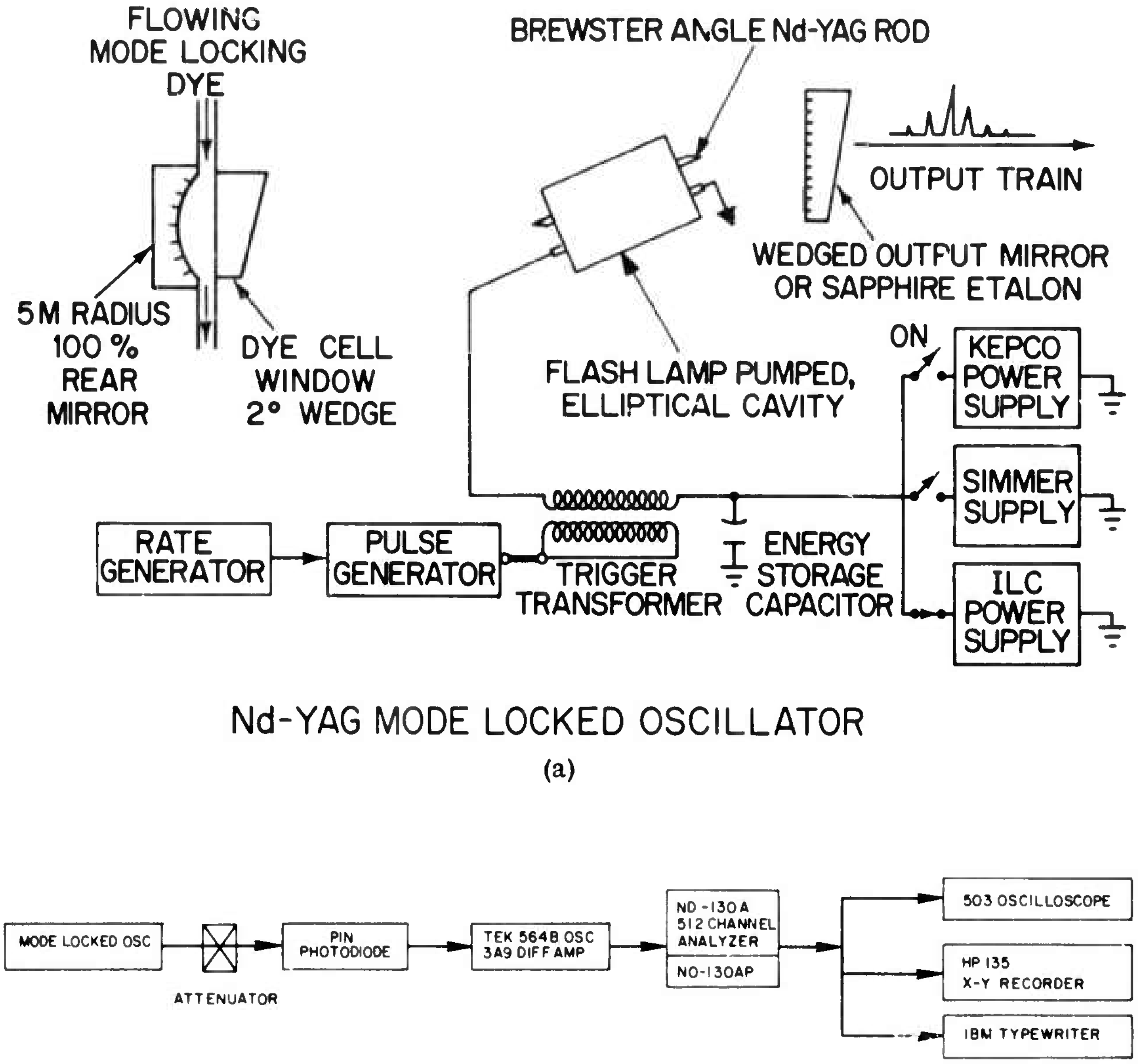
Basic system: 30% dielectric output mirror, water cooled lamp

SYSTEM #	SYSTEM PARAMETERS	DIST FWHM/TIME	REMARKS
1	ILC power supply, 4 mm bore lamp, 30 ppm repetition rate	18.7%/130 min	
2	Kepco power supply, 4 mm bore lamp, 30 ppm	17.6%/150 min	
3	ILC power supply, 4 mm bore lamp, 30 ppm repetition rate, laser rod water cooled	14%/30 min	
4	Kepco power supply, 4 mm bore lamp, 30 ppm, laser rod water cooled	9.6%/110 min	
5	Kepco power supply, 3 mm bore lamp, 30 ppm, laser rod water cooled	(a) 6.1%/50 min (b) 25%/200 min	Air conditioning partially failed.
6	Kepco power supply, 3 mm bore lamp, 60 ppm, laser rod water cooled	6.5%/30 min	Air conditioning partially failed.
7	Kepco power supply, 3 mm bore lamp, 50 ppm, laser rod water cooled, dye vibration filter cooled	10%/360 min	Air conditioning partially failed.
8	Kepco power supply, 3 mm bore lamp, 50 ppm, laser rod cooled, dye vibration filter cooled, dye reservoir cooled	6.4%/18 hrs.	Air conditioning partially failed.
9	Kepco power supply, 3 mm bore lamp, 50 ppm, laser rod cooled, dye vibration filter cooled, dye reservoir cooled, simmer supply	6.4%/13 hrs.	Air conditioning partially failed.

TABLE 2

Basic System: Kepco power supply, 3 mm bore lamp, dye filter and reservoir cooled, lamp and laser rod cooled, Sapphire etalon output mirror (200 psec pulse).

SYSTEM #	SYSTEM PARAMETERS	DIST FWHM/TIME	REMARKS
1	Basic System, 60 ppm	16.6%/16 hrs.	19% of pulses missing, wings of dist. scattered
2	Added Simmer supply	12.7%/18 hrs.	18% of pulses missing, wings of dist. scattered.
3	Basic system, increased dye concentration to $\alpha = 23\ \text{cm}^{-1}$	7.4%/80 min	No missing pulses wings look much better.



Nd-YAG MODE LOCKED OSCILLATOR

(a)

(b)

Fig. 1 - Experimental Set-up

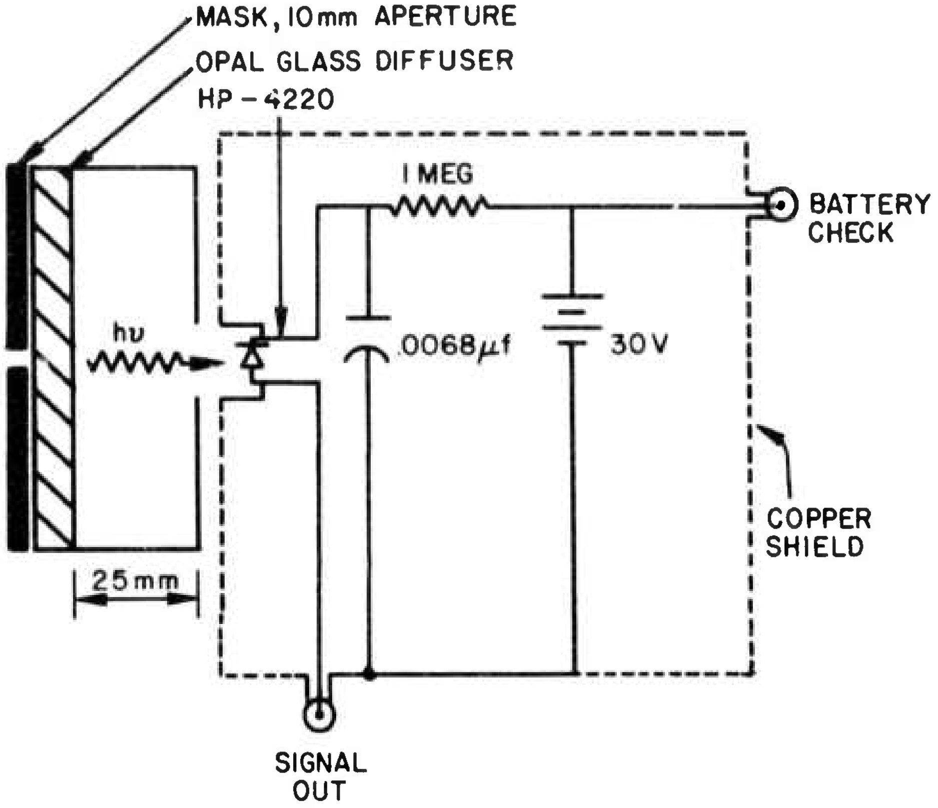


Fig. 2 - Detector and circuit

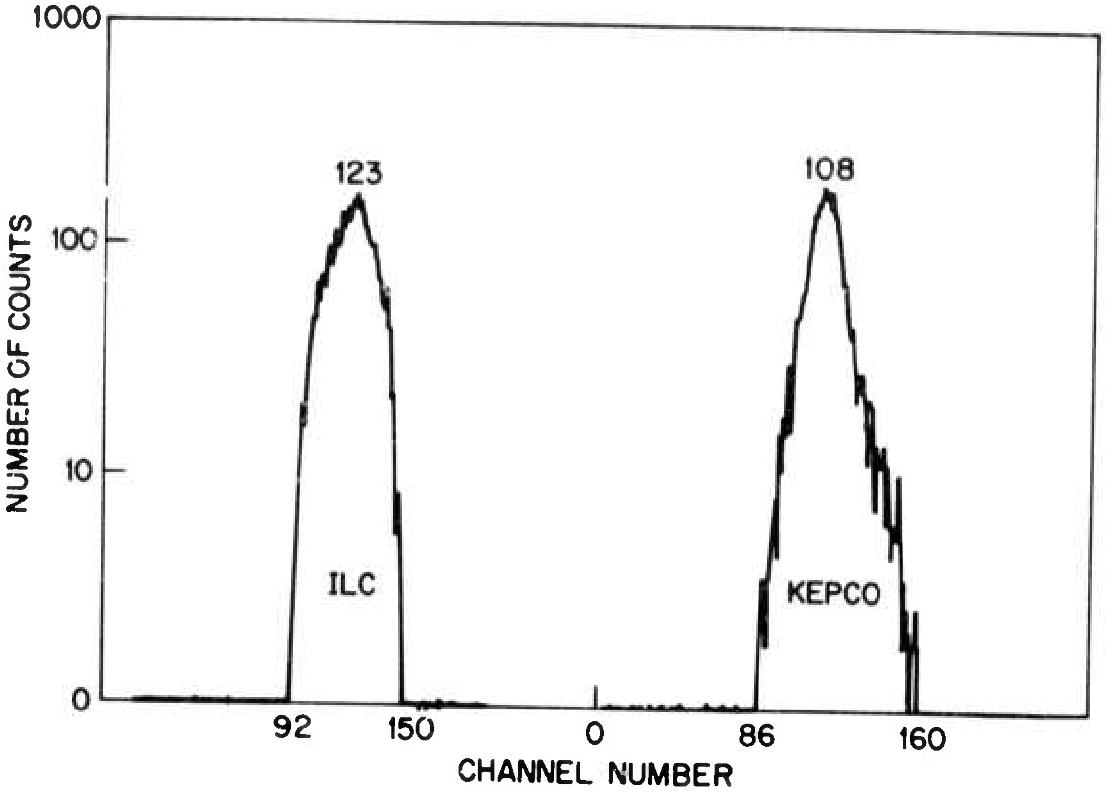


Fig. 3 - 2½ hour test, air conditioning failed

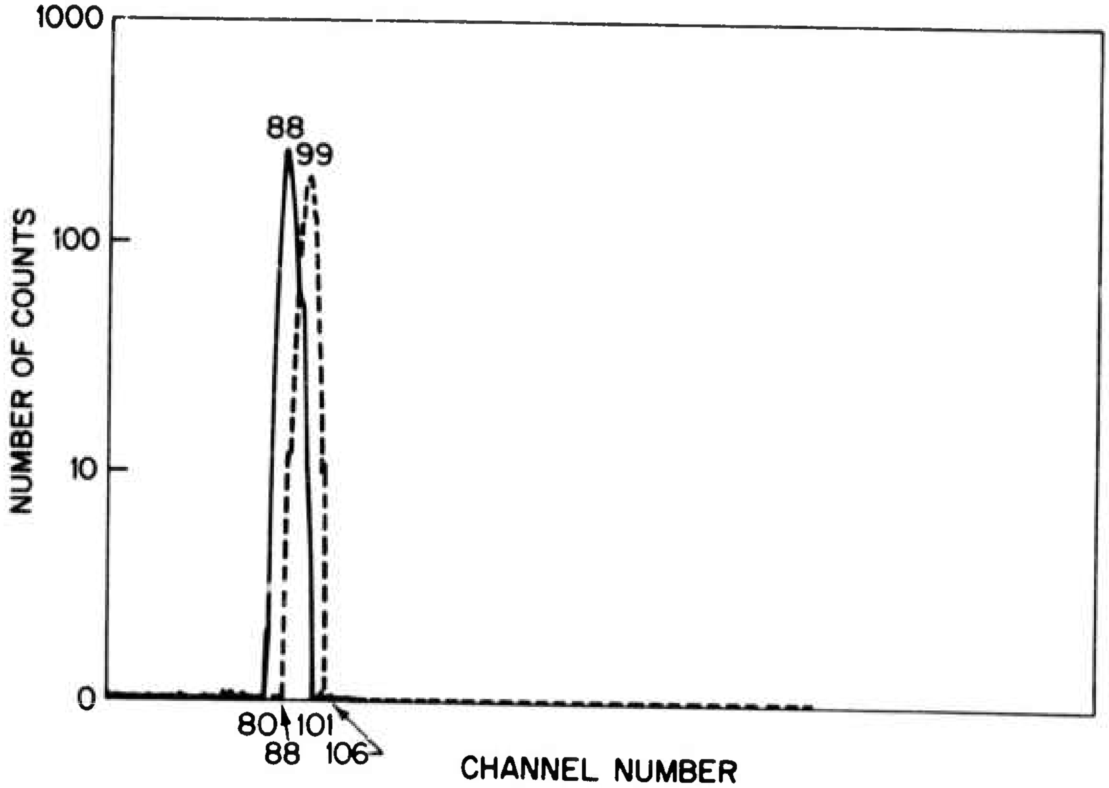


Fig. 4 - Two successive 80 minute tests, air conditioning failed