FINAL REPORT

POLARIZATION EFFECTS
Tasks 3 & 4
(LP-140)

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16. Abstract

The LP-140 is a commercial pulsed CO_2 laser system. This research effort attempted to convert this workhorse laser into a device suitable for coherent LIDAR applications. This required initial laser characterization, and system modification. The key changes which enabled the laser to display encouraging characteristics are:

- cavity length increase
- gas flow increase
- gas mixture modification
- power supply redesign.

With suitable modifications the LP-140 becomes a viable candidate for a coherent LIDAR.

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Table of Contents

Table of Figures

1 INTRODUCTION

This paper will describe the optical characteristics of the LP-140 pulsed CO_2 laser, which was modified for use as a coherent lidar. The LP-140 is a transverse excited pulsed device based on a sympathetic discharge. The system is produced and marketed commercially as a power laser used for applications such as can marking or engraving. The following specifications are quoted by the manufacturer (*Pulse Systems, Inc.*):

-DIMENSIONS: 0.35 x 0.35 x 1.2 m^3 (this dimension includes all optical components)
-ENERGY PER PULSE: 3 J. (multi-mode)
-GAS CONSUMPTION: 0.3 Standard Cubic Feet Per Hour
-GAS MIX: 20% CO_2; 15% N_2; 65% He
-INPUT POWER: 115V, 50-60 Hz, @ 5 amps
-MAXIMUM REPETITION: 8 Hz (Higher rep. rates available but at lower pulse energies)
-PRESSURE: 40 torr
-PULSE WIDTHS: 35 microseconds FWHM (100 nanoseconds to 200 microseconds available on special order)

The goal of the investigation was to modify the laser to meet the following baseline criteria:

-Minimum overall size and compactness

-Energy of 1J/ pulse

-Stable single mode operation

-Frequency stability across the pulse of < 1 MHz

-Maximum pulse length of 5 microseconds

-Maximum rep. rate of 10Hz

The baseline characteristics were derived from the considerations of the laser systems proposed and required for **LAWS**, although this laser was never meant to be a contender for such a program. The relative low cost, simple and rugged design did make it an attractive design choice for smaller scale atmospheric studies if the laser output quality could be improved substantially.

2 LASER DESCRIPTION

The actual laser that was secured for this investigation differed from the standard commercial models in several key manners. First, the active region was extended from the 1.2 m^3 of the standard design to 1.4 m_3. The standard gas mixture was modified as recommended by PSI for producing shorter pulses. The recommended gas mixture for standard operation is:

CO_2 18%

N_2 15%

CO 2%

He balance

The modified gas mix was designed by a Boltzmann distribution code and proprietary software model developed internally by PSI. The new mix for producing shorter pulses is as follows:

CO_2 57.93%

N_2 29.09%

He balance

This mixture was used throughout this investigation. All of the following results are based on its usage. PSI was emphatic in pointing out that a possible loss of power in a properly formulated gas mixture is the presence of trace concentrations of xenon as a contaminate. This was found to be a problem in one replacement cylinder of gas.
Another modification was the design of an unstable resonator with a Bragg angle reflection grating. The standard configuration is designed for high power multi-mode operation. Since our application requires mode discrimination the resonator design was changed to a hybrid, positive branch half-symmetric configu-

ration.

Single mode operation is insured with the use of a Burleigh instruments 150 lp/mm blazed grating. The standard gas flow had been rerouted to enhance the ultimate lifetime during uninterrupted operation.

The standard commercial housing was maintained, but modified to allow for the addition of the grating externally to the housing. The laser resonator was the standard cast aluminum single piece construction. The grating was attached with three spring tension screws directly to the aluminum end face. The grating was also supplied with a PZT driver attached to aid designing techniques for feedback control for single longitudinal mode operation.

2.1 OPTICAL PRESCRIPTION

The optical prescription of the laser is as follows:

Output coupler: (Meniscus element) 5 m radius of curvature on both surfaces 1 and 2, with the convex side toward the discharge. In the center a square mirror was flashed on using gold with an area of 2 cm^2. The thickness of the output coupler is 0.25". The diameter is 2.5". The material is ZnSe. The inside face (convex and mirror side) is also A.R. coated.

Next, two gold fold mirrors fold the discharge into the second branch of the folded cavity. Each is a rectangular flat mirror on a simple three-point mount.

Finally the cavity is sealed with a **plano-convex lens, with the convex side facing the discharge. The lens has a 10 m focal length, with an edge thickness of 0.25" and A.R. coated on both sides.** This lens is also 2.5" in diameter.

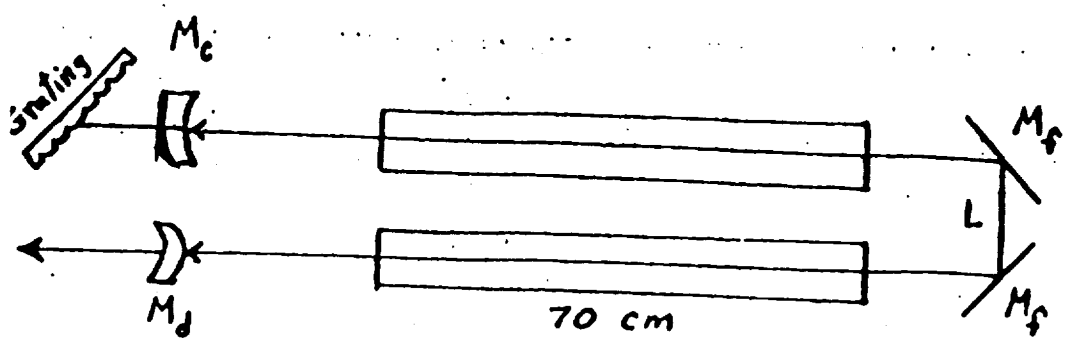
Since this discharge region is square all optical elements are underfilled. The actual beam dimensions are (center obscured) 4 x 4 cm^2.

The optical cavity is completed by a Littrow angle grating just beyond the final lens element a distance of 4.0" from the lens. This results in an overall cavity length of 238 cm.

Figure 1 shows the cavity layout.

Fig. 1. Optical layout of LP-140.

LP-140 Unstable Resonator



3 INITIAL CHARACTERIZATION

The double gain cell has a dimension of 4 cm x 4 cm x 70 cm, with an unsaturated gain of 0.031/ cm and a saturation intensity of 0.017 J/ cm^2. The confocal unstable resonator has a focal length of 238 cm. The output coupler has a 500 cm radius of curvature and a 2 cm x 2 cm active area. The converging lens has a focal length of 1000 cm. By solving the thick lens equations:

$$\Delta = (n-1)[n(r_1 - r_2) - (n-1)t]$$

and

$$f = -f' = \frac{n r_1 r_2}{\Delta}$$

we find that

$$r_1 = -\left(\frac{\left(\frac{(f\Delta)}{r_2}\right)}{n}\right)$$

where for Δ we find

$$r_1 = \left(-r_2 - (n-1)\frac{t}{n}\right) n(n-1)$$

from this we find that r_1 = 14.05 m while $r_2 = \infty$. The magnification can be found for the cavity in various ways. This is important to recognize since the intracavity magnification is significantly different from the whole system magnification. Since the laser is comprised of an unstable resonator the intracavity must be > 1 yet external to the cavity the magnification should be unity to allow for a minimum fresnel divergence of the beam waist upon leaving the cavity.

The magnification internal to the cavity is approximately **1.1** while the magnification on leaving the cavity is **1.007**. The equivalent fresnel number for the laser cavity is highly dependent on the system magnification but is approximately 1.3 for the base line system.

Some concern is noted due to the over simplistic nature of the fold mirror mounts. Since the mirror dimensions are quite large there is a concern that the mirrors may vibrate with a natural frequency during the laser discharge. Verification of this would require a stress analysis that has to date not been performed.

Another important to point to note with the optical configuration is the positioning of the high reflector mirror in the center of the output coupler. In a more traditional configuration this mirror would be off to the side, this however is not the case. This results in higher transmission diffraction in the output beam as will be seen and addressed later in this paper.

3.1 OPTICAL PRESCRIPTION

The optical prescription for the system is as follows:

OLD CAVITY WITH 22 INCH GRATING EXTENSIAN (GAUSSIAN TREATMENT)

SURF	RAD.	THICK	N1	N2	N3		GLASS
0	******	1E+12	1.00000	1.00000	1.00000		AIR
1	-5	-2.28	-1.00000	-1.00000	-1.00000	S	REF
2	-14.2	-.00635	-2.40303	-2.41123	-2.41162		ZNSE
3	******	-.56	-1.00000	-1.00000	-1.00000		AIR
4	******	.56	1.00000	1.00000	1.00000		REF
5	******	.00635	2.40303	2.41123	2.41162		ZNSE
6	14.2	2.28	1.00000	1.00000	1.00000		AIR
7	******	0	1.00000	1.00000	1.00000		AIR

LP140 WITH FLAT WINDOW AND GRATING ATTATCHED 4" ON HOUSING MAG=1

SURF	RAD.	THICK	N1	N2	N3		GLASS
0	******	1E+12	1.00000	1.00000	1.00000		AIR
1	-5	-2.28	-1.00000	-1.00000	-1.00000	S	REF
2	******	-.00635	-2.40303	-2.41123	-2.41162		ZNSE
3	******	-.1016	-1.00000	-1.00000	-1.00000		AIR
4	******	.1016	1.00000	1.00000	1.00000		REF
5	******	.00635	2.40303	2.41123	2.41162		ZNSE
6	******	2.28	1.00000	1.00000	1.00000		AIR
7	******	0	1.00000	1.00000	1.00000		AIR

The system analysis and design was performed using **SODA** version 4.4. Quantum 7.1-4 was also used for verification of the SODA numbers.

3.2 Pulse energy

The initial pulse energy for the system was measured as apx. 1 joule per pulse at 1 Hz. The power stability was poor and varied not only from shot to shot but decreased to below a joule after only a few minutes of operation or apx 20-40 shots. As the rep. rate was increased the average pulse power also decreased dramatically. The following table of output values was noted within 60 minutes after initial startup. During the test it was found a minimum of 40 minutes was required for the operational system to reach thermal equilibrium and maximum stability.

PRF PULSE RATE	OUTPUT POWER
1 Hz	1 joule
2 Hz	0.80 joule
3 Hz	0.78 joule
4 Hz	0.65 joule
5 Hz	0.63 joule
6 Hz	0.50 joule
7 Hz	0.40 joule

8 Hz	0.20 joule

This run was produced within 5 minutes after startup

PRF PULE RATE	**OUTPUT POWER**
1 Hz	1.00 joule
2 Hz	0.9 joule
3 Hz	0.7 joule
4 Hz	0.6 joule
5 Hz	0.5 joule
6 Hz	0.4 joule
7 Hz	0.3 joule
8 Hz	0.2 joule

As seen in the above table the power available at low rep. rates drops considerably as the laser warms up. The shot to shot stability also increases with time. When the laser is cool, individual pulse powers are higher but there is a larger distribution variance as well. In the cool system the power may vary as much as 10% shot to shot, as the laser warms up this drops to apx. 5%.

Double gain cell -

gain cell dimensions - 4 cm X 4 cm X 70 cm

unsaturated gain - .031 /cm

saturation intensity - .017 J/cm²

wavelength - 10.59 μm

Unstable resonator - confocal

length - 238 cm

diverging mirror - (M_d) <u>OUTPUT COUPLER</u>

radius of curvature - -500 cm

dimensions - 2 cm x 2 cm

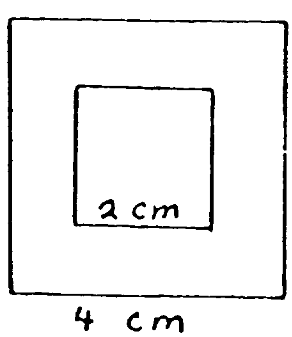
converging mirror - (M_c)

~~radius of curvature~~ = 1000 cm.

magnification - 2.0

equivalent Fresnel number - 1.880

output beam -



3.3 Temporal profile

The temporal profile was measured using a PSI fast response pyroelectric detector, model # UF-1. The responsivity is

$R \times 10^{-7} V/W$

The maximum energy permissible without damage is given as:

$E_m \leq (50t)^{1/2} \leq 1.5 \times 10^{-3} J$

where t = FWHM laser pulse in seconds, or **1.5 mJ.**

Since the detector area was only 2 mm x 2mm square, the beam had to be focussed onto the detector. The high energy density would quickly vaporize the detector so the raw beam was attenuated using several sheets of transparent mylar, of the type used for over-head transparencies. A total of 4 sheets were required to sufficiently attenuate the beam to enable focussing on the detector.

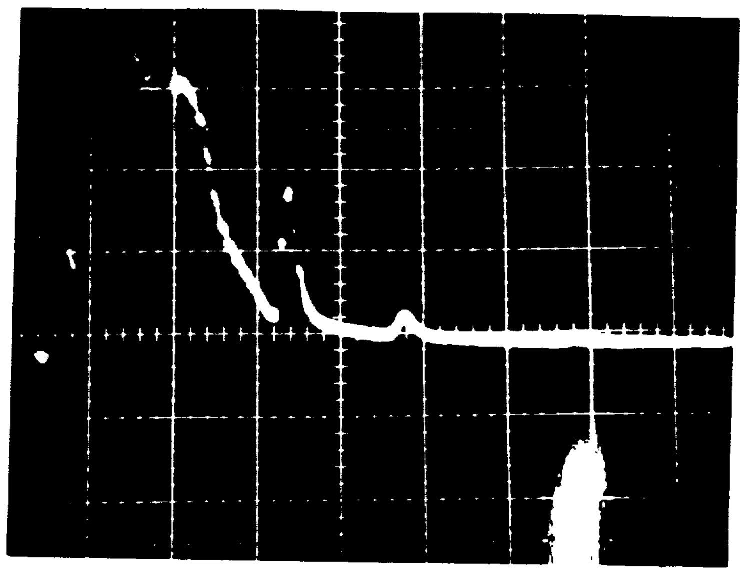
The attenuated beam is focussed by a three inch diameter spherical aluminum mirror (F#10.2) to a 32 inch focal point. The mirror was aluminum. If a gold mirror was substituted which had a higher net reflectivity, dielectric breakdown of the potting compound around the detector resulted from the inciding beam.

The following is an example of the initial temporal profiles observed as a baseline characterization.

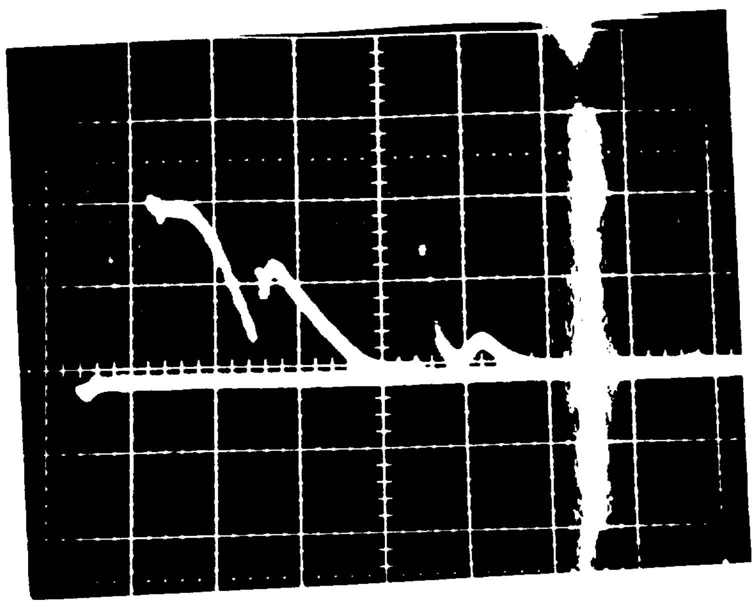
3.3.1 50 Torr

A 1Hz pulse rep. rate at a gauge pressure of 50 torr gives a temporal pulse as shown. Only relative vacuum levels are given here, since not attempt was made to determine absolute vacuum levels. The vacuum was measured using 0-50 torr Wallace-Tiernan FA-160 gauge. The pressure was measured on the vacuum port side of the laser tube and therefore represents the vacuum within the 0.25 inch plastic tubing going to the Sargent Welch roughing pump.

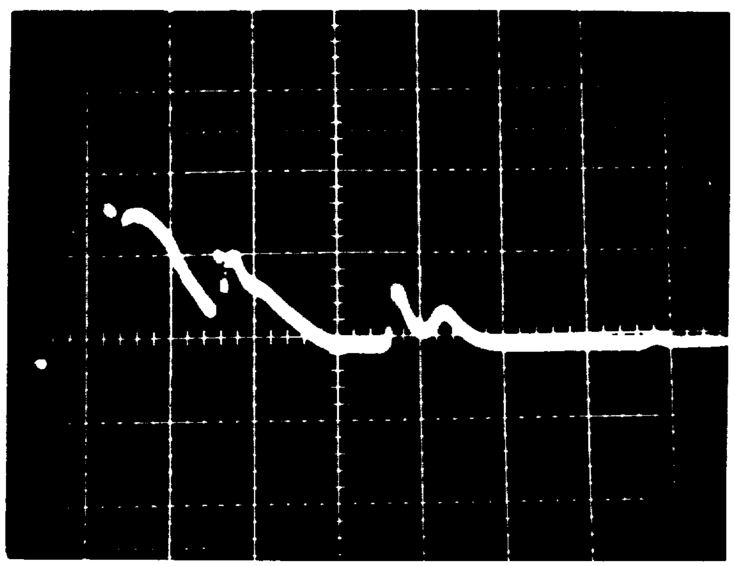
50 Torr. 5 mV/ Div. 5 mV/Div 5μsec/Div This profile is very stable and repeatable.



40 Torr temporal profile. 5 mV/ div, 5μsec/Div



35 Torr temporal profile. 5 mV/ Div, 5μsec/Div



3.4 Spatial profile

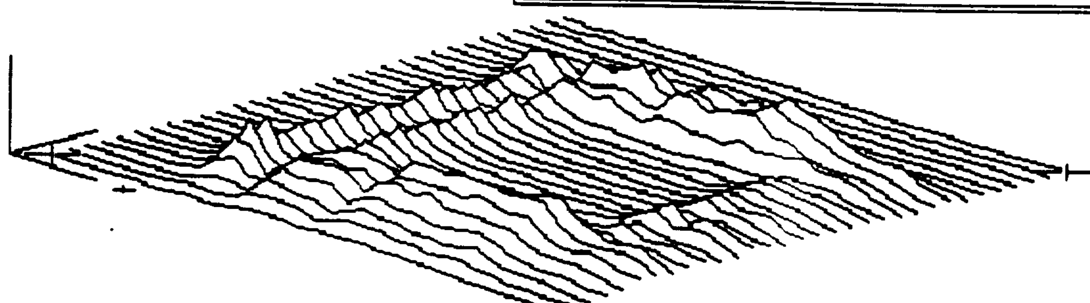
The spatial profile was measured using a Spiricon beam profiler. The first most prominent point of interest is the large degree of beam pointing instability as well as mode hopping noted with the baseline system. The following images were taken with the laser fixed to an optical rail and the detector held stationary, but the x-y translation of the entire pattern across the field of the aperture is obvious.

The mode hopping is evidenced by local hot spots in the beam distribution which arise and disappear on a shot to shot basis. The normal cavity configuration is highly unstable and gives indication of being at a mode crossing point. This suspicion was confirmed later during a more rigorous modeling stage. It is difficult to quantify an *l or m* mode designation for the output.

LP-140 spatial mode record # 1.

11:16:55 3/ 6/90
LP140A Rec # 1

Diam=	19.28,	Eny=	57005,	Pk/A=	4.95
X= 17.27,	Y= 14.36,		PX= 22,	PY=	25
Gaus X =	0.00,	Y =	0.00,	Height=	0.0
Wx=	0.00,	Wy=	0.00,	Coeff=	0.000
Cyl dia=	0.0,	Ht=	0,	Coeff=	0.000
TopH Dia=	0.0,	Ht=	0,	Sd=	0



MAIN MENU

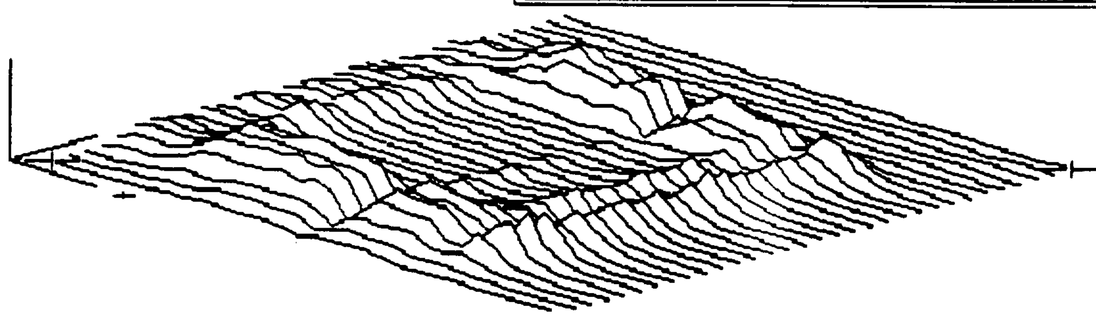
<F1> Execute	<F2> Print
<F3> Get from Disk	<F4> Save to Disk
<F5> Main On/Off	<F6> Aux M On/Off
<F7> Setup Menu	<F8> Jittr/Diverg
<F9> Help	<Alt F10> Exit

<S> Sec Data NONE <+/-> Mag. 1x
<X> Format HL <Ins/Del> CW/CCW -45
<↑/↓> Up/Down <Pg Up/Dn> Tilt 20
<◄/►> Left/Right <M/L> Slice 1
<Home> A/B <P> Prnt <W> (Whole) Part
A(1, 1), B(32, 32)

LP-140 spatial mode record # 6.

11:47:27 3/ 6/90
LP140A Rec # 6

Diam= 18.94, Eny= 49343, Pk/A= 5.01
X= 14.87, Y= 13.57, PX= 10, PY= 24
Gaus X = 0.00, Y = 0.00,Height= 0.0
Wx= 0.00, Wy= 0.00, Coeff= 0.000
Cyl dia= 0.0, Ht= 0, Coeff= 0.000
TopH Dia= 0.0, Ht= 0, Sd= 0



MAIN MENU
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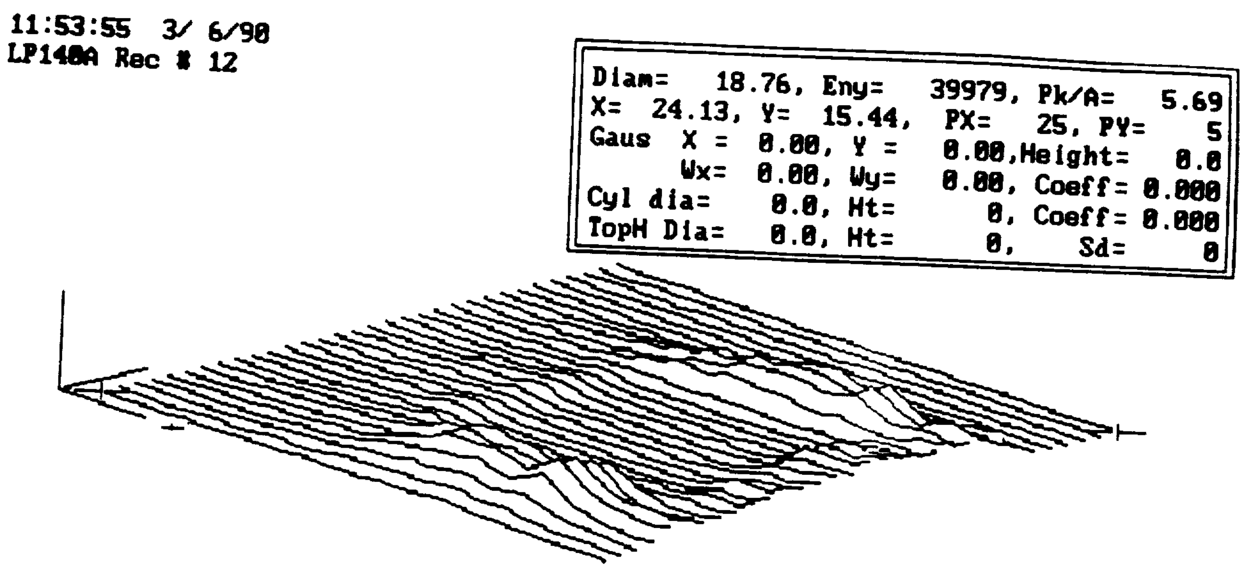
<F5> Main On/Off <F6> Aux M On/Off
<F7> Setup Menu <F8> Jittr/Diverg
<F9> Help <Alt F10> Exit

<S> Sec Data NONE <+/-> Mag. 1x
<X> Format HL <Ins/Del> CW/CCW -45
<↑/↓> Up/Down <Pg Up/Dn> Tilt 20
<◄/►> Left/Right <M/L> Slice 1
<Home> A/B <P> Prnt <W> (Whole) Part
A(1, 1), B(32, 32)

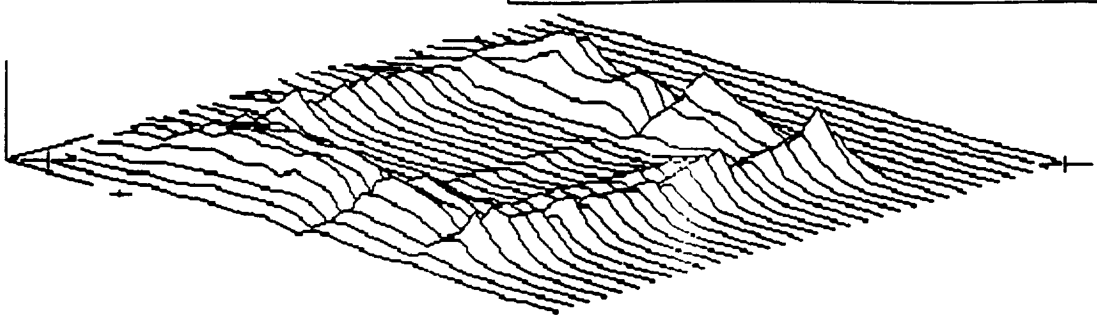
LP-140 spatial mode record # 12.



LP-140 spatial mode record # 15.

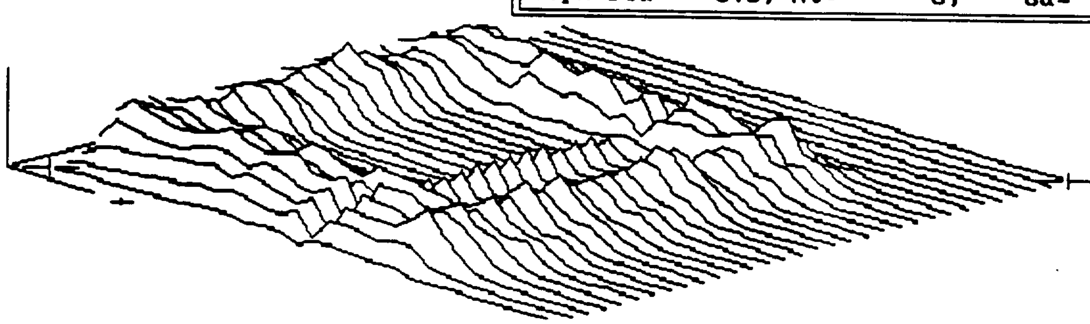
11:56:53 3/ 6/90
LP140A Rec # 15

```
Diam=    18.32, Eny=   58145, Pk/A=   5.34
X=  14.74, Y=  13.94,  PX=    10, PY=   24
Gaus  X =  0.00, Y =   0.00,Height=   0.0
      Wx=  0.00, Wy=   0.00, Coeff= 0.000
Cyl dia=     0.0, Ht=      0, Coeff= 0.000
TopH Dia=   0.0, Ht=       0,    Sd=     0
```



12:15:12 3/ 6/90
LP140A Rec # 30

```
Diam=    27.08, Eny=   81279, Pk/A=   3.81
X=  10.61, Y=  13.73,  PX=     3, PY=   17
Gaus  X =  0.00, Y =   0.00,Height=   0.0
      Wx=  0.00, Wy=   0.00, Coeff= 0.000
Cyl dia=     0.0, Ht=      0, Coeff= 0.000
TopH Dia=   0.0, Ht=       0,    Sd=     0
```



LP-140 spatial mode record # 30.

3.5 Chirp

The initial chirp data was collected on the 916μ line. The beam was directed into the receiving telescope optics of the existing Marshall LIDAR. The raw beam was attenuated with four mylar sheets, and the beam then scattered from a sand wheel target.

The initial collected data was very noisy and gave clear indication of multi-pulsing phenomena. The chirp far exceeded 8 MHz and varied dramatically from pulse to pulse. The total signal amplitude also varied greatly. There were distinct indications of multiple pulses in the train and a great deal of ringing during and after the discharge.

It was quite difficult to sort out noise from the discharge and isolate the equipment well enough to obtain a clear picture of how severe the problem was. This was an early indicator that RF noise produced by the sympathetic discharge would present a major problem downstream.

The average chirp pulse train lasted for 18-20μsec. Also the profile made it clear that there were off band multi-pulses occurring which actually make the chirp instability far worse than 8 MHz.

4 SYSTEM MODIFICATIONS

The modifications made to the system were required to be simple and essentially non-invasive in nature. The long procurement times for obtaining parts through the government purchasing system provided a great incentive for designing modifications that were readily implemented by the team.

All of the final modifications which have been performed to date are of a nature that marginally improved system performance individually, but collectively dramatically improved it.

4.1 Gas flow

The gas flow was considered to be insufficient based on the characteristics of the shot to shot temporal profile. Indications were that gas heating and possible *LIMP* effects were limiting to power output. The degradation of power in a successive pulse train was also thought to be due to this. Inspection of the laser head showed that the gas in and out flow were limited by the orifice size of the flow tubing. The original arrangement was to have a 3/8" tube introduce gas directly through the top center of the discharge region, while two 1/4" tubes located at the bottom and on either side of the discharge drew it out to the vacuum pump. These two 1/4" lines met at a Tee where a 3/8" tube connected to a vacuum pump.

Prior to reaching the pump, the line was isolated by a nupro 1/4" valve. This reduced the actual vacuum pump line diameter to 1/4".

The base laser flows gas through the discharge at a slow trickle rate of 1/2 cubic meter of gas a minute. The pressure at the gauge is maintained between 40 and 50 torr.

During operation, the needle on the pressure gauge momentarily rises by as much as 10 torr. This is indicative of the pressure wave which exists inside the cavity during the laser discharge.

The gas lines were simple reversed. In the new configuration, the gas is drawn through the top center orifice into a 3/8" tube which is maintained to the pump. The gas is introduced into the system through the bottom two 1/4" tubes at a pressure of 40 psi. The overall flow is increased, but no actual measurement has been performed to date. The pressure adjustment does become extremely sensitive to small adjustments on the second stage of the regulator.

The increased flow has provided a substantial improvement in general system performance as will be shown later. PSI, the manufacturer of the laser did point out that the original routing for the gas flow was instigated to facilitate a substantial increase in duty cycle and ultimate lifetime. By having the incoming gas pass downward over the electrodes, particulate contaminants are swept away from the electrodes. In practice PSI reported verbally to have secured an increase of lifetime in the range of hundreds of hours. For our use, the ultimate lifetime is not crucial, therefore may be neglected. *In future designs for possible space based applications, these designed considerations should be taken into account, because routine servicing may not be feasible.*

4.2 Cavity length

The extreme mode hopping discovered in the original configuration was felt to be due to the cavity operating at an unstable mode point. The extreme pointing instability even suggested that the cavity may be at a mode crossing point. Two workers, Tratt and Smithers *et Al*, calculated the original cavity to be at a very unstable point. Both suggested a change in the optical cavity prescription. Tratt suggested an increase in cavity length.

This was accomplished by translating the grating backward along the -z- axis, thereby increasing the cavity length. Experimentally, the cavity was extended in one inch increments. As the cavity length increased the mode distribution quickly become much more uniform around +20.00". Previously, the grating would have to be tweaked every two to three shots to maintain a similitude of a uniform discharge square. In the region between 19 and 23 inches the distribution became very uniform and stable. The optimum beam stability and mode distribution point did not coincide. The power increased to apx. 1.25 joules at 20.00" but there was very slight mode instability characterized by the occasional appearance and disappearance of a mode hot-spot.

At 22.00 inches, the power decreased to 1.15 joules per shot at 1Hz, but the mode distribution became the most stable of the settings. The cavity quickly became chaotic as the cavity was decreased below an 18.00" extension. There was also an accompanying power drop to .75 joules at 10.00". As the cavity distance was closed in again, the power once again increased. Beyond 23.00" the power started to drop off linearly. Instability never set in as such as the cavity length increased out to 36.00 inches. Instead, the mode filling distribution collapsed and the beam filled only a single corner of the entire possible output mode. This corner remained very stable in distribution but fluctuated in power. Beyond 30.00 inches it became impossible to fill the output mirror with any amount of tweaking on the grating.

Initial attempts at modeling the laser cavity geometrically and solving for the equivalent fresnel number have been unsuccessful. Various investigators have used different approaches at solving the system magnification and arriving at an equivalent fresnel number. To date the resulting equivalent fresnel number as defined by Siegmann have differed enough to be considered an inaccurate quantity for laser performance characterization.

4.2.1 Equivalent Mirror model

The equivalent mirror model as defined by Smithers replaces the rear lens and grating combination with a single equivalent mirror of appropriate curvature and spatial position. The predicted result including diffraction effects are as follows:

Below is a table showing the equivalent Fresnel number of the LP-140 vs. the cavity length.

L (cm)	238	250	290	350
N_{eq}	1.94	1.88	1.69	1.375

A mode-crossing point is expected for $N_{eq} = 1.875$. Maximum transverse mode discrimination should occur at $N_{eq} = 1.375$.

Martin E. Smithers

Calculations done by Dr. Martin Smithers.

4.2.2 Matrix Method Model

The matrix method was used by Spiers to generate a complimentary set of data for equivalent fresnel number and system magnification. The final results are shown.

LP-140 CAVITY MODEL

The cavity proposed by Martin:-

Output Coupler
$R1 := -19.04$

Cavity Space
$L1 := 2.28$

First surface of window
$R2 := 1 \cdot 10^{6}$ $\quad n_{2} := 2.407$

$$M_{1} := \begin{bmatrix} 1 & 0 \\ \dfrac{-2}{R1} & 1 \end{bmatrix} \qquad M_{2} := \begin{bmatrix} 1 & L1 \\ 0 & 1 \end{bmatrix} \qquad M_{3} := \begin{bmatrix} 1 & 0 \\ \dfrac{\dfrac{1}{n_{2}} - 1}{R2} & 1 \end{bmatrix}$$

Thickness
$t := 6.35 \cdot 10^{-3}$

Second surface
$R3 := 1 \cdot 10^{6}$

Grating Spacing
$L2 := 0.1$

Grating

$$M_{4} := \begin{bmatrix} 1 & \dfrac{t}{n_{2}} \\ 0 & 1 \end{bmatrix} \qquad M_{5} := \begin{bmatrix} 1 & 0 \\ \dfrac{\dfrac{1}{n_{2}} - 1}{R3} & 1 \end{bmatrix} \qquad M_{6} := \begin{bmatrix} 1 & L2 \\ 0 & 1 \end{bmatrix} \qquad M_{7} := \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Then reverse direction through the system with M.5 and M.3 changed to:-

Grating side surface
$R4 := -R3$

Cavity surface
$R5 := -R2$

$$M_{52} := \begin{bmatrix} 1 & 0 \\ \dfrac{1.407}{R4} & 1 \end{bmatrix} \qquad M_{32} := \begin{bmatrix} 1 & 0 \\ \dfrac{1.407}{R5} & 1 \end{bmatrix} \qquad M_{5} \cdot M_{4} \cdot M_{3} = \begin{bmatrix} 1 & 0.003 \\ 2.814 \; 10^{-6} & 1 \end{bmatrix}$$

System matrix:-

$$M_{s} := M_{2} \cdot M_{32} \cdot M_{4} \cdot M_{52} \cdot M_{6} \cdot M_{7} \cdot M_{6} \cdot M_{5} \cdot M_{4} \cdot M_{3} \cdot M_{2} \cdot M_{1}$$

$$M_{s} = \begin{bmatrix} 1.501 & 4.765 \\ 0.105 & 1 \end{bmatrix} \qquad \left| M_{s} \right| = 1$$

This is a check on the validity of the system matrix.

Output coupler half width, a and optical wavelength, lambda:-

$a := 9.525 \cdot 10^{-3}$ $\qquad \lambda := 10.6 \cdot 10^{-6}$

Now calculate the round trip position

$$I := M_{s} \cdot \begin{bmatrix} a \\ -0.002 \end{bmatrix} \qquad I = \begin{bmatrix} 0.005 \\ -9.995 \; 10^{-4} \end{bmatrix}$$

Then determine the magnification,M:-
Firstly the half-trace parameter,m

$$m := \frac{M_{s_{0,0}} + M_{s_{1,1}}}{2}$$

$m = 1.25$

Then M

$$M := \mathrm{if}\left[m > 1, m + \sqrt{m^2 - 1}, 0\right]$$

$$M := \mathrm{if}\left[m < -1, -m - \sqrt{m^2 - 1}, M\right]$$

$M = 2.001$

Collimated Fresnel number and equivalent Fresnel number:-

$$N_c := \frac{M \cdot a^2}{M_{s_{0,1}} \cdot \lambda} \qquad N_c = 3.594$$

$$N_{eq} := \frac{M^2 - 1}{2 \cdot M^2} \cdot N_c \qquad N_{eq} = 1.348$$

Gain coefficient:- $\alpha := 2$ Gain length:- $l := 1.4$

Effective reflectivity:-

$$R := \frac{1}{M^2} \qquad R = 0.25$$

Assume only output coupling losses and express the effective reflectivity as a loss factor:-

$$\delta_r := \ln\left[\frac{1}{R}\right] \qquad \delta_r = 1.387$$

Net power gain or loss per round trip given by:-

$$g_{rt} := 4\cdot\alpha\cdot l - \delta_r \qquad g_{rt} = 9.813$$

Number of round trips required for oscillation build-up is approximated by:-

$$N_{rt} := \frac{\ln\left[\frac{a^2}{(L1 + L2)\cdot\lambda}\right]}{\ln(M)}$$

$$N_{rt} = 1.846$$

Calculations done by Dr. Gary Spiers.

LP-140 CAVITY MODEL

The old cavity without the grating extended:-

Output Coupler
$R1 := -5$

Cavity Space
$L1 := 2.28$

First surface of window
$R2 := 14.05 \quad n_2 := 2.407$

$$M_1 := \begin{bmatrix} 1 & 0 \\ \dfrac{-2}{R1} & 1 \end{bmatrix} \qquad M_2 := \begin{bmatrix} 1 & L1 \\ 0 & 1 \end{bmatrix} \qquad M_3 := \begin{bmatrix} 1 & 0 \\ \dfrac{n_2 - 1}{R2} & 1 \end{bmatrix}$$

Thickness
$t := 6.35 \cdot 10^{-3}$

Second surface
$R3 := 1 \cdot 10^{6}$

Grating Spacing
$L2 := 0.1$

Grating

$$M_4 := \begin{bmatrix} 1 & \dfrac{t}{n_2} \\ 0 & 1 \end{bmatrix} \qquad M_5 := \begin{bmatrix} 1 & 0 \\ \dfrac{n_2 - 1}{R3} & 1 \end{bmatrix} \qquad M_6 := \begin{bmatrix} 1 & L2 \\ 0 & 1 \end{bmatrix} \qquad M_7 := \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Then reverse direction through the system with M.5 and M.3 changed to:-

Grating side surface
$R4 := -R3$

Cavity surface
$R5 := -R2$

$$M_{52} := \begin{bmatrix} 1 & 0 \\ \dfrac{1.407}{R4} & 1 \end{bmatrix} \qquad M_{32} := \begin{bmatrix} 1 & 0 \\ \dfrac{1.407}{R5} & 1 \end{bmatrix} \qquad M_5 \cdot M_4 \cdot M_3 = \begin{bmatrix} 1 & 0.003 \\ 0.1 & 1 \end{bmatrix}$$

System matrix:-

$$M_s := M_2 \cdot M_{32} \cdot M_4 \cdot M_{52} \cdot M_6 \cdot M_7 \cdot M_6 \cdot M_5 \cdot M_4 \cdot M_3 \cdot M_2 \cdot M_1$$

$$M_s = \begin{bmatrix} 2.918 & 4.755 \\ 0.388 & 0.975 \end{bmatrix} \qquad \left| M_s \right| = 1$$

This is a check on the validity of the system matrix.

Output coupler half width, a and optical wavelength, lambda:-

$$a := 9.525 \cdot 10^{-3} \qquad \lambda := 10.6 \cdot 10^{-6}$$

Now calculate the round trip position

$$I := M_s \cdot \begin{bmatrix} a \\ -0.002 \end{bmatrix} \qquad I = \begin{bmatrix} 0.018 \\ 0.002 \end{bmatrix}$$

Then determine the magnification,M:-
Firstly the half-trace parameter,m

$$m := \frac{Ms_{0,0} + Ms_{1,1}}{2}$$

$$m = 1.946$$

Then M

$$M := \mathrm{if}\left[m > 1, m + \sqrt{m^2 - 1}, 0\right]$$

$$M := \mathrm{if}\left[m < -1, -m - \sqrt{m^2 - 1}, M\right]$$

$$M = 3.616$$

Collimated Fresnel number and equivalent Fresnel number:-

$$N_c := \frac{M \cdot a^2}{Ms_{0,1} \cdot \lambda} \qquad N_c = 6.509$$

$$N_{eq} := \frac{M^2 - 1}{2 \cdot M^2} \cdot N_c \qquad N_{eq} = 3.006$$

Gain coefficient:- $\alpha := 2$ Gain length:- $l := 1.4$

Effective reflectivity:-

$$R := \frac{1}{M^2} \qquad R = 0.076$$

Assume only output coupling losses and express the effective reflectivity as a loss factor:-

$$\delta_r := \ln\left[\frac{1}{R}\right] \qquad \delta_r = 2.571$$

Net power gain or loss per round trip given by:-

$$g_{rt} := 4 \cdot \alpha \cdot l - \delta_r \qquad g_{rt} = 8.629$$

Number of round trips required for oscillation build-up is approximated by:-

$$N_{rt} := \frac{\ln\left[\dfrac{a^2}{(L1 + L2) \cdot \lambda}\right]}{\ln(M)}$$

$$N_{rt} = 0.996$$

It is obvious that in the case of system magnification both numbers and methods show good agreement. But in the case of equivalent fresnel number they diverge. It is more interesting to note that neither method coincides with the actual collected data. To date this discrepency has not been resolved.

Further development was based on the empirical evidence rather than the theoretical models.

4.3 Gas pressure

The gas pressure was varied, but the required equipment to quantify the actual *in situ* conditions was not available. Only relative pressure measurements were possible and these were obtained from the pressure meter mounted directly on the head. Clearly this bears no indication of absolute pressure within the head but serves as a relative guide for this discussion.

4.4 Gas mix

The gas mix was modified by PSI to a higher than traditional concentration of CO_2. This was done primarily to induce the laser to operate producing shorter pulse lengths. The danger exists that there will be enhanced tendencies for arcing. Pulse time reductions were obtained, and seemed to be quite repeatable and stable. There seemed to be no increased tendency toward arcing in the pressure range of standard operation (35- 50 torr.)

The normal gas mixture recommended by PSI is:

CO_2 18%

N_2 15%

CO 2%

He Balance.

The gas mixture used to collect the following data was:

CO_2 57.93%

N_2 29.09%

He Balance

Even though the CO_2 concentration was high there were no abnormal signs of enhanced arcing.

5 NEW CHARACTERISTICS

The following characteristics were measured in the lab and compared to the baseline results. Although a quantitative analysis is difficult at this point, there are certain important trends which have manifested that are worth mentioning.

5.1 Pulse power

The pulse power was immediately observed to have increased slightly and stabilized. Although, at the most stable point for pulse to pulse repeatability, the power is only equal to the original performance of 1 J/ pulse. When the cavity length is slightly modified from this point by extension of 2- 5 cm, the power increases by 10-15%. The spatial profile however is not quite as stable.

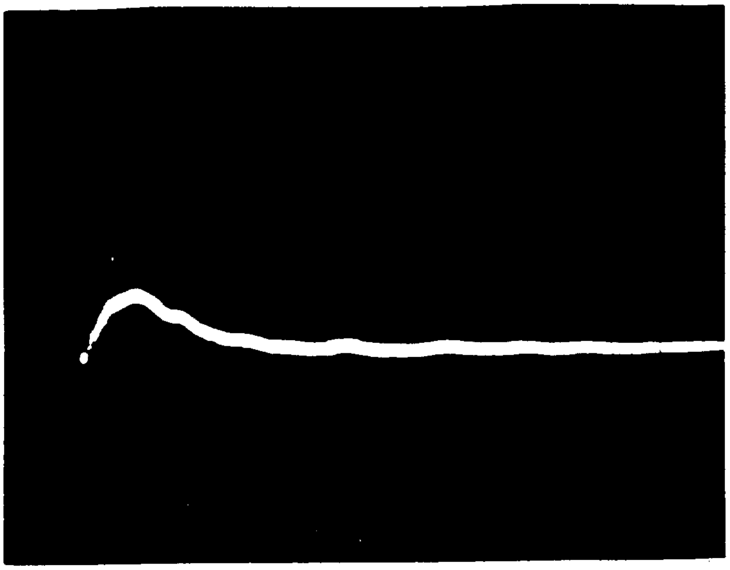
The optimum point of operation is better described as a range or window about 11 cm wide peaked at a cavity length extended by 22.00 inches. Anywhere within this window the laser operates with great stability and consistency.

5.2 Temporal profile

The temporal profile at the peak cavity length improves substantially as well. The pulse length not only shortens, but the tendency for multi-pulsing is also greatly reduced.

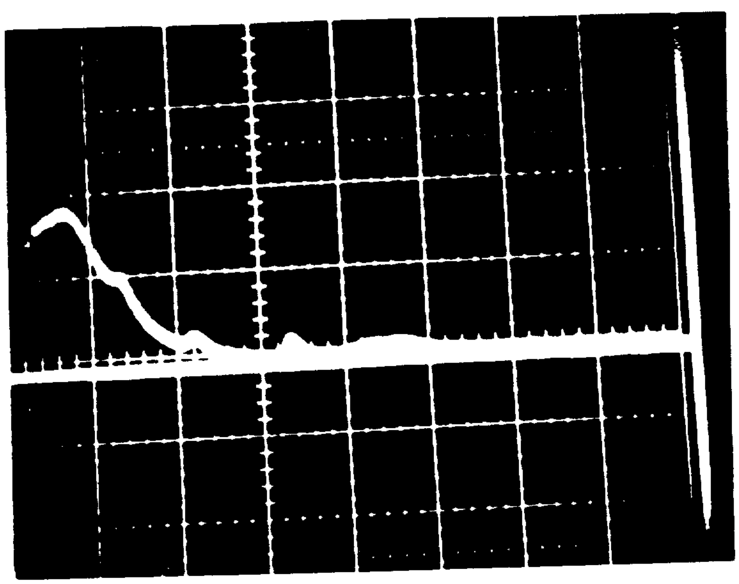
At the original cavity length, inconsistent pulse ranging up to 12 μsec were not uncommon with triple lobes in the pulse. By extending the cavity, these pulses have been reduced to 5 - 8 μsec with a single well defined lobe. It is important to note that at all cavity lengths, the g as mixture and pressure also play an important role in defining the temporal profile.

Temporal profiles at varying pressures.



35 Torr
3 Hz Rep rate

5 mV/Div 5 μsec/Div



45 Torr
1 Hz

5mV/Div 5μsec/Div
Moved grating to 22" back

5.3 Spatial profile

The spatial profile at the peak cavity length demonstrates the most significant improvement, Outside of the 11 cm window, the profile is chaotic and exhibits strong beam pointing instabilities. Within the window the temporal profile fills out and the beam settles down to a high degree of stability.

It is difficult to quantify the exact nature of the spatial mode. The center obscuration creates a square output beam with a square hole in the center. The far-field diffraction pattern seems to approximate a gaussian or top-hat Distribution quite well.

Spatial profiles with extended cavity length.

5.4 Chirp

The chirp data taken was remarkably stable and repeatable at a given pressure. The Chirp did vary considerably with pressure variation. The higher pressure range from 40- 50 torr provided the best results.

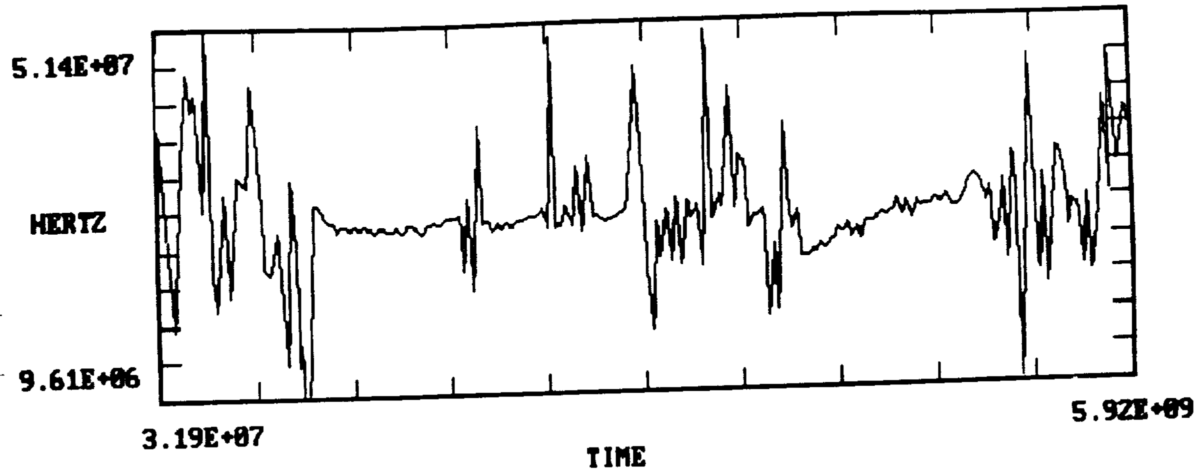
The total chirp across the pulse is apx. 1MHz. It is characterized by a curve which starts high at the start of pulse and quickly arcs to a minimum value of 200 KHz, following which it slopes back up at the tail end of the pulse.

It should be possible to incorporate a mechanical chopper in such a fashion that the lead and tail of the pulse are truncated. The center slice would contain 70% of the pulse energy, with e total pulse length being reduced to < 5 μsec.

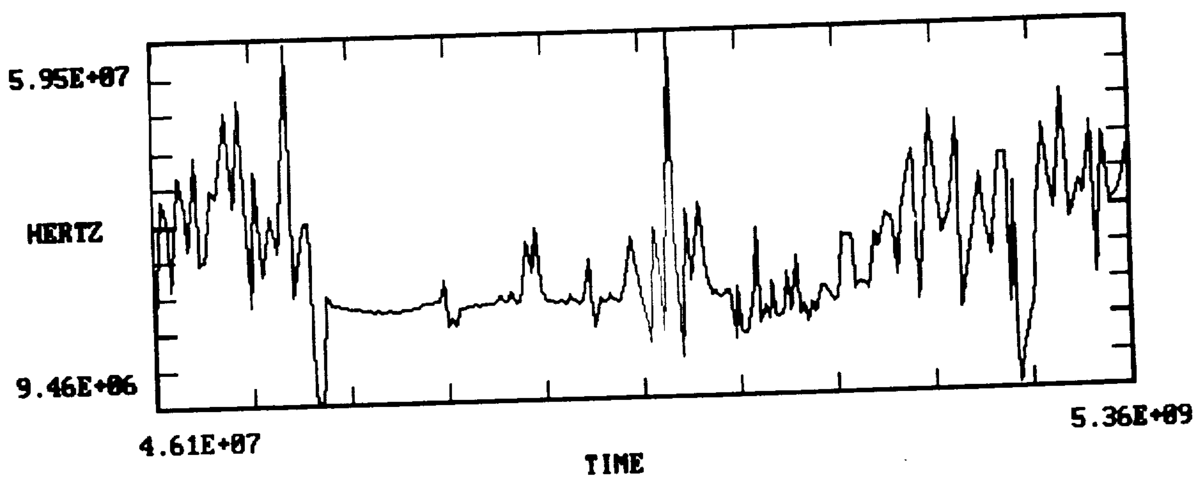
It is felt that *LIMP* plays a role in the final chirp profile.

It is felt that the start of pulse chirp cannot be readily reduced without sacrificing beam quality. The tail end may be truncated, but several methods are being explored for actively compensating for chirp increase.

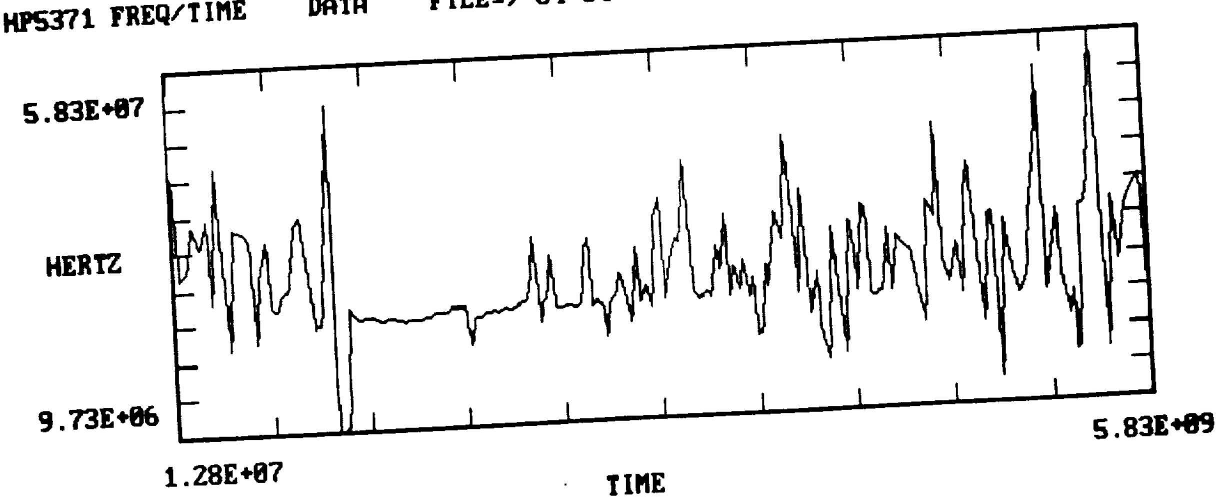
HP5371 FREQ/TIME DATA FILE=> 04-04-0 47



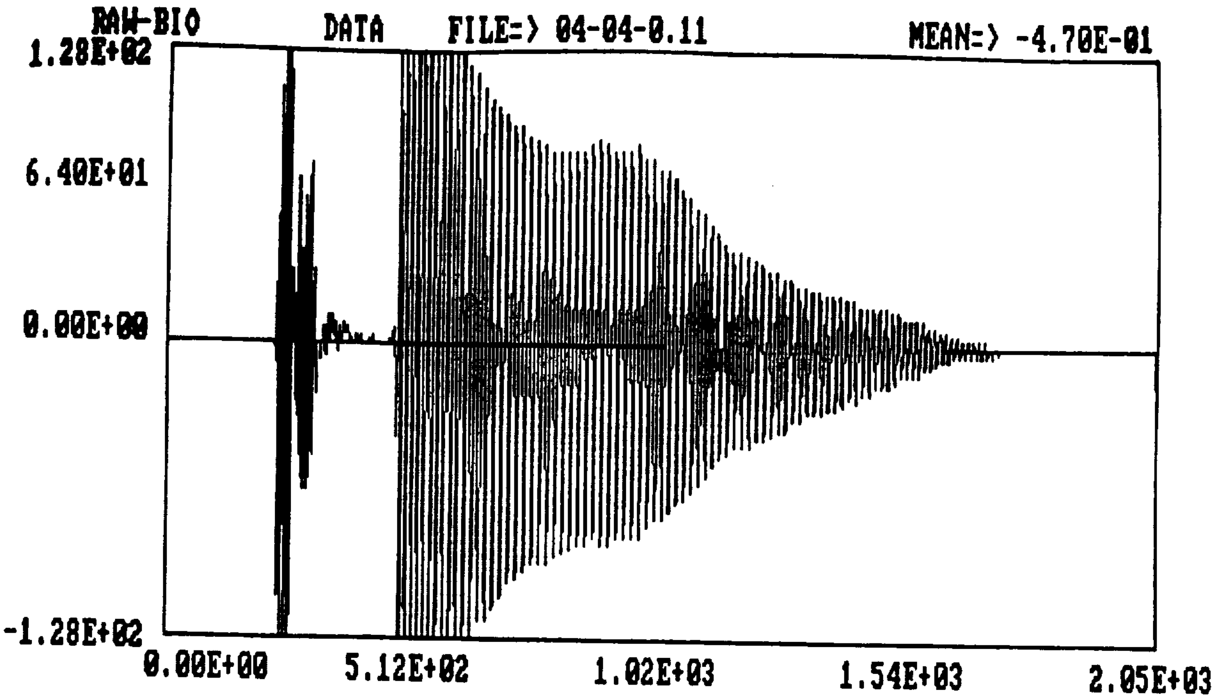
HP5371 FREQ/TIME DATA FILE=> 04-04-0 44



HP5371 FREQ/TIME DATA FILE=> 04-04-0 43



A sample of chirp data.



. INPUT THE SIZE OF THE FFT===>

04-04-0.11
PEAKS FREQUENCY OF PSD DATA FROM FILE 04-04
THIS DATA IS STORE IN FILE

FORMAT OF DATA IS AS FOLLOWS:
INDEX CNT, PSDPEAK, PEAKLOC

1	1562500	33
2	48828.13	2
3	1.352539E+07	278
4	48828.13	2
5	8203125	169
6	7470703	154
7	6542969	135
8	6201172	128
9	6201172	128
10	6298828	130
11	6494141	134
12	6494141	134
13	6494141	134
14	7031250	145
15	7421875	153
16	8056641	166
17	8740234	180
18	9375000	193
19	48828.13	2
20	48828.13	2

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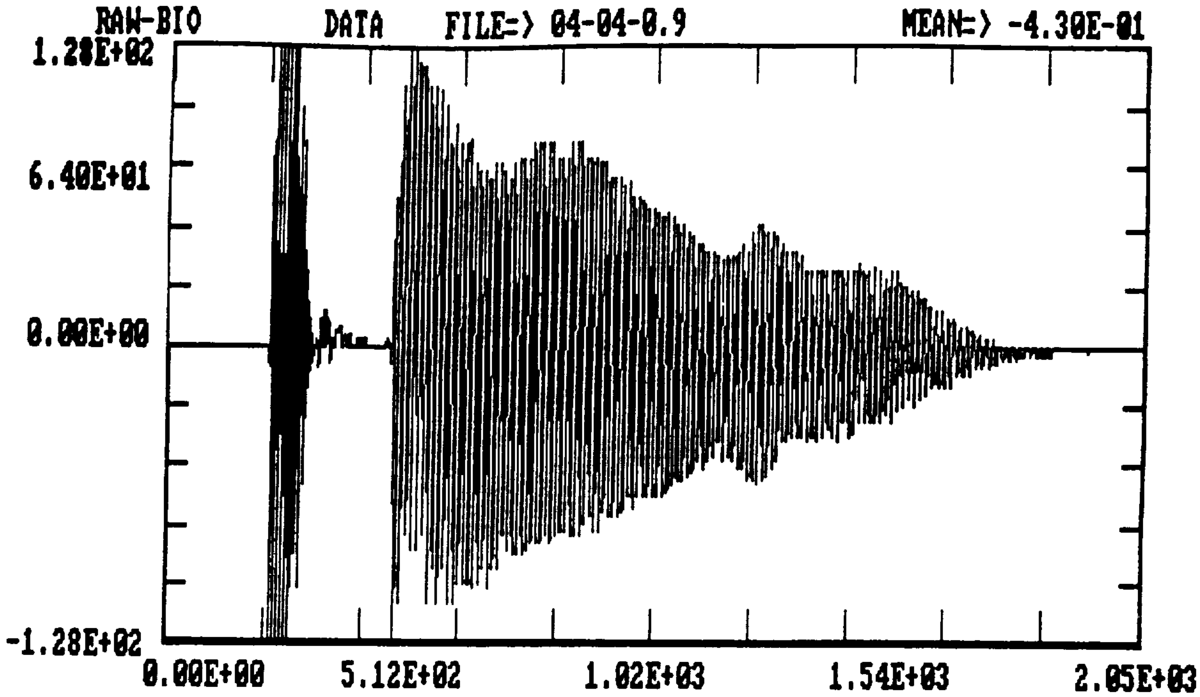

INPUT THE SIZE OF THE FFT===>

04-04-0.9
PEAKS FREQUENCY OF PSD DATA FROM FILE 04-04
THIS DATA IS STORE IN FILE

FORMAT OF DATA IS AS FOLLOWS:
INDEX CNT, PSDPEAK, PEAKLOC

1	48828.13	2
2	48828.13	2
3	1.293945E+07	266
4	48828.13	2
5	7617188	157
6	8886719	183
7	9570313	197
8	9912109	204
9	9960938	205
10	9716797	200
11	9667969	199
12	9570313	197
13	9619141	198
14	9375000	193
15	8837891	182
16	8251953	170
17	7617188	157
18	48828.13	2
19	48828.13	2
20	48828.13	2

6 LASER MODEL

The following section represents the latest attempt at generating a model of the LP-140 which approximates the real collected data. An attempt has been made to incorporate the various models found in the literature into a single system as follows.

The following data was produced by Dr. Gary Spiers using *MathCad* ver 2.5.

6.1 Magnification

LP-140 CAVITY MODEL

The old cavity with the grating extended:-

Output Coupler

$R1 := -5$

Cavity Space

$L1 := 2.28$

First surface of window

$R2 := 14.05 \quad n_2 := 2.407$

$$M_1 := \begin{bmatrix} 1 & 0 \\ \frac{-2}{R1} & 1 \end{bmatrix} \qquad M_2 := \begin{bmatrix} 1 & L1 \\ 0 & 1 \end{bmatrix} \qquad M_3 := \begin{bmatrix} 1 & 0 \\ \frac{\frac{1}{n_2} - 1}{R2} & 1 \end{bmatrix}$$

Thickness

$t := 6.35 \cdot 10^{-3}$

Second surface

$R3 := 1 \cdot 10^{6}$

Grating Spacing

$L2 := 0.56$

Grating

$$M_4 := \begin{bmatrix} 1 & \frac{t}{n_2} \\ 0 & 1 \end{bmatrix} \qquad M_5 := \begin{bmatrix} 1 & 0 \\ \frac{\frac{1}{n_2} - 1}{R3} & 1 \end{bmatrix} \qquad M_6 := \begin{bmatrix} 1 & L2 \\ 0 & 1 \end{bmatrix} \qquad M_7 := \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Then reverse direction through the system with M.5 and M.3 changed to:-

Grating side surface

$R4 := -R3$

Cavity surface

$R5 := -R2$

$$M_{52} := \begin{bmatrix} 1 & 0 \\ \frac{1.407}{R4} & 1 \end{bmatrix} \qquad M_{32} := \begin{bmatrix} 1 & 0 \\ \frac{1.407}{R5} & 1 \end{bmatrix} \qquad M_5 \cdot M_4 \cdot M_3 = \begin{bmatrix} 1 & 0.003 \\ 0.1 & 1 \end{bmatrix}$$

System matrix:-

$$M_s := M_2 \cdot M_{32} \cdot M_4 \cdot M_{52} \cdot M_6 \cdot M_7 \cdot M_6 \cdot M_5 \cdot M_4 \cdot M_3 \cdot M_2 \cdot M_1$$

$$M_s = \begin{bmatrix} 3.338 & 5.627 \\ 0.333 & 0.862 \end{bmatrix} \qquad \left| M_s \right| = 1$$

This is a check on the validity of the system matrix.

Output coupler half width, a and optical wavelength, lambda:-

$a := 9.525 \cdot 10^{-3} \qquad \lambda := 10.6 \cdot 10^{-6}$

Now calculate the round trip position

$$I := M_s \cdot \begin{bmatrix} a \\ -0.002 \end{bmatrix} \qquad I = \begin{bmatrix} 0.021 \\ 0.001 \end{bmatrix}$$

6.2 Gain

Then determine the magnification,M:-
Firstly the half-trace parameter,m

$$m := \frac{Ms_{0,0} + Ms_{1,1}}{2}$$

$m = 2.1$

Then M

$$M := \mathrm{if}\left[m > 1, m + \sqrt{m^2 - 1}, 0\right]$$

$$M := \mathrm{if}\left[m < -1, -m - \sqrt{m^2 - 1}, M\right]$$

$M = 3.946$

Collimated Fresnel number and equivalent Fresnel number:-

$$N_c := \frac{M \cdot a^2}{Ms_{0,1} \cdot \lambda} \qquad N_c = 6.002$$

$$N_{eq} := \frac{M^2 - 1}{2 \cdot M^2} \cdot N_c \qquad N_{eq} = 2.808$$

Gain coefficient:- $\alpha := 2$ Gain length:- $l := 1.4$

Effective reflectivity:-

$$R := \frac{1}{M^2} \qquad R = 0.064$$

Assume only output coupling losses and express the effective reflectivity as a loss factor:-

$$\delta_r := \ln\left[\frac{1}{R}\right] \qquad \delta_r = 2.745$$

6.3 Equivalent Fresnel number

Net power gain or loss per round trip given by:-

$$g_{rt} := 4 \cdot \alpha \cdot 1 - \delta_r \qquad g_{rt} = 8.455$$

Number of round trips required for oscillation build-up is approximated by:-

$$N_{rt} := \frac{\ln\left[\frac{a^2}{(L1 + L2) \cdot \lambda}\right]}{\ln(M)}$$

$$N_{rt} = 0.804$$

STATISTICAL EVALUATION OF CAVITY EXTENSION 3/6/90

$65.0 = 1J$

[illegible]

ΔG	I_0	Δs	ϕ	$\Delta\phi$	θ_{mR}	σ_x	σ_y	
0	66.6K	11.60	22.28	3.72	3.90.	3.91	0.92	
18	66.7	11.54	16.91	3.06	1.84	5.95	0.73	
19	75.8	4.88	13.41	1.07	0.56	0.60	0.78	
20	68.8	9.95	20.19	1.82	0.95	0.69	0.32	
21	80.42	9.08	17.80	1.63	1.35	0.64	1.10	
22	77.74	3.28	22.04	0.87	0.19	1.40	0.15	
23	73.19	6.52	20.59	1.79	4.30	2.95	1.29	
34	60.7	10.26	14.30	1.15	0.12	0.68	0.71	
1	10	10	5	10	5	5	5	weig[illegible]

ΔG = distance Grating [illegible]

I_0 = Relative Intensity

Δs = Standard deviation of intensity

ϕ = diameter of beam

$\Delta\phi$ = standard deviation of beam diameter [illegible] of transverse mode [illegible]

θ_{mR} = Angle of divergence over I_m [illegible]

σ_x = Standard deviation of position (beam po[illegible]) $\angle$

σ_y = standard deviation of position [illegible]

Recommended operational grating distance [illegible]

$\boxed{22.00''}$

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The equivalent fresnel number as calculated by Dr. Martin Smithers varied somewhat and his results are included for completeness:

7 FUTURE WORK

The primary goal for this laser development project is to produce a coherent lidar system. Since the start of this project the goal has shifted from developing a commercially viable and inexpensive sounding system to a full scale *LAWS* development test bed.

The goals have been redefined to include a shortening of the total single pulse length to less than $2\mu sec.$, with a total beam chirp of 250 KHz. This is required with a high quality stable beam in both temporal and spatial modes as well as high power. This entails producing a 1.0 Joule output at a 10 Hz rep. rate. To achieve these goals one of the first issues that must be addressed is the modification and redesign of a driver power supply and trigger circuit to deliver the requisite energy loads. Also the mechanical resonator must be lengthened while maintaining stability to achieve stable spatial mode operation. One way to circumvent this may be to modify the optical prescription.

The gas mixtures and flow rates must also be optimized for the energy load, flow time, short pulse length, but high power. Specific problems dealing with RF generation must be addressed and methods must be sought to quantify and potentially control adverse *LIMP* effects.

8 CONCLUSIONS

In conclusion, the first year of development work using the LP-140 has proven to be very encouraging. It is strongly believed that the LP-140 may be used as a scaled model test bed for the LAWS development program immediately, and that with some work it may be turned into a quality coherent lidar in its own right. The basic commercial laser has been characterized. Simple improvements were made and results quantified. These included: lengthening the optical cavity, rerouting the gas flow lines, increasing the gas flow rates, and modifying the gas mixture. Demonstration of a coherent lidar with the LP-140 is expected within the year.

9 APPENDIX

Information related top the LP-140 not appropriate in the main body of the text.

Laser Induced Medium Perturbation

Gladstone-Dale coefficient, $K := 2 \cdot 10^{-4}$

Equivalent frequency of lower laser level, 41.7 THz for 10 μm band, 38.7 THz for 9 μm $f0 := 41.7 \cdot 10^{12}$

Output pulse energy, $E := 2 \cdot 10^{-0}$

Molar gas constant, $R := 8.314$

Time,t $t := 0, 0.1 \cdot 10^{-6} .. 5 \cdot 10^{-6}$

Mode spot radius, $\sigma := 1.33 \cdot 10^{-2}$

Cavity length, $L := 2.5$

Specific heat capacity at constant volume, $Cv := 16.97$

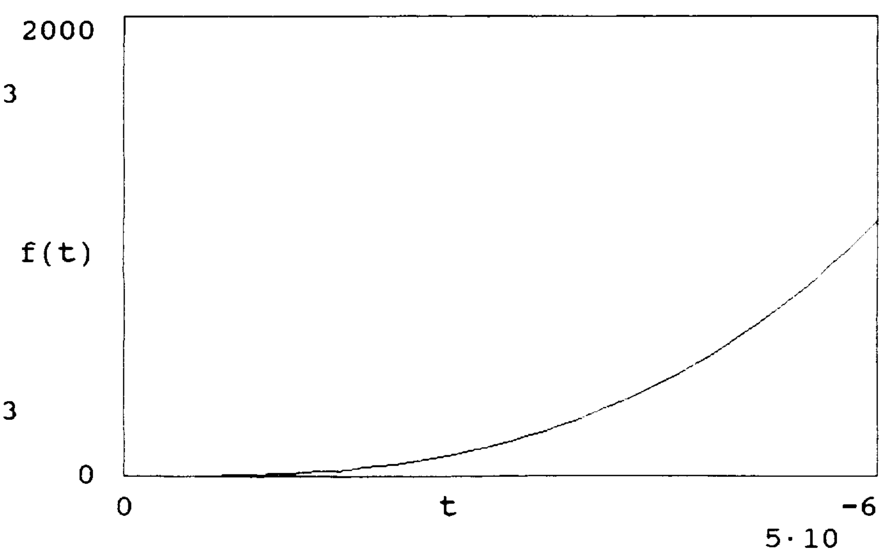
Optical Pulse length, $\tau := 2.5 \cdot 10^{-6}$

$$f(t) := \frac{2 \cdot K \cdot f0 \cdot E \cdot R \cdot t^{3}}{3 \cdot \pi \cdot \sigma^{4} \cdot L \cdot Cv \cdot \tau \cdot 10^{3}}$$

$f\left[5 \cdot 10^{-6}\right] = 1.108\ 10^{3}$

kHz

$f\left[2.5 \cdot 10^{-6}\right] = 138.553$



Idealised Laser Mode Profiles

This program calculates the Rayleigh range for a given Gaussian beam together with the spot size and mode profile at any given location. The profile calculated is the idealised rectangular mode profile of the beam at the chosen location for values of l and m, the TEM indices, up to 3. Firstly select the initial parameters:-

Minimum spot size

$$w_0 := 3\cdot 10^{-3}$$

Wavelength

$$\lambda := 10.6\cdot 10^{-6}$$

Refractive Index

$$n := 1$$

Calculate the Rayleigh range at the beam waist, given by:-

$$z_R := \pi\cdot w_0^{2}\cdot\frac{n}{\lambda} \qquad z_R = 2.667$$

Define the beam waist location as position z=0, then chose a position for the calculation of the spot size and mode profile:-

$$z_0 := 0 \qquad z := 5$$

Calculate the spot size at the chosen location using:-

$$w := \sqrt{w_0^{2}\cdot\left[1+\frac{z^2}{z_R^{2}}\right]} \qquad w = 0.006$$

Then calculate the radius of curvature of the beam at the chosen location using:-

$$R := z\cdot\left[1+\frac{z_0^{2}}{z^2}\right] \qquad R = 5$$

Now start on the mode profile by chosing values for l and m, the mode indices, and the electric field, E. The mode is calculated using a 50x50 array of points.

$$l := 3 \qquad m := 3 \qquad E_0 := 1 \qquad q := 0..50$$
$$v := 0..50$$

Next calculate the relevant x and y Hermite polynomials for the chosen mode profile:-

$$H_x(x) := \mathrm{if}\left[l \approx 0, 1, \mathrm{if}\left[l \approx 1, \left[2\cdot\sqrt{2}\cdot\frac{x}{w}\right], \mathrm{if}\left[l \approx 2, \left[4\cdot\left[\sqrt{2}\cdot\frac{x}{w}\right]^2 - 2\right], \mathrm{if}\left[l \approx 3, \left[8\cdot\left[\right.\right.\right.\right.\right.\right.$$

$$H_y(y) := \mathrm{if}\left[m \approx 0, 1, \mathrm{if}\left[m \approx 1, \left[2\cdot\sqrt{2}\cdot\frac{y}{w}\right], \mathrm{if}\left[m \approx 2, \left[4\cdot\left[\sqrt{2}\cdot\frac{y}{w}\right]^2 - 2\right], \mathrm{if}\left[m \approx 3, \left[8\cdot\left[\right.\right.\right.\right.\right.\right.$$

Finally calculate the intensity mode profile:-

$$I(x,y) := \left[E_0\cdot\frac{w_0}{w}\cdot H_x(x)\cdot H_y(y)\cdot\exp\left[\frac{-\left[x^2 + y^2\right]}{w^2}\right]\right]^2$$

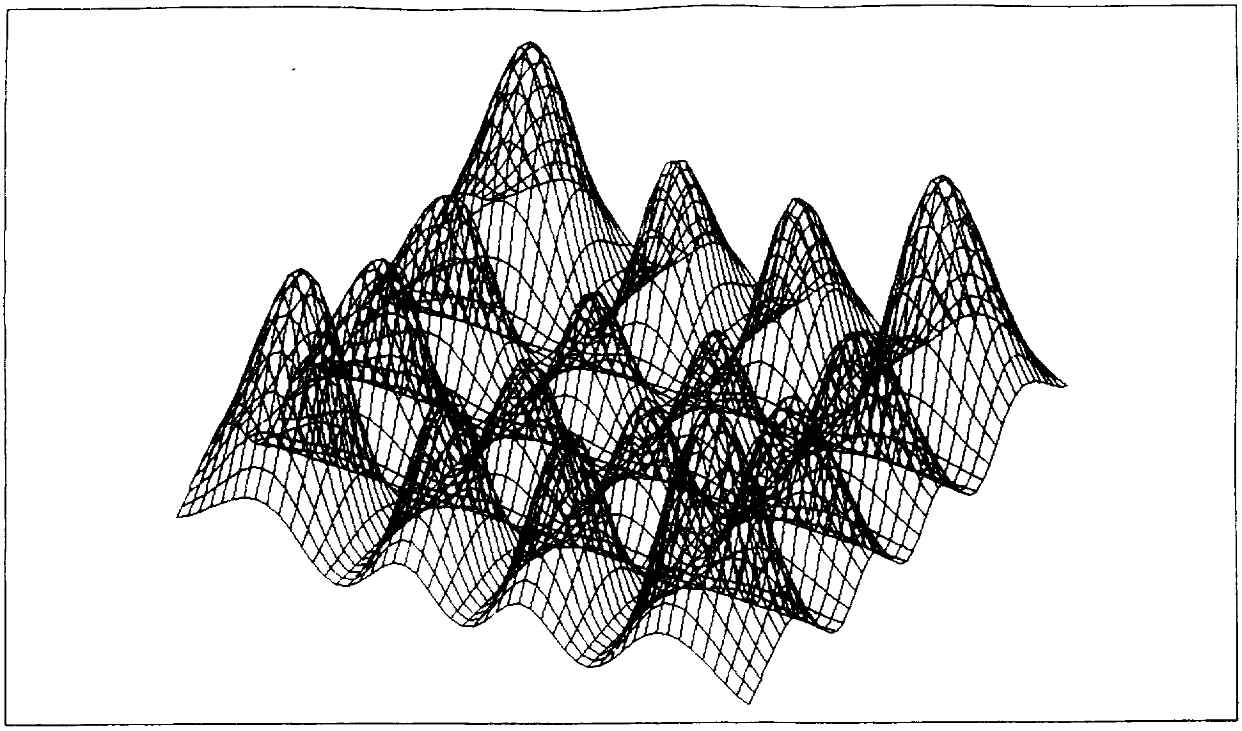
The following variables are associated with scaling the grid size to cover the chosen spot size, whilst M is a dummy array required by the surface plotting routines.

$$x_q := \frac{q\cdot 4\cdot w}{50} - 2\cdot w \qquad y_v := \frac{v\cdot 4\cdot w}{50} - 2\cdot w \qquad M_{q,v} := I\left[x_q, y_v\right]$$

$$\sqrt{2}\cdot\frac{x}{w}\Big]^{3} - 12\cdot\sqrt{2}\cdot\frac{x}{w}\Big], 0\Big]\Big]\Big]\Big]$$

$$\sqrt{2}\cdot\frac{y}{w}\Big]^{3} - 12\cdot\sqrt{2}\cdot\frac{y}{w}\Big], 0\Big]\Big]\Big]\Big]$$

The mode profile



M

Transverse mode profile indices   l = 3   m = 3

Power Supply Design Criteria

This determines some of the basic requirements of the high voltage power supply based on the required inputs to the laser which are;-

Maximum voltage	(V)	$V_{max} := 40000$
Maximum pulse energy	(J)	$E_{max} := 200$
Maximum pulse rate	(Hz)	$PRF := 20$
Average power	(W)	$P_{av} := PRF \cdot E_{max}$
		$P_{av} = 4 \cdot 10^{3}$

Allow a 100uS period for discharge and thyratron recovery, during which the charging unit is off, therefore the time available to pulse charge a capacitor is given by

$$t_{discharge} := 1 \cdot 10^{-4} \quad S$$

$$t_{charge} := \frac{1}{PRF} - t_{discharge}$$

$$t_{charge} = 0.0499 \quad S$$

Thus allow a 49mS charge time

$$t_{charge} := 0.049 \quad S$$

This gives an average charging current for the chosen pulse energy of

$$I_{av} := \frac{E_{max}}{V_{max} \cdot t_{charge}}$$

$$I_{av} = 0.102 \quad A$$

The capacitor will charge exponentially where the charging current will be given by :-

$$I = I_{pk} \exp(-ct)$$

where I_{pk} is the peak charging current, c is the time constant and t is the time.

When the capacitor is fully charged the current will fall to zero, however due to the exponential decay the point at which this occurs can be said to vary, depending on how accurately the capacitor is to be charged. If we assume that we require the capacitor to be fully charged to better than 0.5% then this will give a time and time constant product of:-

$$ct := -\ln(0.005)$$

$$ct = 5.298$$

This gives for the time constant,c assuming the charging time t_{charge} above.

$$c := \frac{ct}{t_{charge}}$$

$$c = 108.129 \quad S^{-1}$$

We now need to calculate the peak charging current. The average current obtained above can be regarded as the integration of the charging current over the charging time, divided by the charging time ie

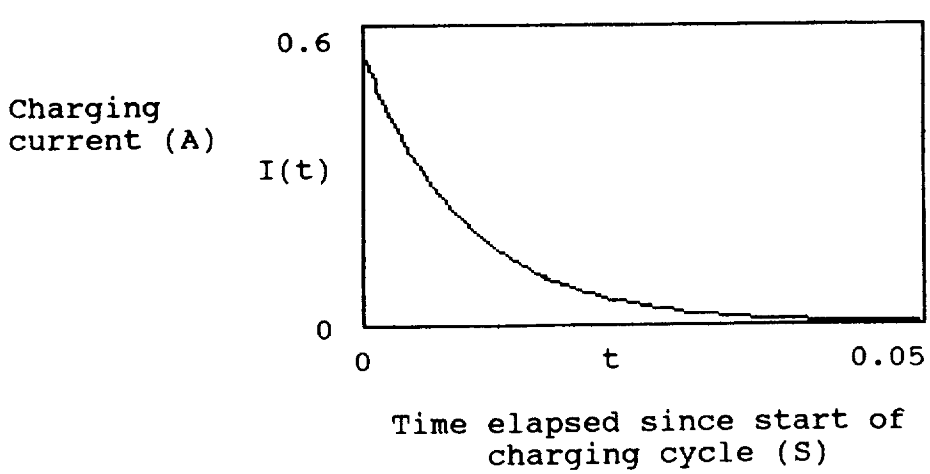
$$I_{pk} := \frac{I_{av} \cdot t_{charge}}{\int_0^{t_{charge}} \exp(-c \cdot t)\, dt}$$

$$I_{pk} = 0.543 \quad A$$

We can then plot the charging cycle

$$t := 0, 0.001 .. 0.05$$

$$I(t) := I_{pk} \cdot \exp(-c \cdot t)$$



LP-140 CO_2 Laser
Grating / Cavity Extended 21.00"

```
Diam=   18.85, Eny=   99495, Pk/A=   5.24
X=  12.84, Y=  22.89,  PX=    9, PY=   31
Gaus  X =  0.00, Y =  0.00,Height=   0.0
      Wx=  0.00, Wy=  0.00, Coeff= 0.000
Cyl dia=    0.0, Ht=      0, Coeff= 0.000
TopH Dia=   0.0, Ht=      0,    Sd=     0
```

```
Divergence File: LP140F21,  1st Rec: 1,  2nd Rec: 30
Diam1=  18.85, Diam2=  16.15, Dist=  1.000M, Divergence=-1.35047 mRad

Press 'P' to print or any other key to return to Jitter & Divergence Menu
```

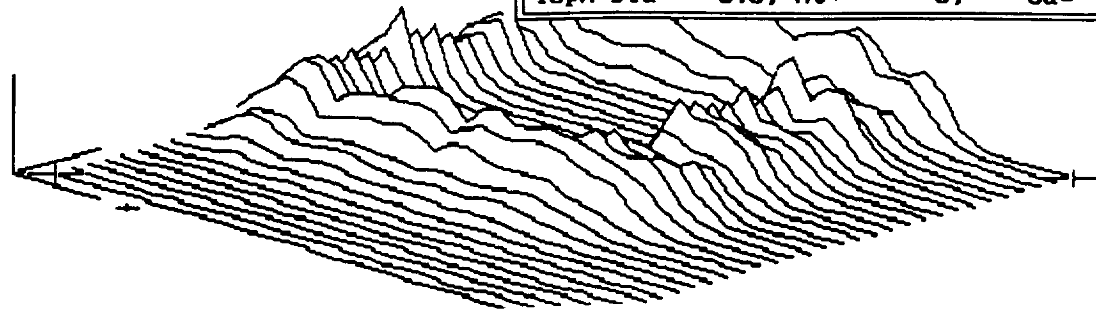
```
16:09:35  3/ 6/90
LP140F21 Rec # 30
```

```
Diam=   16.15, Eny=   81848, Pk/A=   5.39
X=  11.34, Y=  25.46,  PX=    4, PY=   31
Gaus  X =  0.00, Y =  0.00,Height=   0.0
      Wx=  0.00, Wy=  0.00, Coeff= 0.000
Cyl dia=    0.0, Ht=      0, Coeff= 0.000
TopH Dia=   0.0, Ht=      0,    Sd=     0
```

```
Jitter File: LP140F21   Record 1 to Record 30, 30 samples
X mean=   12.11, Y mean=   23.92, Diam mean=   17.80, Energy mean=80428.40
X Sd =     0.64, Y Sd =     1.10, Diam Sd =     1.63, Energy Sd= 9082.89
Press 'P' to print or any other key to continue
```

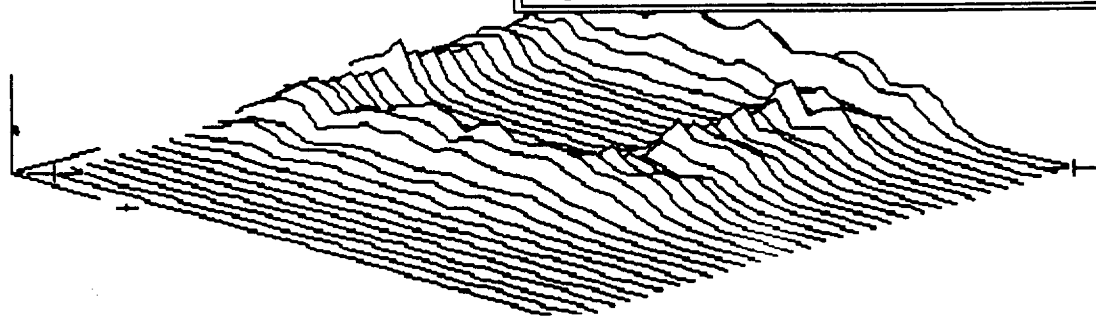
14:39:14 3/ 6/90
LP140F21 Rec # 1

```
Diam=    18.85, Eny=   99495, Pk/A=   5.24
X=  12.84, Y=  22.89,  PX=     9, PY=   31
Gaus  X =  0.00, Y =   0.00,Height=   0.0
     Wx=  0.00, Wy=   0.00, Coeff= 0.000
Cyl dia=    0.0, Ht=      0, Coeff= 0.000
TopH Dia=   0.0, Ht=      0,    Sd=     0
```



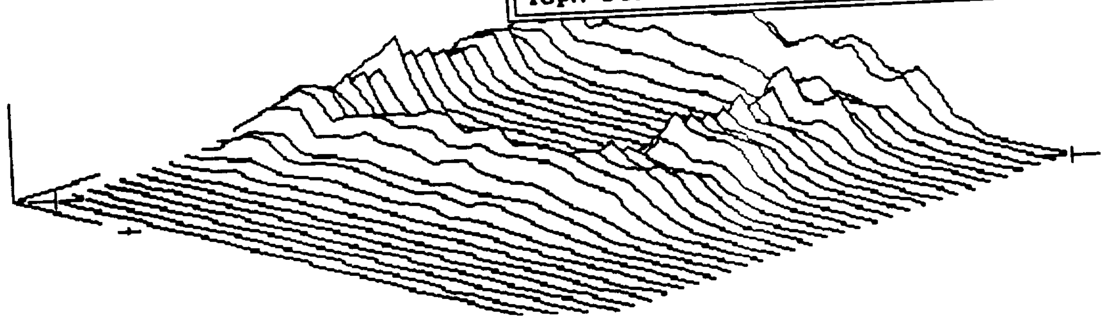
14:47:15 3/ 6/90
LP140F21 Rec # 3

```
Diam=    18.23, Eny=   64865, Pk/A=   5.20
X=  13.00, Y=  22.68,  PX=    14, PY=   31
Gaus  X =  0.00, Y =   0.00,Height=   0.0
     Wx=  0.00, Wy=   0.00, Coeff= 0.000
Cyl dia=    0.0, Ht=      0, Coeff= 0.000
TopH Dia=   0.0, Ht=      0,    Sd=     0
```



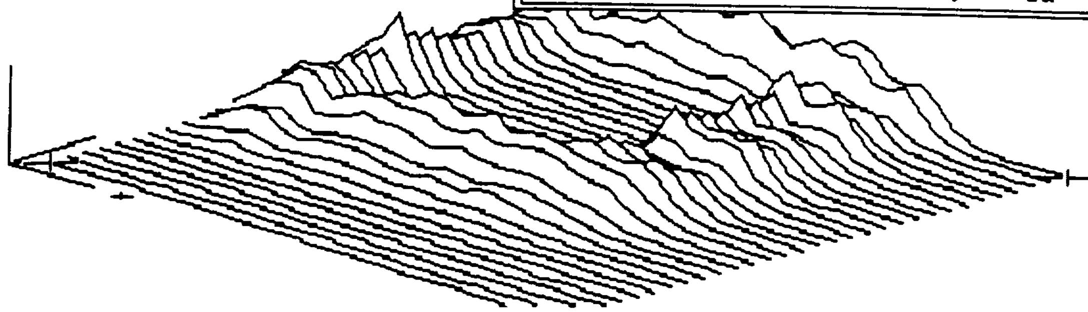
15:09:13 3/ 6/90
LP140F21 Rec # 6

```
Diam=    19.61, Eny=   80720, Pk/A=   5.06
X=  12.32, Y=  22.95,  PX=     4, PY=   31
Gaus  X =  0.00, Y =   0.00,Height=   0.0
     Wx=  0.00, Wy=   0.00, Coeff= 0.000
Cyl dia=    0.0, Ht=      0, Coeff= 0.000
TopH Dia=   0.0, Ht=      0,    Sd=     0
```



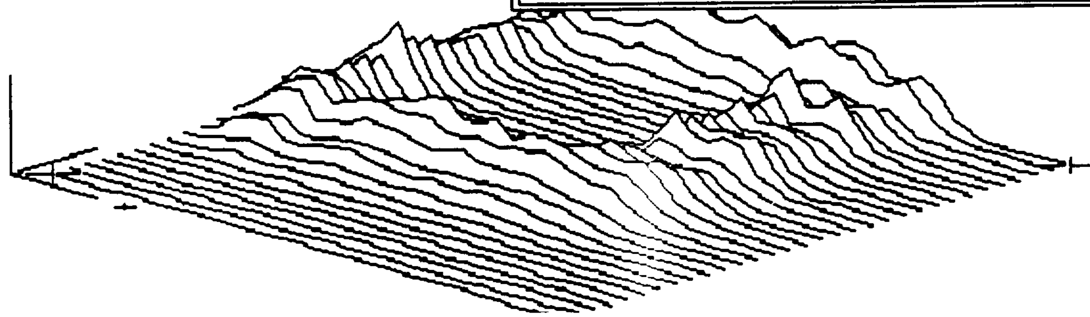
15:13:05 3/ 6/90
LP140F21 Rec # 9

Diam= 17.78, Eny= 81597, Pk/A= 5.33
X= 12.31, Y= 23.27, PX= 9, PY= 31
Gaus X = 0.00, Y = 0.00, Height= 0.0
Wx= 0.00, Wy= 0.00, Coeff= 0.000
Cyl dia= 0.0, Ht= 0, Coeff= 0.000
TopH Dia= 0.0, Ht= 0, Sd= 0



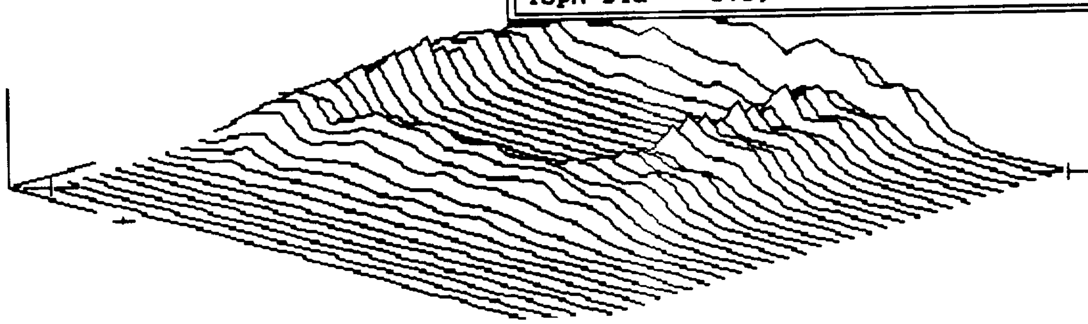
15:25:33 3/ 6/90
LP140F21 Rec # 12

Diam= 18.50, Eny= 76923, Pk/A= 5.11
X= 12.50, Y= 22.51, PX= 9, PY= 31
Gaus X = 0.00, Y = 0.00, Height= 0.0
Wx= 0.00, Wy= 0.00, Coeff= 0.000
Cyl dia= 0.0, Ht= 0, Coeff= 0.000
TopH Dia= 0.0, Ht= 0, Sd= 0



15:28:34 3/ 6/90
LP140F21 Rec # 15

Diam= 16.74, Eny= 78723, Pk/A= 5.25
X= 11.31, Y= 24.81, PX= 9, PY= 31
Gaus X = 0.00, Y = 0.00, Height= 0.0
Wx= 0.00, Wy= 0.00, Coeff= 0.000
Cyl dia= 0.0, Ht= 0, Coeff= 0.000
TopH Dia= 0.0, Ht= 0, Sd= 0



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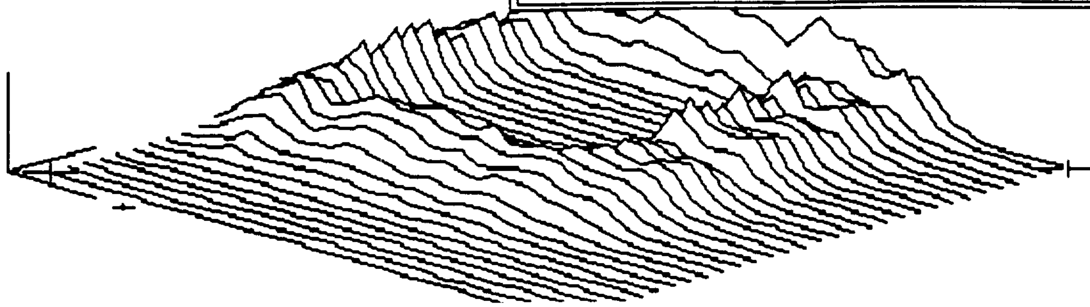
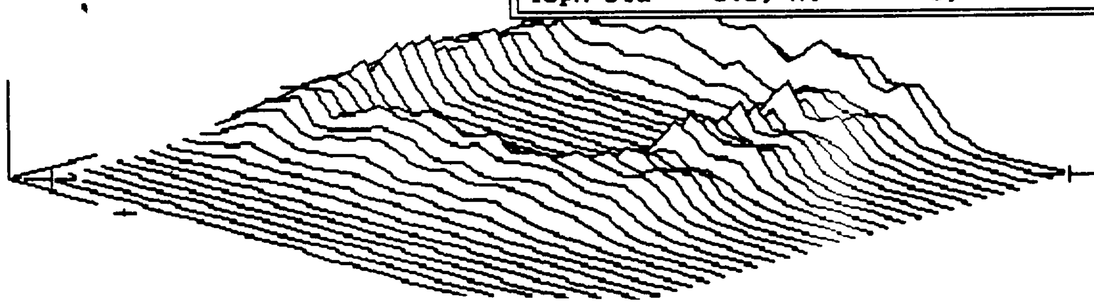
15:34:57 3/ 6/90
LP140F21 Rec # 18

Diam= 17.32, Eny= 84957, Pk/A= 5.26
X= 11.08, Y= 24.51, PX= 18, PY= 31
Gaus X = 0.00, Y = 0.00,Height= 0.0
Wx= 0.00, Wy= 0.00, Coeff= 0.000
Cyl dia= 0.0, Ht= 0, Coeff= 0.000
TopH Dia= 0.0, Ht= 0, Sd= 0



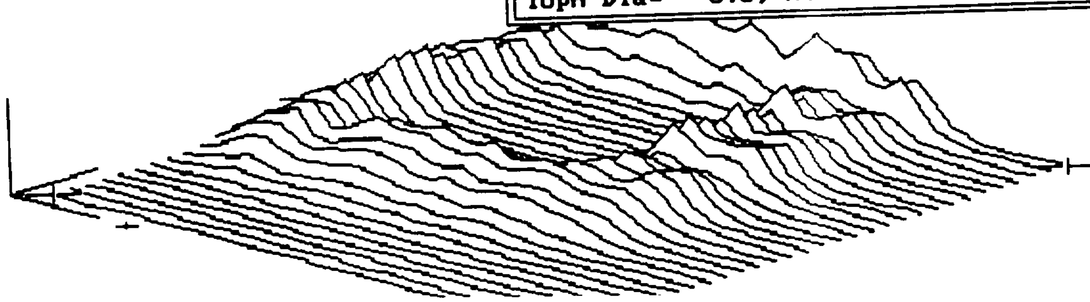
15:54:57 3/ 6/90
LP140F21 Rec # 21

Diam= 16.35, Eny= 78152, Pk/A= 5.38
X= 11.68, Y= 24.55, PX= 9, PY= 31
Gaus X = 0.00, Y = 0.00,Height= 0.0
Wx= 0.00, Wy= 0.00, Coeff= 0.000
Cyl dia= 0.0, Ht= 0, Coeff= 0.000
TopH Dia= 0.0, Ht= 0, Sd= 0



15:58:11 3/ 6/90
LP140F21 Rec # 24

Diam= 16.05, Eny= 77859, Pk/A= 5.30
X= 11.84, Y= 25.14, PX= 9, PY= 31
Gaus X = 0.00, Y = 0.00,Height= 0.0
Wx= 0.00, Wy= 0.00, Coeff= 0.000
Cyl dia= 0.0, Ht= 0, Coeff= 0.000
TopH Dia= 0.0, Ht= 0, Sd= 0



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