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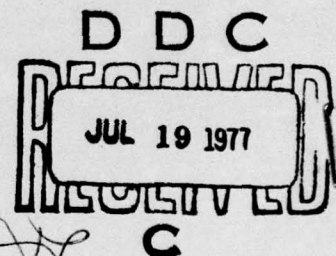
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Temporal Stability of Single-Line CW HF Chemical Laser with Unstable Resonator

Aerophysics Laboratory
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24 June 1977

Interim Report



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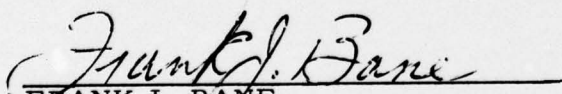
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The temporal stability of the output from a single-line cw HF chemical laser with an unstable resonator was investigated experimentally to determine if large-scale output power fluctuations, associated with a "mode-medium" instability of the type originally postulated by Dreizin and Dykhne, would be observed. Cases where the gain at the resonator inlet was less than or greater than the threshold value were studied. In all cases, the output was found to be stable. For inlet gain less than the threshold value, this result is in accord with the theoretical prediction of Mirels.		

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PREFACE

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I. INTRODUCTION

The temporal stability of the output from cw lasers employing unstable resonators with cross flow is discussed theoretically in Refs. 1 through 3 and experimentally in Ref. 4. Dreizin and Dykhne¹ treated the case of an unstable resonator with magnification near one, a single-level laser model (i.e., infinitely fast deactivation of lower laser level), and no "pumping" of excited species within the resonator. With geometric optics assumed, it was found that the interaction between the radiation field and the gain medium was unstable to small perturbations, resulting in large-scale periodic output fluctuation. The period of these fluctuations was of the order of the resonator length divided by the flow velocity. Yoder and Ahouse⁴ observed such large-scale periodic fluctuations in the output from a cw CO₂ electric discharge laser. These were attributed to the instability mechanism proposed in Ref. 1.

In a recent paper, Mirels² extended the analysis of Dreizin and Dykhne to include pumping within the resonator. The assumptions of magnification near one and a single-level laser model were retained. It was found that the output is stable when the gain at the resonator inlet is less than the threshold value and when the volumetric pumping rate decreased with streamwise distance. These are sufficient, but not necessary, conditions for stability. The method discussed in Ref. 2 cannot be applied to determine stability when the gain at the resonator inlet is larger than the threshold value, except for specialized pumping distributions.

In a cw HF chemical laser (e.g., Ref. 5), the gain is generally zero, or small, at the resonator inlet, and the pumping decreases with streamwise distance (since the rate of diffusion between the streams containing F and H_2 , respectively, decreases with streamwise distance). Hence, the theory discussed in Ref. 2 indicates that the output from a cw HF chemical laser operating on a single transition should be stable. No conclusions can be made regarding the stability for the case where the gain at the resonator inlet is larger than the threshold value.

The purpose of the present study is to observe experimentally the temporal stability of the output from a single-line cw HF chemical laser and to compare with the prediction of Ref. 2. Cases where the gain at the resonator inlet is less than or greater than the threshold value are considered.

II. EXPERIMENTAL EQUIPMENT

The laser device used for these experiments has been described by Spencer, Mirels, and Durran.⁵ Helium is used as a diluent gas, and atomic fluorine is produced by the dissociation of SF_6 in an electric arc. The nozzle bank has a height of 1.3 cm and a length of 17.8 cm in the direction of the optical axis. The laser operating conditions are given in Table I.

The variation of zero power gain with streamwise distance, x , has been measured by Chodzko⁶ at these operating conditions with the 36-slit nozzle. This variation for the $P_1(6)$ and $P_2(5)$ lines used in the present experiments is shown in Fig. 1. The notation $P_v(J)$ denotes a P-branch transition, where v and J are upper and lower level values, respectively. The gain is nonzero at $x = 0$ (i. e., at the exit of the nozzles, which is generally the entrance section to the resonator) because of boundary-layer separation and some recirculation near the nozzle exit.⁶ For $P_2(5)$, the gain at $x = 0$ appears to be about 4%/cm, and the peak gain of 9.3%/cm occurs at $x = 0.8$ cm. The positive-gain region extends to $x = 3.5$ cm. For $P_1(6)$, the gain at $x = 0$ is 2.5%/cm, the peak gain is 7.5%/cm at 1.3 cm, and the positive-gain region extends to 8.5 cm.

The single-line unstable resonator configuration used in the present study (discussed in Ref. 7) is indicated in Fig. 2. The resonator consists of a gold-coated convex spherical mirror and a diffraction grating in a Littrow configuration. The diffraction grating acts as a plane mirror perpendicular to the optical axis for a single spectral line. The laser power is continuously coupled⁷ out of the resonator by the zeroth-order reflection from the grating.

Table I. CW HF Flow Conditions

SF ₆	4.25 g/sec
He	4.50 g/sec
O ₂	0.70 g/sec
H ₂	0.67 g/sec
P _{cavity}	6.3 Torr
P _{plenum}	24 psia
Arc Current	450 A

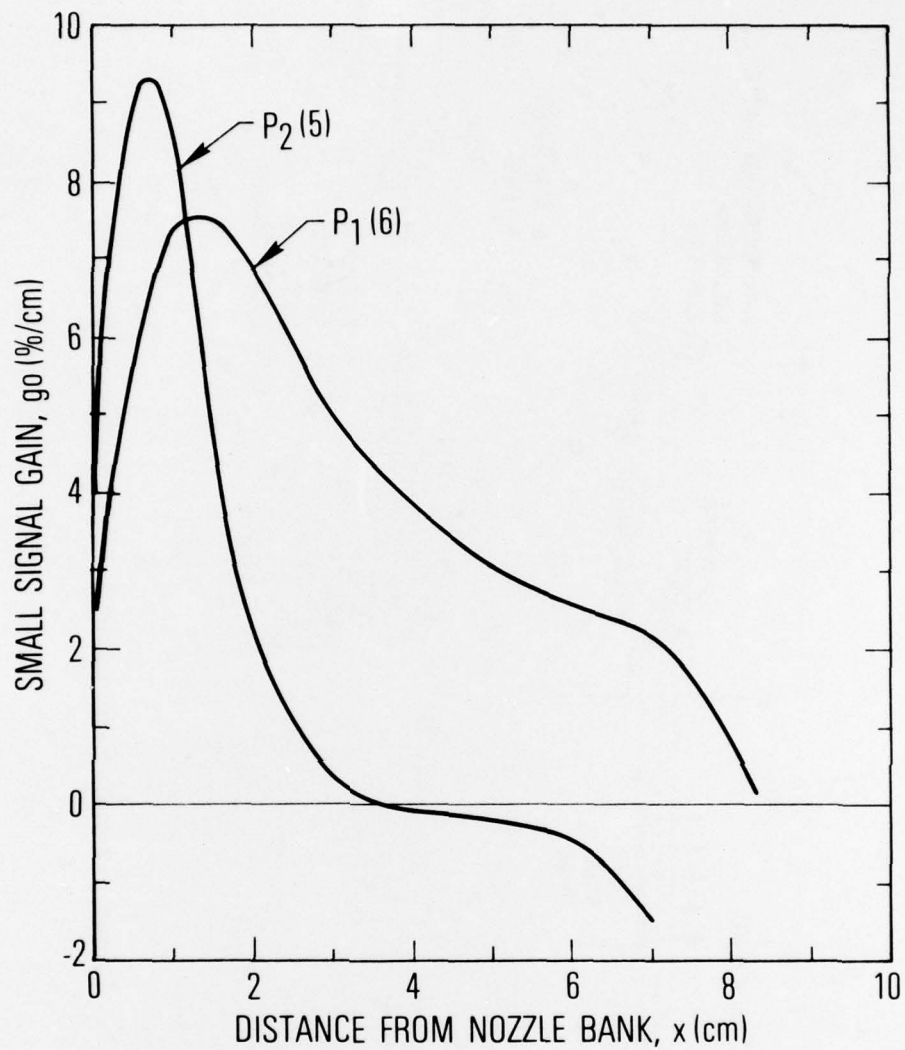


Fig. 1. Variation of small signal gain with streamwise distance for $P_1(6)$ and $P_2(5)$ line of HF laser

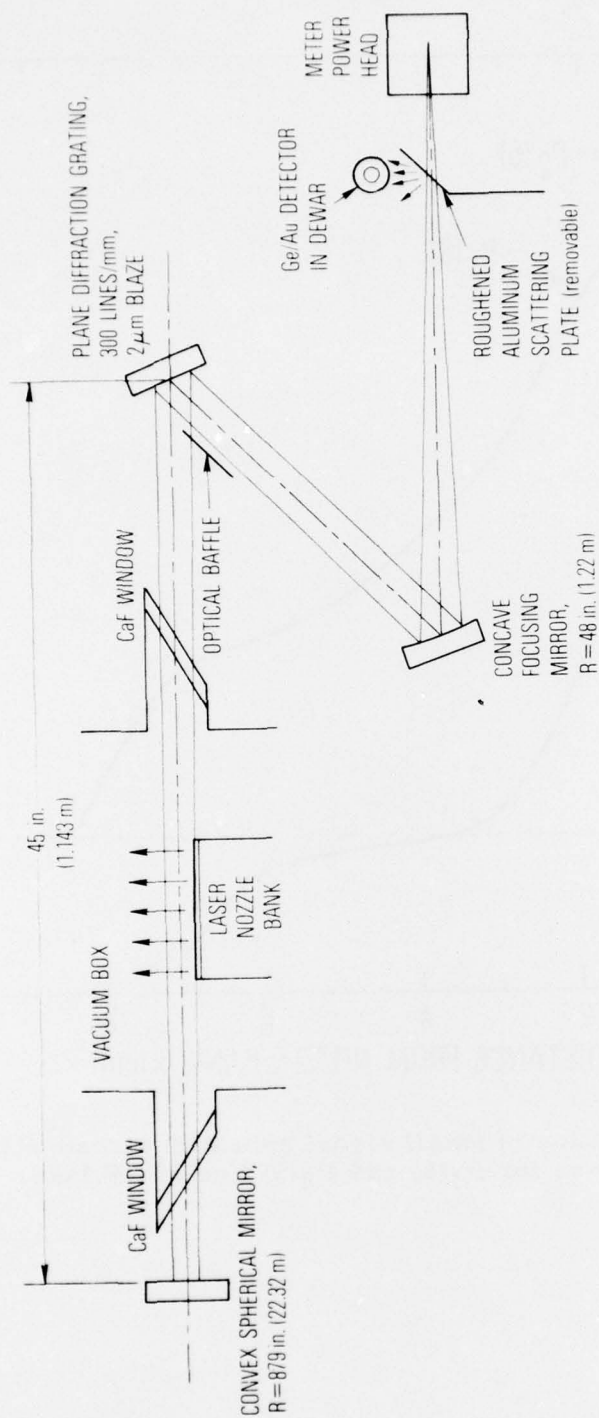


Fig. 2. Laser resonator and optical-detection configuration

For a mirror separation of $L = 1.143\text{m}$ and a mirror radius of $R = -22.3\text{m}$, the magnification of the resonator is

$$M = \frac{\sqrt{1 - R/L + 1}}{\sqrt{1 - R/L - 1}} = 1.566$$

With values of 0.80 for the effective reflectivity of the grating, 0.98 for the reflectivity of the convex mirror, and 17.8 cm for the gain length, the threshold gain was calculated to be 3.2%/cm. The entire optical system was enclosed in a plexiglass box, which could be dried to a relative humidity of a few percent. A dry atmosphere is necessary because of the strong absorption of most HF laser lines by water vapor.

The location of the optical axis, x_c , could be varied by rotation of the convex mirror about a vertical axis. The approximate location of the optical axis, for each test, was established by use of a fluorescent screen, as indicated in Figs. 2 and 3. In accordance with geometric optics, the width of the laser beam reflected from the convex mirror that illuminates the fluorescent screen is $a = (M - 1)b$. The distance of the optic axis from the nozzle face is $x_c = b + d$. Thus, x_c could be determined from a measurement of the illumination width, a , and the screen insertion depth, d . The boundary of the laser illumination on the fluorescent screen was somewhat diffuse; therefore, measurements of a could be made to an accuracy of only about 2 mm, which, however, was adequate for these experiments. Several insertion depths, d , were used to obtain each value of x_c . These results indicated that diffraction effects were not excessive.

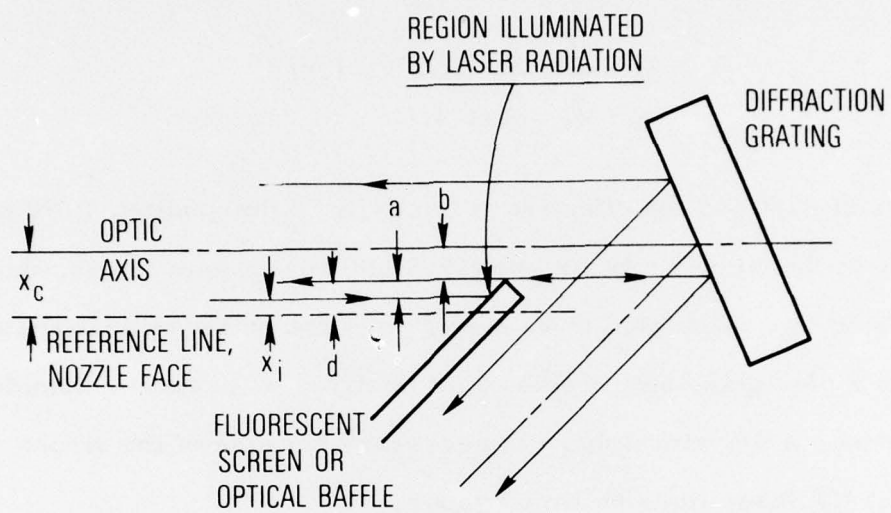


Fig. 3. Use of fluorescent screen to locate position of optic axis of laser resonator

An optical baffle (see Figs. 2 and 3) was inserted into the resonator beam during some laser stability measurements. The purpose of the optical baffle in these tests was to change the effective resonator inlet location x_i from the conventional value of $x_i = 0$ to some downstream location. (The resonator inlet location is given by $x_i = d - a$ in Fig. 3.) The object of these tests was to determine if gain, larger than the threshold value of 3.2%/cm, at x_i was destabilizing.

The output laser beam, which was slightly divergent, was focused by a concave mirror and scattered from a roughened aluminum plate. A cooled Ge:Ga detector was used to measure output power fluctuations. The Ge:Ga detector was used in the photoconductive mode and had a risetime of less than 70 nsec. The detector was used without a preamp and was dc-coupled into a Type D plug-in amplifier of a Tektronix Type 535 oscilloscope. This plug-in amplifier, however, is limited to a bandwidth of 1.3 MHz at a sensitivity of 20 mV/cm.

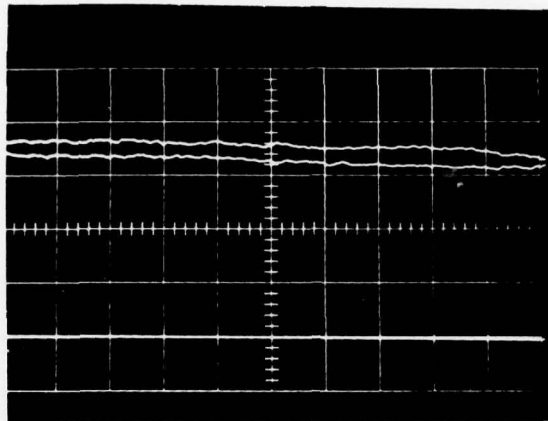
Frequency spectra were obtained with a Hewlett-Packard spectrum analyzer consisting of a 141 T display section, an 8552 B i.f. section, and an 8553 B rf section. The frequency range was set up and calibrated with a Tektronix square-wave generator.

III. EXPERIMENTAL RESULTS

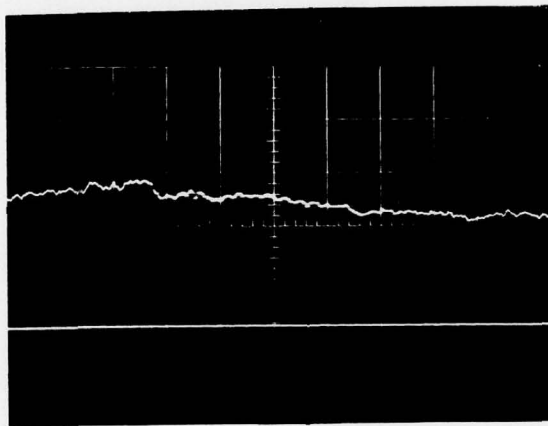
A series of HF laser output power fluctuation measurements were made with the optical baffle removed from the resonator. In these cases, x_1 was zero, and the gain at the resonator inlet was less than the threshold value. The resonator was adjusted for the $P_2(5)$ line and then for the $P_1(6)$ line; x_c was measured to be about 1.2 cm for both cases, and the output power was 23 W for $P_2(5)$ and 26 W for the $P_1(6)$ line. Oscilloscope measurements of the signal from the cooled Ge:Au detector are shown in Figs. 4(a) and 4(b). There are some small amplitude, high-frequency fluctuations present in the signal, but there are no large-scale, limit-cycle fluctuations and no pre-dominant frequency that could be associated with a mode-medium instability,* as were observed in Ref. 4.

The signal from the Ge:Au detector was observed further with a spectrum analyzer; these displays, Figs. 5(a) and 5(b), show essentially random fluctuations whose power spectrums decrease monotonically with frequency.

* The period of mode-medium instability¹ is of the order of $T = (x_c - x_1)/u$. For the present case, $u = 4$ km/sec, $x_1 = 0$ cm, $x_c = 1.2$ cm, and $T = 6$ μ sec. Hence, the frequency of the instability should be approximately 200 kHz.



(a)



(b)

Fig. 4. Oscilloscope traces of laser detector signal. Sweep speed = $20 \mu\text{sec/cm}$. Sensitivity = 20 mV/cm . $R_L = 280 \text{ ohm}$ for Ge:Au detector. (a) $P_2(5)$ line. (b) $P_1(6)$ line.

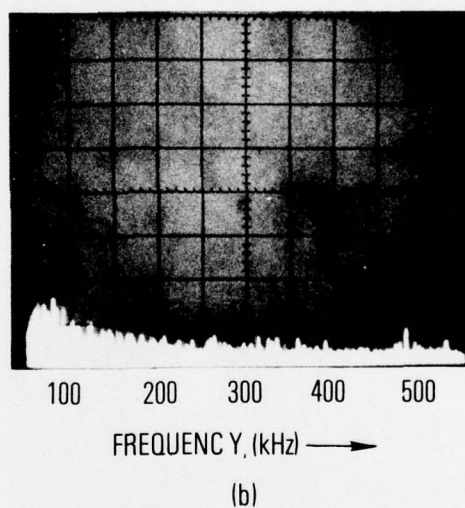
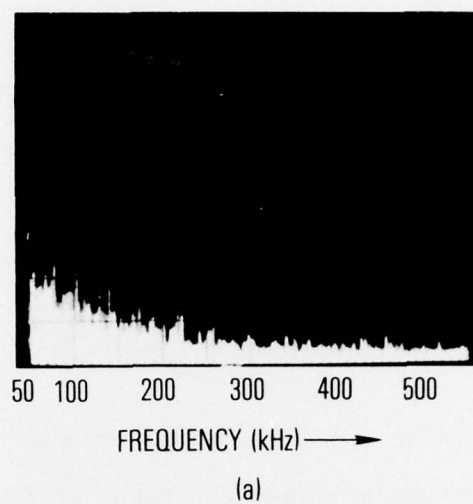
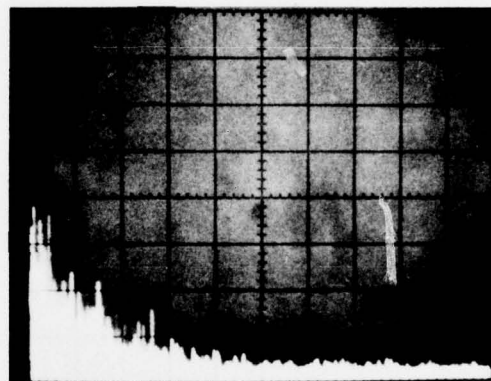


Fig. 5. Spectrum analysis of laser detector signal. Bandwidth = 3 kHz. Sensitivity = 0.04 mV/div. (a) $P_2(5)$ line. (b) $P_1(6)$ line.

Experiments were continued with an optical baffle inserted into the resonator beam in order to increase the gain at the resonator inlet x_i to a value significantly above the threshold value of 3.2%/cm. The output power decreased as the baffle was inserted into the beam. The power decreased to 50% for a baffle insertion distance, $d = 0.76$ cm, and decreased rapidly with further insertion. For $d = 0.76$ cm and $x_c = 1.2$ cm, the effective resonator inlet was at $x_i = 0.5$ cm. The inlet gain for the $P_1(6)$ line was then $g_o = 5.5\%/cm$, which compares with the value 2.5%/cm for the case of no baffle ($x_i = 0$). The results of these measurements are shown in Figs. 6(a) and 6(b). Although the fluctuations appear to increase somewhat, there is still no evidence of a mode-medium instability.



(a)



FREQUENCY (kHz) →

(b)

Fig. 6. Laser detector signal for $P_1(6)$ line with baffle inserted. (a) Oscilloscope trace. Sweep speed = $20 \mu\text{sec/cm}$. Sensitivity = 20 mV/cm . $R_L = 280 \text{ ohm}$. (b) Spectrum analysis. Bandwidth = 3 kHz . Sensitivity = 0.04 mV/div .

IV. CONCLUDING REMARKS

The output from a single-line cw HF chemical laser with an unstable resonator was observed experimentally for cases where the gain at the resonator inlet was below or greater than the threshold value. In both cases, it was found that the output did not exhibit large-scale amplitude fluctuations of the type observed in Ref. 4 for an electrically driven CO₂ laser and attributed therein to the mode-medium interaction first described in Ref. 1. The present results are consistent with the theoretical predictions of Ref. 2.

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