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BEHAVIOR OF A CO_2 LASER NEAR THRESHOLD : DIFFERENCE BETWEEN PUMP MODULATION AND LOSS MODULATION

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Abstract - Different behaviors of a single mode CO_2 laser near threshold are observed depending on whether the threshold condition is overcome by varyng the pump or the cavity losses. The difference is accounted for by a suitable model.

1 - INTRODUCTION

The dynamics of a single mode CO_2 laser has been investigated by performing low frequency modulation of either the cavity loss parameter or the pump parameter.
Delayed bifurcations/1/ are observed only in the second case. This phenomenon is related to a dynamic stabilization of the zero state intensity which becomes unstable for a pump value larger than the stationary value.
In contrast, when we perform a linear sweep on the cavity loss parameter we observe a dynamical hysteresis depending on the modulation depth and on the sweep frequency but without time delay /2/.
This difference between pump and loss modulation can be explained by considering a four-level molecular model which takes into account the coupling between the two active resonant levels of the P(20) transition and the other rotational levels of the vibrational bands ($00^{\circ}1$ and $10^{\circ}0$) to which they belong /3/.

2 - EXPERIMENTAL RESULTS

Cavity loss modulation has been obtained by applyng a triangular high voltage sweep to an electro optic modulator (E.O.M.) inside the laser cavity. The voltage applied to the EOM drives the laser from its maximal intensity corresponding to V=0, to zero-intensity, which means below threshold.
In fig.1 we report the time evolution of the laser output intensity and the corresponding signal applied to the EOM. For each temporal behavior the associated laser intensity vs. modulation voltage is shown in a x-y plot. In fig. 1a the sweep rate occurs at a frequency of 11 Hz. At this low sweep rate the laser intensity clearly shows a purely symmetric behavior which corresponds to an x-y plot without hysteresis, fig.1b. Increasing the sweep rate new features appear, fig.1c. First, we observe the rising of the initial spike associated with the switch-on of the laser and a very fast damping with only few relaxation oscillations. Second, we observe the appearence of "negative" hysteresis as clearly shown in fig.1d and 1f.
Pump modulation has been achieved by modulating the discharge current in the laser tube. In fig.2 we show the laser intensity vs. discharge current when the sweep rate occurs at frequency of 200Hz. This figure shows evidence of large pump delay with respect to stationary pump value. The corresponding time delay is about 0.5msec.

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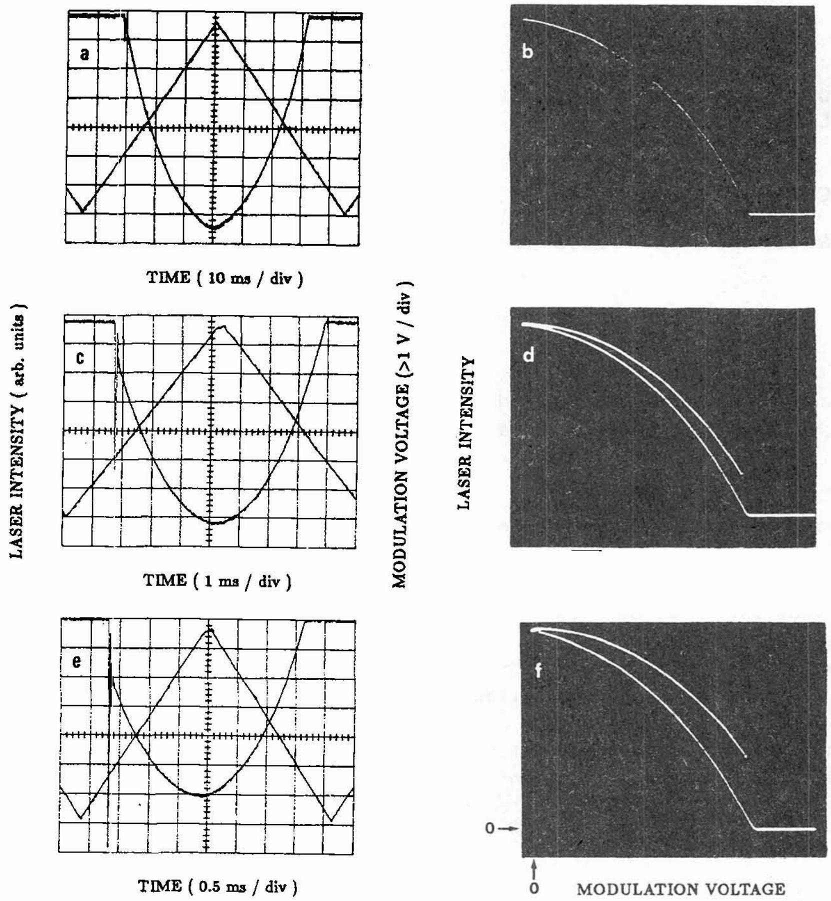

Fig. 1 Time evolution of the laser output intensity and triangular modulation applied to the EOM (left side). Corresponding x-y plots (laser intensity vs. modulation voltage) are reported in the right hand side. Fig. 1a, c and e refer to a modulation frequency f=11 Hz, 96 Hz and 232 Hz respectively. The laser threshold is about 700 Volt (0.52 in normalized units).

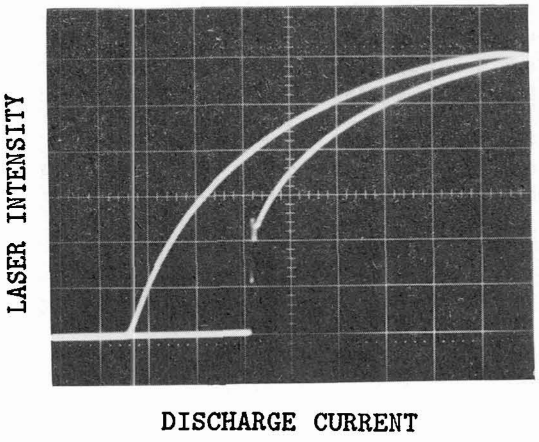

Fig.2 Laser intensity versus discharge current. The mean value around which the modulation is performed is 4.83mA.Horizontal scale 0.8mA/div,vertical scale 2mV/div.

3 - THEORETICAL RESULTS

Our experimental results can be explained considering a four-level molecular model in which the two active levels are coupled to all the other rotational levels of the same vibrational band. This model is described by three differential equations for intensity x(t), population inversion of the active resonant levels y(t) and population inversion of the vibrational band z(t) as follows:

$$x = -k_o x(1+f(u)-y), \quad (1)$$

$$y = -(\gamma_R + \gamma)y + \gamma'_R z - \mu xy + \eta\gamma y_o, \quad (2)$$

$$z = -(\gamma'_R + \gamma)z + \gamma_R y + (Z-1)\eta\gamma y_o, \quad (3)$$

here $\mu = \gamma(\gamma_R+\gamma'_R+\gamma)/(\gamma'_R+\gamma)$ and $\eta = (\gamma_R+\gamma'_R+\gamma)/(\gamma_R+\gamma)$, γ is the decay rate from the band (ν,J) to (ν',J') for $\nu' \neq \nu$, γ_R and γ'_R are the decay rates from resonant level (ν,J) to the vibrational band (ν,J') (for all $J' \neq J$) and for the reverse process, respectively. The intensity x(t) is normalized to the saturation intensity $I_s = \mu/2G$. Both y(t) and z(t) are normalized to the threshold inversion k_o/G, where G is the field matter coupling constant and $k_o = (c/L)(T + D_f)$ is the nonmodulated cavity parameter, L being the cavity length, T and D_f are the effective transmission and diffractive loss of the cavity respectively.
$f(u) = \alpha \sin^2(u)$ is the modulation function where $\alpha = (1-T)/(T+D_f)$ and u is the voltage applied to EOM normalized to the $\lambda/2$ voltage, $V_{\lambda/2}$ = 4240 Volt y_o is the normalized pump parameter, and Z is the effective number of levels of the vibrational band.
In the case of pump modulation f(u) in Eq.(1) is set equal to zero and $y_o = y_o(t)$ is a time dependent function of the type:

$$y_o(t) = A_o + \beta t \quad (4)$$

Numerical results are summarized in fig.4 for cavity loss modulation and in fig.3 for pump modulation. They show a satisfactory agreement with the experiment. A model based on two levels would lead to same qualitative differences and , furthermore it would yield a partial quantitative agreement only for a γ artificially put equal to 100 times the known experimental value.

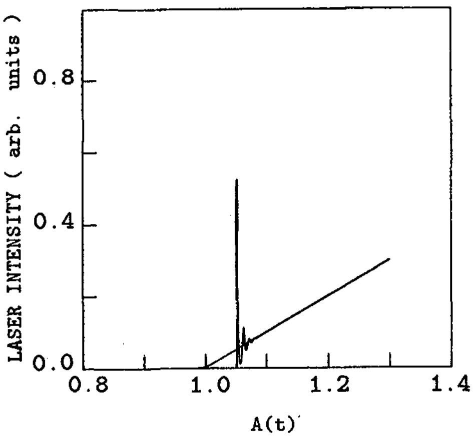

Fig.3 - Numerical result for the laser intensity versus pump parameter. The stationary laser threshold occurs at A(t) = 1. The parameters values are: T = 0.25, $\gamma_R = 10^7 sec^{-1}$, $\gamma'_R = \gamma_R/Z$, Z=16 and $\gamma = 0.5 \cdot 10^4 sec^{-1}$

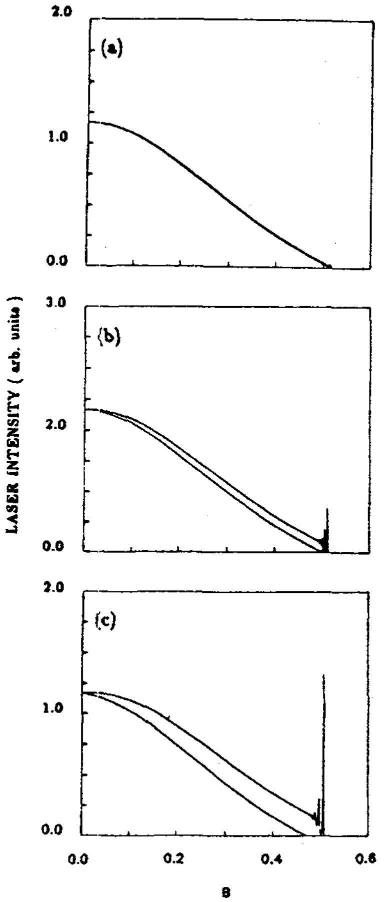

Fig.4 – Numerical results for the laser output intensity versus B (the triangular modulation voltage applied to the EOM) for a four-level laser model. (a),(b) and (c) correspond to a modulation frequency f = 10Hz, 100Hz and 250Hz respectively. The laser threshold was set at B = 0.52. The parameters values are: $T = 0.05$, $D_f = 0.15$, $\gamma = 0.5 \cdot 10^4 \sec^{-1}$, $\gamma_R = 10^7 \sec^{-1}$, $\gamma'_R = \gamma_R/Z$, $Z=16$, and $y_o=2.17$

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