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دراسة خصائص مرنان الليزرات المستقرة وغير المستقرة

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الخلاصة

تم في هذا البحث دراسة استقرارية المرنان البصري لنوعين من الليزرات وهما ليزر He-Ne وهو من الليزرات واطئة القدرة يقع الطول الموجي لشعاعه في المنطقة المرئية من الطيف الكهرومغناطيسي عند القيمة 0.6328 μm ، والثاني هو ليزر CO_2 اذ يعتبر من الليزرات القديرة وقيمة الطول الموجي لشعاعه هي 10.6 μm في المنطقة تحت الحمراء (غير المرئية).

تناول البحث في جانبه النظري توضيح المعنى الفيزيائي لعوامل استقرارية المرنان البصري وهي العامل (g) وعدد فرينل والعامل (Q) (عامل النوعية) وخسائر الحيود في المرنان ، كما تناول المعادلات الرياضية التي تربط هذه العوامل بعضها ببعض من جهة وعلاقتها بالمواصفات الهندسية للتجويف الليزري من جهة اخرى.

من خلال دراسة المنحنيات البيانية بين عوامل استقرارية المرنان تم اثبات ان ليزر He-Ne اكثر استقرارية من ليزر CO_2 نظرا لفرق الطاقة التي تمتلكها فوتونات كلا الليزرين وبالتالي فرق القدرة الليزرية الخارجة.

الكلمات المفتاحية: استقرارية المرنان ، هيليوم–نيون ليزر ، ليزر CO_2 ، المرنان المستقر وغير المستقر

Study of Resonator Properties of Stable and Unstable Lasers

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ABSTRACT

In this work, the stability of optical resonator for two types of lasers are studied which are, He-Ne laser and CO_2 laser. The first type, is a low power laser and 0.6328 µm of wave length and the second type (CO_2 laser) is a high power laser and 10.6 µm of wave length .

Theoretical part deals with illustrating the physical meaning of stability factors which are g-factor, Fresnel No. , Q-factor and diffraction losses , also the mathematical equations of these factors and the geometrical specifications related with optical resonator.

According to the figures which show the relationships between the stability factors, He-Ne laser is more stable than CO_2 laser ; it has been verified and this is due to the high difference of photon ’s energy and also to the difference in output powers for the two laser.

Key Words: resonator stability, He-Ne laser, CO_2 laser, stable and unstable laser

1. Introduction

The gain of laser resonator G_{LR} is a measure of the amount of the light intensity increases by the stimulated emission for one round trip inside the resonator (this trip is starting from the output coupler OC thru the active medium, reflected off the high reflector HR back thru the active medium, backing again at the OC).The gain of laser medium G_{LM} is the light intensity increasing due to the stimulated emission from one of two ends of the active medium to the others.There will be lasing if G_{LR} togther with G_{LM} and the total losses(the output laser is one of these losses), is more than one.

The output power will be increase till the losses bring G_{LR} down to preciely one (that means the laser blows up),all the losses is due to non-linearties in the lasing process and finite pumping input.The output power decreases and finally damps if the G_{LR} is less than one. In the same side of the output beam, the losses will built up from imperfect mirror (absorption at the OC and the partial reflction at the HR), Absorption with the reflection at the Brewster window as well as the absorption an d scatter in the lasing medium.[1]

A perfect He-Ne laser may addionally have G_{LM} of only 1.01 to 1.05 that depends on the length of resonator (1 to 5%). All optics must be close to perfection as viable to get whatever out of a short tube. For these reasons, the following approximate equation for (LRG) can be used: [1]

G_{LR} (approximate) = L * G …(1)

Where:

- L: length of lasing medium (discharge bore, rod, etc.).
- G: gain per unit length.

the exact equation for G_{LR} should be used:

$G_{LR}(exact) = e^{a\ L}$ …(2)

Where:

a : gain coefficient of the lasing medium = $\ell n(G)$.

In both cases, the total full trip (G_{LR}) will be:

G_{LR} = $R_{(HR)}$ * [$T_{(B\text{-}HR)}$ * G_{LM} * $T_{(B\text{-}OC)}$]^2 * $R_{(OC)}$ …(3)

Where ($R_{(HR)}$ **,** $T_{(B\text{-}HR)}$**,** $T_{(B\text{-}OC)}$ **&** $R_{(OC)}$**) are** coefficient**s of:**

- The reflection of the High Reflector mirror.
- The transmission of HR-end Brewster window (if used).
- The transmission of OC-end Brewster window (if used).
- The reflection of the Output Coupler mirror, respictivly

While the G_{LR} is determined whether a given configuration will be a laser or not, the on hand power that can be drawn from every spectral line will have an affect on the real output power from the laser. In different words, where all different factors are equal, a low gain line may also truely produce a higher proportion of the output power than a high gain line at higher power input.[2] [1]

2. Stability of Resonator

A resonator of laser can be both stable or unstable. This does not now typically refer to a design that will not now be flexed or distorted due to mechanical stress or temperature variations (though that is additionally a exact requirement for a most lasers, unless deliberatelly introduced so that sure parameters like fantastic mirror alignment can be adjusted with the aid of a feedback control system in similar to adaptive optics in high performance telescopes). The design of the resonator is the one which is accountable for the kind and form of laser beam which is produced. A foremost section of the laser beam is a function of the cavity optics (as properly as the length and cross-sectional form of the real bore and different factors).[2] [1]

The key equation determines whether a given configuration of mirrors will end result in a steady resonator is: [1]

$\mathbf{0 \leq g_1 * g_2 \leq 1}$ …(4)

With:

$\mathbf{g_1 = 1 - (L/}R_{\mathbf{1}}\mathbf{)}$ $\mathbf{g_2 = 1 - (L/R_2)}$ …(5)

Where:

- R_1 & R_2: the curvature radii of mirrors 1 and 2 respectively.
- L : the displacment between the two mirrors.

3. Fresnel number

Essentially, the Fresnel number was added in the context of the diffraction concept for beam propagation. If a light wave first passes thru an aperture of size (e.g. radius (a)) and then propagates over a distance L to a screen, the situation is characterised with the Fresnel number.**[3]**

$\boldsymbol{F = \frac{a^2}{\lambda\, L}}$ …(6)

a : is the size characteristic (e.g. radius) of the aperture

L : is the distance of the screen from the aperture
λ: is the incident wavelength.

The value of F is very impotant to determine the type of the diffraction, so there are two special cases:

- Fraunhofer diffraction for $F \ll 1$.
- Fresnel diffraction for $F \gtrsim 1$.

When $F \gg 1$, geometrical optics laws are applied.

The idea of the Fresnel number has additionally been utilized to optical resonators (cavities), in specific to laser resonators. where (a) is now the radius of the back mirrors, and L is the length of resonator.[3] [4]

The losses of diffraction, at the back mirrors, are small for the typical mode sizes (i.e. not near the stability limit of the resonator, where the mode sizes can diverge) leads to large Fresnel number (F>1) of resonators (cavities). This is the ordinary situation in a stable laser resonator. Conversely, a small Fresnel number means that the diffraction losses can be significant – particularly for higher-order modes, so that the diffraction-limited operation may alsobe favored. [6]

Most stable laser resonators have a fairly large Fresnel number, whereas small Fresnel numbers occur in unstable resonators, which are sometimes applied in high-power lasers.[5]

4. Q Factor and Diffraction Losses in Laser Resonator

The 'Q' factor of a laser resonator is analogous to the Q factor of a tuned circuit. It is a measure of the energy stored in the cavity versus the losses as the light bounces back and forth between the mirrors.

Some definitions of the Q factor of a laser resonator are: [6] [7]

$$\boldsymbol{Q = 2\pi \frac{E}{\delta E}} \qquad \ldots(7)$$

Where:

- E : stored energy in the resonator.
- δE : lost energy for one trip.

The final equation of Q factor as a function of the wavelength , the length of resonator and the losses of resonator due to the diffraction is given by:

$$\boldsymbol{Q = \frac{2\,\pi\, L}{\lambda}\ \frac{1}{\delta}} \qquad \ldots(8)$$

where (δ) is the diffraction losses which is given by:[6]

$$\boldsymbol{\delta = e^{-\,2\,\pi\,F\sqrt{1-g_1 g_2}}} \qquad \ldots(9)$$

where:
F: Fresnel Number.
g_1, g_2: Resonator stability factors for the mirrors R_1, R_2 respectively

5-Results and Discussion

In this work, a theoretical study of design factors of stable and unstable resonators, for two lasers such as He-Ne and CO_2 lasers, respectively is dealt with. The table below shows the specifications of the two lasers mentioned above.

Table (1) shows the specifications design of He-Ne and CO_2 lasers[2] [3]

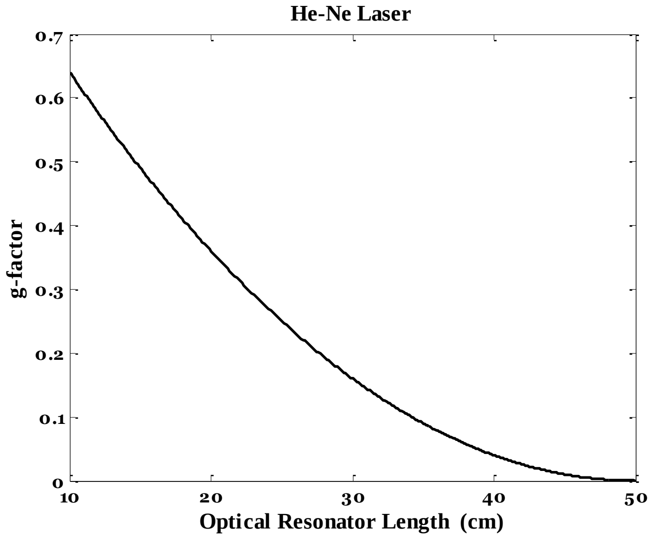
Specifications \ Laser type	He-Ne laser	CO_2 laser
Wave length	632.8 nm	10.6 µm
Beam diameter (at aperture)	1 mm	2.6 mm
Radii of curvature	R_1=R_2 = 50 cm (concave)	R_1=inf (plano) R_2=100 cm(concave/plano)
Output Power	1 mW	5 W
Resonator Length	25.5 cm	40 cm

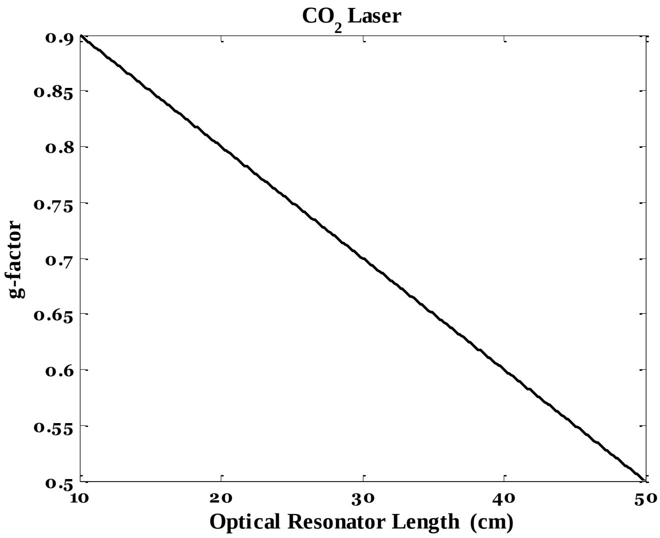
Figure (1), shows the relation between the g-factor and the resonator length (L). It 's clear that, the g-factor decreases- in the two lasers- with (L) at the range (10-50) cm. Therefore, the stability of the two lasers is still in the range of equation (4), which means that the stability of the resonator decreases with the increasing of (L) because it depends on the curvature radii of mirrors and the distance between them but not depending on the type of the laser medium.

In figure (2), the resonator length (L) versus the Fresnel Number (F) is plotted. Nonlinear curves show the decreasing of (F) factor with the increasing of (L) within the range (10-50) cm for the two lasers. The illustration of this behavior is that: at a large values of (L), the resonator losses(diffraction, scattering….) will built up that means the (F) will be less than or approach one for CO_2 and He-Ne laser respectively, which is also verifying by the figure (3).In the He-Ne laser the range of (F) is much larger than that in CO_2 laser ; this comes from the fact that the stability of the former laser is better than the latter

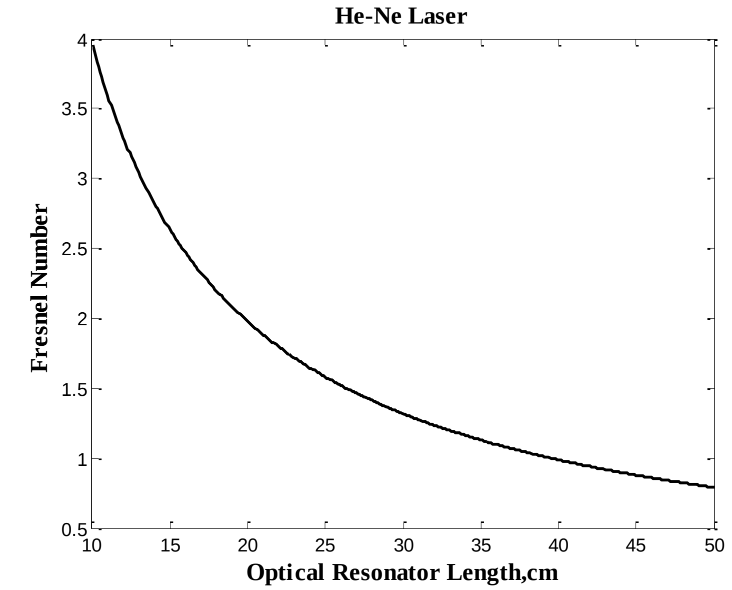
The relationship between Fresnel Number (F) and diffraction losses shown in figure (4). As appearing, the diffraction losses decreasing with increasing of (F) for two lasers because the (F) is depending on resonator length.

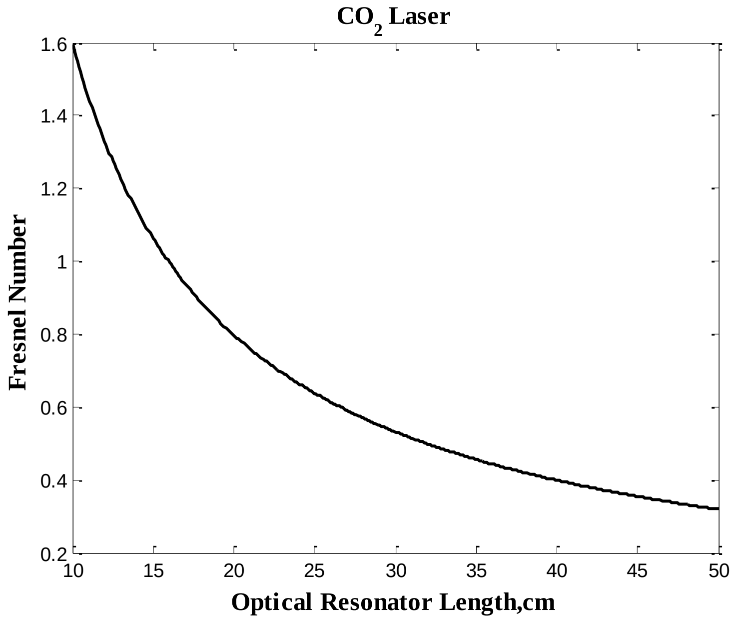
Returning to the Eq. (4),the value of $(\boldsymbol{g_1} * \boldsymbol{g_2})$ approach to (0) at a large resonator lengths, so the diffraction losses will be maximum but latter will be minimum when the value of $(\boldsymbol{g_1} * \boldsymbol{g_2})$ approach to (1) because of little resonator lengths. This is explained in Figure (5).





Figure(1): g-factor as a function of optical resonator length for He-Ne & CO_2 lasers





Figure(2): Fresnel Number as a function of optical resonator length for He-Ne & CO_2 lasers

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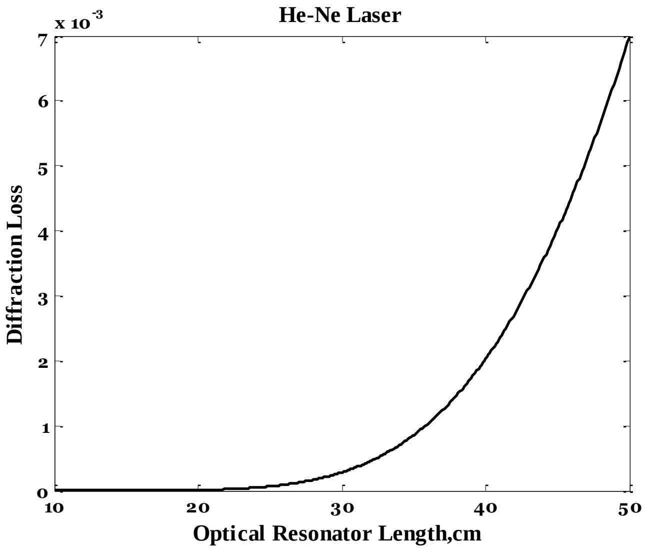
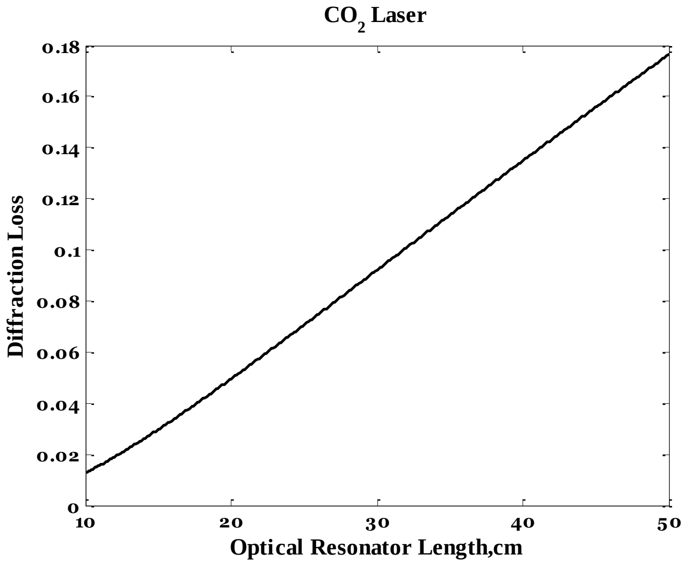
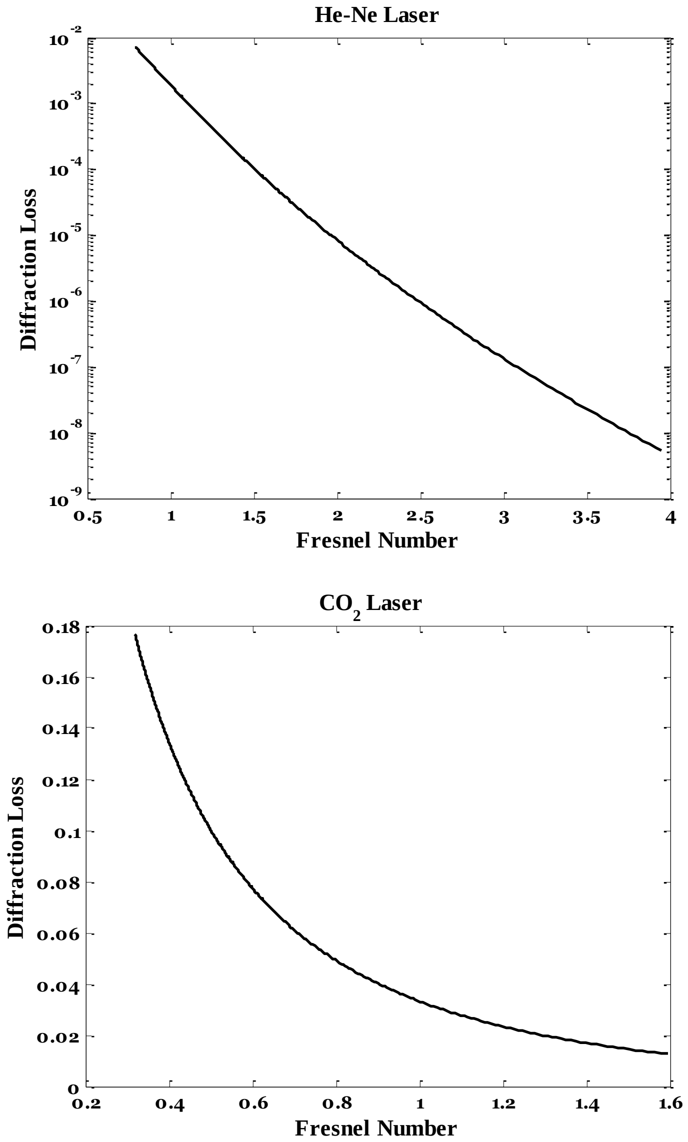
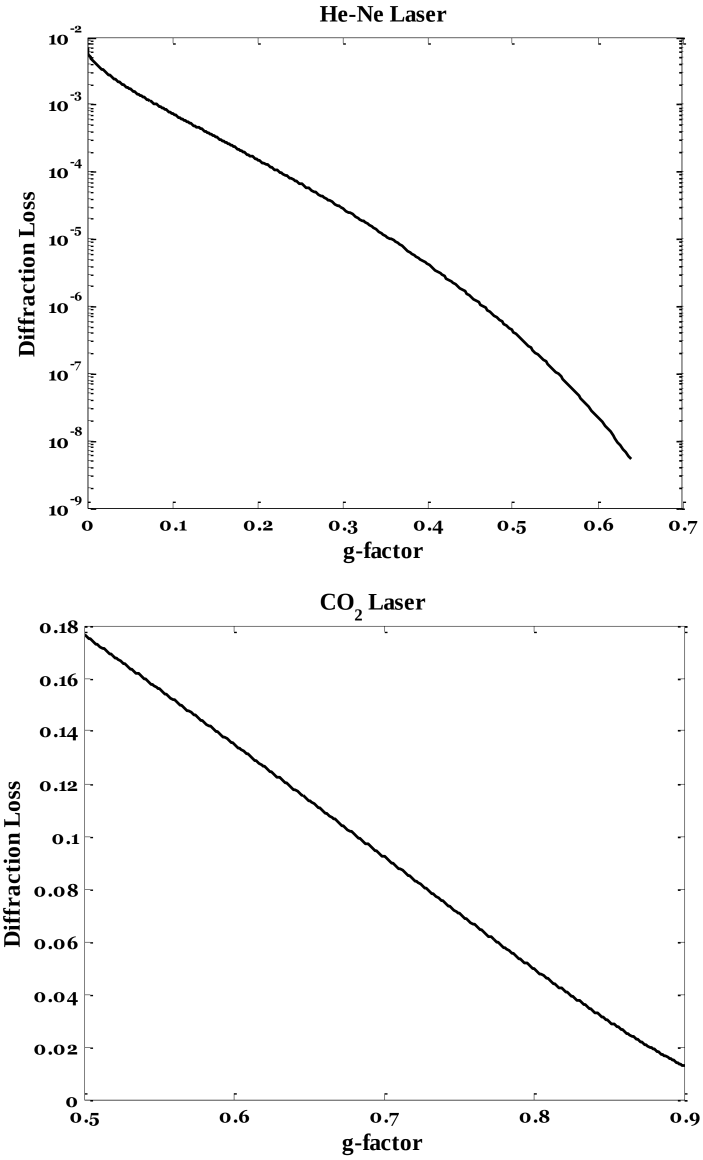




Figure(3): Diffraction Losses as a function of optical resonator length for He-Ne & CO_2 lasers



Figure(4): Diffraction Losses versus Fresnel Number for He-Ne & CO_2 lasers



Figure(5): Diffraction Losses as a function of g-factor for He-Ne and CO_2 lasers

Conclusions:

It is clear that, the He-Ne laser is more stable than CO_2 that is caused by the photons of laser action. In He-Ne laser the photons stay in the optical resonator oscillating between the two mirrors for a long time in comparing with that in CO_2 laser because of the high energy of these photons of CO_2 laser.

Acknowlegments:

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