

A Remotely Controllable Optical Multi-Pass System

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Received June 7, 2004; accepted July 17, 2004

PACS numbers: 39.90.+d, 39.30.+w, 42.15.Eq, 42.62.Fi.

Abstract

An optical planar multi-pass geometry is presented and the number of passes as well as the total absorption path length is described mathematically. The system is easily aligned, offers a possibility for remote control as well as a simultaneous multi-passing of different laser beams in a flat design. Applications are expected in experiments where space is limited or where an average but easily achievable increase in absorption path length is useful.

In the past several optical multi-pass configurations have been proposed to improve the sensitivity of direct absorption experiments by increasing the effective path length through an absorbing medium. Well known geometries have been introduced by White [1], Welsh [2], Herriott [3, 4], Perry [5], McManus [6] and Chernin [7, 8] and their coworkers. Optical multipass arrangements based upon these geometries use high quality spherical mirrors resulting in an efficient roundtrip refocusing that prohibits a divergence of the laser beam. Inherent to these spherical optical multipass systems is a rather critical alignment: a small change in the incoupling scheme necessitates a rather complete re-alignment and in general it is hard to change the total number of passes (N_{tot}) in an easy way. As a consequence remotely controlled multi-pass systems have not been reported so far.

In this short contribution a planar multi-pass system is described in which N_{tot} can be varied in a defined way by using one single translation stage without the necessity of realigning the system. To put this very clearly: this planar geometry is *not* as effective as the systems described in Refs. [1–8] in terms of effective absorption path length, but it offers a number of other advantages that are worth considering.

A schematic drawing is shown in Figure 1. The setup consist of four plane first surface mirrors, M1 to M4, mounted on mirror holders that are positioned under 45° with respect to the symmetry axis of the multipass system. M1 is slightly larger than the other three mirrors that have the same size (D). M4 and M1 are mounted on a single axis translation stage for movement in x and y direction, respectively. M2 and M3 are mounted under 90° and may be replaced by a corner reflector. The laser beam enters the system parallel to the symmetry axis in the middle of the opening between M1 and M4, i.e. the distance (a) of the laser beam to the symmetry axis is half the value of the entrance opening (d) and this is easily achieved by moving M1. In this case the actual number of passes

$$N_{\text{tot}} = 2N_{\text{mp}} - 1$$

is determined by the first integer value N_{mp} for which the multipass condition

$$N_{\text{mp}} > \frac{1}{2}(2^{1/2}D/d + 1)$$

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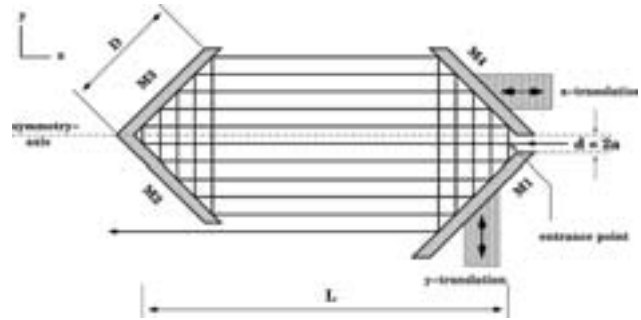


Fig. 1. A systematic view of the proposed planar multi-pass configuration. The system consists of four mirrors with M1 and M4 mounted onto single axis translation stages for translation in y - and x -direction, respectively. The y -translation is used to achieve the initial alignment criterium that the distance between M1 and M4 is twice the diameter of the laser beam and the x -translation is used to control the total number of passes.

is fulfilled. This means that the maximum number of passes in the system is intrinsically limited by the diameter of the laser beam. In the case of a HeNe laser with a typical diameter of 1 mm and mirrors with $D = 5$ cm up to 71 passes are expected, basically independent from the length (L) of the system. In practice this number is not achieved. As stated before, the number of roundtrips is limited by the divergence of the laser beam [9]. In our test setup with $L = 17$ cm a maximum of 41 passes (i.e. $N_{\text{mp}} = 21$) has been obtained. This corresponds to a total absorption pathlength of $L_{\text{tot}} = 7.4$ m. This value is calculated in the following way: starting from the entrance point (defined in the figure) all roundtrips have equal length ($2L + 3d$), apart from the last (incomplete) round trip where the value to the exit amounts to $(L + d)$, i.e.

$$L_{\text{tot}} = L(2N_{\text{mp}} + 1) + d(3N_{\text{mp}} + 1).$$

The beam leaves the multipass unit on the opposite site parallel to the symmetry axis, shifted $(N_{\text{mp}} - 1) \cdot d$ with respect to the incoming beam. A convenient way to change the number of passes and consequently the total absorption path length is obtained by moving the second translation stage to which M4 is mounted along the x -axis. Every translation over d in negative x -direction (to the left in the figure) decreases N_{mp} by one and consequently the number of passes by two. This translation does not change the exit point of the laser beam.

This rather simple configuration has three major advantages above spherical multipass systems. First of all the alignment is straight forward and the number of passes can be changed in a systematic way. The latter allows a remote control of the number of passes by moving the corresponding translation stage. Secondly, the system allows multipassing of different laser beams simultaneously: the beams remain in one plane and consequently by choosing different incoupling heights

simultaneous multipassing becomes possible. Finally, the system can be made very flat. In a static design, in which no translation stages are used, the system can be made nearly as flat as the diameter of the laser beam. The disadvantage of the system is that only moderate absorption pathlengths are achieved because of divergence of the laser beam. This disadvantage makes a planar multipass configuration as described here less favourable for a number of applications, but in those cases where an average increase in absorption path length is useful and for example space is limited or where a remote control of the system is required, the system described here has its advantages. Presently, it is implemented in a cell that is used for recording reference gas spectra for absolute frequency calibrations. As different gases have different absorption cross sections a variation of the absorption path length is a better alternative than varying cell pressures, particularly in view of line broadening effects. Comparably, the system might be used in remote sensing experiments to monitor gases in the earth's atmosphere that have varying densities at different heights. Another application could be in a planar gas expansion through a long and narrow slit as Doppler broadening cannot occur [10]. The main application of this new design, however, might be simply in experiments

where an average increase in absorption pathlength is sufficient to increase S/N ratios and where the use of generally rather expensive spherical mirrors is not necessary.

Acknowledgement

Financial support by the Dutch organisation for fundamental research (FOM) is gratefully acknowledged.

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