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SIMPLE DESIGNS TO MEASURE EFFICIENCY OF DIFFERENT TYPES OF MONOCHROMATORS

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Quelques montages simples pour mesurer l'efficacité de différents types de monochromateurs

SUMMARY : The monochromators are being widely used in most of the optical experiments and the efficiency or throughput of a monochromator is an important parameter to be known. There are three types of monochromators commonly and commercially available, for example, Model-A : its entrance and exit slits are provided with two arms inclined at an angle of 90 degree to each other, Model-B : it has been provided with entrance and exit slits in line on opposite faces of the monochromator body, and Model-C : having entrance and exit slits side by side provided on the same face. In the present article we have described three designs to measure the efficiency of the above mentioned three monochromators, for the light of a laser beam. In case this laser is replaced by a tunable dye laser the efficiency of the monochromators can be measured for the light of other wavelengths also. The designs are based on the principle of modulation radiometry.

RÉSUMÉ : Les monochromateurs sont largement utilisés dans la plupart des expériences optiques et l'efficacité d'un monochromateur est un important paramètre à connaître. Il y a trois types de monochromateurs habituellement disponibles commercialement : Modèle A : les fentes d'entrée et de sortie sont à 90° l'une de l'autre ; Modèle B : les fentes sont sur les faces opposées du corps du monochromateur et Modèle C : les fentes sont sur la même face. Dans cet article nous décrivons trois montages pour mesurer l'efficacité de ces différents monochromateurs avec un faisceau laser. Lorsque le laser est accordable, l'efficacité peut être mesurée à différentes longueurs d'onde. Ces montages reposent sur le principe de la radiométrie modulée.

INTRODUCTION

The monochromators are being widely used in most of the optical experiments and for this purpose the efficiency of a monochromater is an important parameter to be known. There are three types of monochromators commonly and commercially available. Model-A : Its entrance and exit slits are provided with two arms inclined at an angle of 90 degree to each other [1], and employs a constant deviation prism. Model-B : It has been provided with entrance and exit slits in line and on opposite faces of the monochromator body [2], and Model-C : Having entrance and exit slits side by side provided on same face [3]. Obviously, a single experimental set up or design is not sufficient to measure the efficiency of all the above mentioned models of the monochromators.

In the present paper we have described three designs to measure the efficiency of the three types of monochromators, but emphasis has not been given on the resolution.

DESCRIPTION OF THE DESIGNS

Model-A : This design is depicted in *figure 1*. According to it, radiation from a laser source L is divided by a beam splitter B into two parts with intensities I_1 and I_2 respectively. The beam I_1 after suffering a reflection at a plane mirror P_1 enters into an integrating sphere IS with a screen S to protect the photo-detector PD against any incident radiation directly falling on it. Beam I_2 after suffering a reflection at a plane mirror P_2 enters into the integrating sphere. At an another occasion, in the absence of

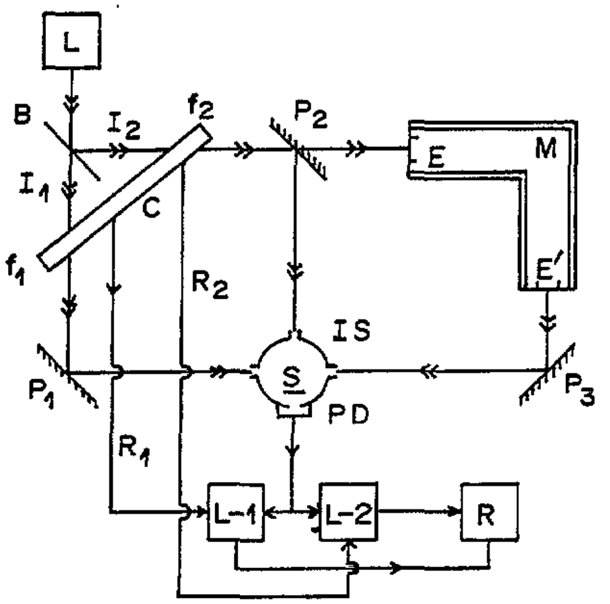

FIG. 1.

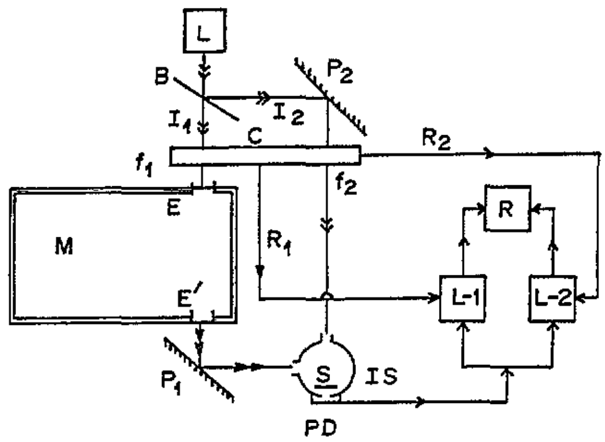

FIG. 2.

mirror P_2, beam I_2 enters into the monochromator M with its entrance and exit slits E and E' respectively, and after suffering a reflection at a plane mirror P_3 enters into the integrating sphere where all the radiations are detected by the photo-detector. The beams I_1 and I_2 are modulated by a dual frequency chopper C at the frequencies f_1 and f_2 respectively. The electrical output signal from the detector is fed into two similar lock-in-amplifiers L_1 and L_2 and the reference signals R_1 and R_2 for the lock-in-amplifiers are drawn from the chopper. The *DC* outputs of the lock-in-amplifiers are fed into a ratiometer R to record the ratio of the two signals due to beams I_1 and I_2. The calculation of the efficiency T_A of the monochromator is done as follows,

(1) Without setting up of mirror P_2 in the light beam I_2 :

The beam I_2 after passing through the monochromator of model-A is reduced to an intensity of $I_2 T_A$. Subsequently, this beam also suffers a reflection at a plane mirror P_3 and reduced to an intensity of $I_2 T_A r_3$. Similarly, the beam I_1 after suffering a reflection at a plane mirror P_1 is reduced to an intensity of $I_1 r_1$. In this case, the ratio k_1 (say) of the intensity of beam I_2 to that of beam I_1 reaching at a detector through the integrating sphere is given by the expression,

$$(I_2 T_A r_3 / I_1 r_1) = k_1 . \quad (1)$$

Where r_1 and r_3 are the reflectances of plane mirrors P_1 and P_3 respectively, and the ratio k_1 is read on the ratiometer.

(2) With mirror P_2 set up in the beam I_2 :

In this situation the beam I_2 suffers a reflection at the plane mirror P_2 and reduces to an intensity of $I_2 r_2$ and the ratio k_2 (say) of the intensity of beam I_2 to that of beam I_1 reaching at the detector through the integrating sphere is given by,

$$(I_2 r_2 / I_1 r_1) = k_2 . \quad (2)$$

Where r_2 is the reflectance of the plance mirror P_2 and ratio k_2 is again read on the ratiometer. From Eqs. (1) and (2),

$$T_A = (k_1 r_2 / k_2 r_3) \quad (3)$$

$$T_A = (k_1 / k_2) \quad (4)$$

if, $r_2 = r_3$.

Thus, the above expression gives the efficiency of the monochromator of Model-A in question. Here r_2 is made equal to r_3 by taking mirrors P_2 and P_3 from the same piece of the mirror.

Model-B : This design is shown in *figure* 2, here also, alike design for the monochromator of Model-A, two experiments are performed.

(1) With the monochromator set up in the beam I_1 :

It is evident from the schematic diagram of this design that the ratio q_1 (say) of the intensities due to beams I_2 and I_1 reaching at the detector is given by,

$$(I_2 r_2 / I_1 T_B r_1) = q_1 . \quad (5)$$

Where T_B is the efficiency of the monochromator of Model-B.

(2) Without the monochromator setting up in the beam I_1 :

As in the above case, the ratio q_2 (say) of intensities due to the beams I_2 and I_1 reaching at the detector will be given by,

$$(I_2 r_2 / I_1 r_1) = q_2 . \tag{6}$$

Now from Eqs. (5) and (6)

$$T_B = q_2 / q_1 . \tag{7}$$

Model-C : This design is a little complicated and has been depicted in *figures 3(a)* and *3(b)*.

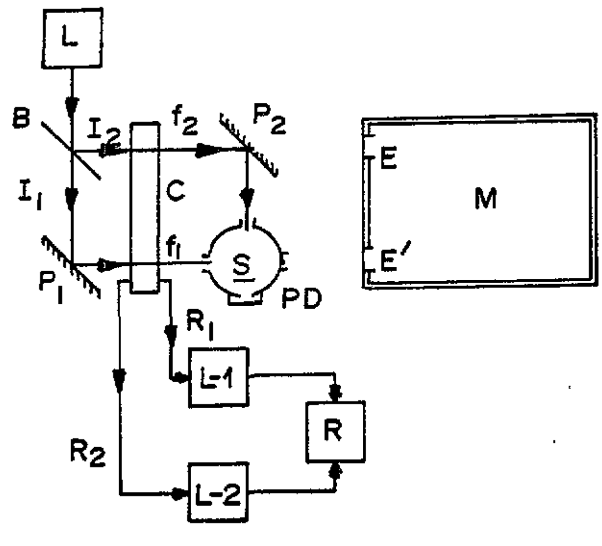

FIG. 3(a).

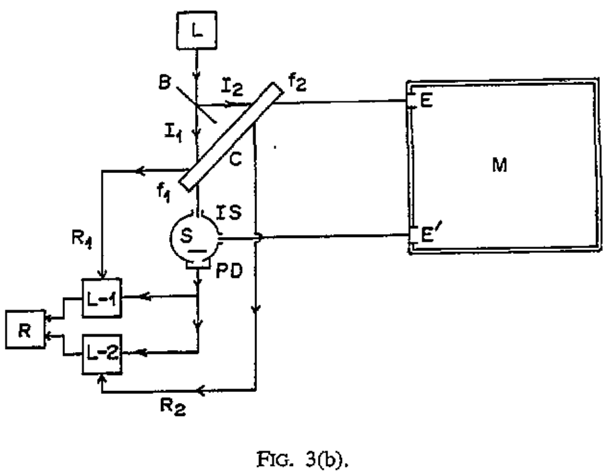

FIG. 3(b).

(1) Mirror P_2 set up in the beam I_2 :

According to *figure 3(a)*, the ratio s_2 (say) of the intensity of the beam I_2 to that of the beam I_1, reaching at the detector is given by the expression,

$$(I_2 r_2 / I_1 r_1) = s_2 . \tag{8}$$

(2) Without mirror P_2 set up in the beam I_2, and the integrating sphere replaced the mirror P_1, as shown in *figure 3(b)* :

The ratio s_1 (say) of the intensity of beam I_2 to that of beam I_1 reaching at the detector is given by,

$$(I_2 T_C / I_1) = s_1 . \tag{9}$$

Where T_C is the efficiency of the monochromator of model-C. From Eqs. (8) and (9)

$$T_C = (s_1 / s_2)(r_2 / r_1)$$

or,

$$T_C = s_1 / s_2 \tag{10}$$

if, $r_1 = r_2$.

Thus by using the appropriate expression for efficiency of the monochromator in each case, this parameter can be determined for the radiation of the laser beam employed. The care has to be taken that there should be no obstruction of the laser beam at the entrance or exit slits of the monochromator and also radiation should not directly illuminate the photo-detector. The values of r_1 and r_2 can be made equal by taking the mirrors P_1, P_2 from the same piece. Here we are using the light beam from a laser source of one wavelength, however, if this laser is replaced by a tunable laser working in the wavelength range of interest, the efficiency of the monochromators can be determined for these wavelengths also.

DISCUSSION

(A) Electronic processing of the signal :

Referring to *figure 1*, the light intensities set to beams I_1 and I_2 entering into the integrating sphere and detected by the detector, produce their combined and modulated effect on the photo-detector simultaneously. Consequently, the electrical signal output of the photo-detector consists of two combined effects due to the intensities of light beams I_1 and I_2. As the output electrical signal from the photo-detector is simultaneously fed into two similar lock-in-amplifiers and the reference signals R_1 and R_2 for the lock-in-amplifiers L_1 and L_2 are drawn from the dual frequency chopper, modulating the beams I_1 and I_2 at the frequencies of f_1 and f_2 respectively, and thus each of the lock-in-amplifiers L_1 and L_2 detects the part of the electrical signals of the photo-detector corresponding to their respective modulation frequency and convert them into D. C. signals. Consequently, the D. C. output signals from the lock-in-amplifiers L_1 and L_2 are proportional to the respective intensities of light beams I_1 and I_2 entering into the integrating sphere and being detected by the photo-detector. Thus the ratio of output signals from these lock-in-amplifiers is the ratio of the intensities of light beams I_1 and I_2 as recorded by the ratiometer.

(B) Systematic errors :

Like transmittance of an optical glass plate we can define the efficiency of the monochromator as the output radiation divided by the input radiation. From this definition it is evident that for an accurate measurement (4) of the efficiency of the monochromator, it is desired that : (i) the intensity of output and input radiations should be measured simultaneously, (ii) the input and output radiation should be measured by a single detector on its same specified area, and (iii) the spectral sensitivity of the detector, source fluctuations and the back ground light should not affect the measurements.

In the present designs the errors introduced due to above mentioned factors have been minimised by providing the necessary arrangement such as, the radiation from the source has been divided into two beams following the separate paths. The beams intensities have been modulated at differing frequencies. This provision has facilitated the detection of radiation by the use of the technique of modulation spectroscopy (5), which has been recognized as a sensitive powerful tool to investigate the solid state structures of the materials. In this method the electronic processing (6) of the electrical signal is unique with the use of solid state devices for the normalisation and compensation functions. This particular approach permits the use of essentially any radiation detector. The use of an integrating sphere has made possible to shine the same area of a single detector by both the beams of radiation. The effect of stray and scattered radiation due to radiation source or otherwise is equally present in both the beams, and hence its effect is neutralised. Also the back ground light does not affect the measurements as only the signal due to modulated radiation is detected by the lock-in-amplifiers. The present designs do not require an efficiency reference standard for comparison, for the measurement of the efficiency of the monochromators in each design, the experiments have been bifurcated into two parts. One part of the experiment in each case is performed simply to compensate the systematic as well as parametric errors (7-11) introduced due to the presence of optical components. The second part of the experiment is performed to actually measure the efficiency. Now as mentioned above, the beam of laser radiation which is a parallel with a small area cross section has been used to see the efficiency of the monochromator, which is not representative of the actual situation in practice. The reasons for the use of a laser radiation beam are as follows. In a possible conventional method, for non parallel beams and covering the full aperture of the monochromators, the radiation detector has to be placed (a) behind the entrance slit (in side the monochromator) to measure the input radiation and then, (b) the detector has to be placed just infront of the exit slit (out side of the monochromator) to measure the output radiation (coming out of the exit slit). In this process a few difficulties to be faced are (i) it is not practicable to place the photo-detector inside the monochromator, (ii) it is not necessary that output radiation covers exactly the same area of the detector as in the previous case. Thus the area sensitivity of the detector may affect the measurements. Moreover, there may be source fluctuations during the process of measuring input and output radiations that may also affect the measurements, and (iii) the above situation is with monochromatic radiation whereas, with the use of polychromatic input radiation the situation would be altogether different, as one would be measuring the polychromatic input (total) radiation, while output radiation would be a monochromatic radiation, forming a small fraction of the polychromatic radiation. In the above method it is difficult to avoid the systematic errors introduced due to polarisation effects (12, 13) on the beam of radiation, because the radiation from common sources like tungsten filaments is slightly polarised. Besides it, monochromators using prism/gratiting also introduce polarisation. But we have not to worry about it in the present case, because, in order to measure the efficiency of the monochromators, we have to measure the output radiation whether it is modified due to polarisation or otherwise inside the monochromator.

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