SIMPLE DESIGNS TO MEASURE EFFICIENCY OF DIFFERENT TYPES OF MONOCHROMATORS

O. PRAKASH, R. S. RAM

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 degrees 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.

INTRODUCTION

The monochromators are being widely used in most of the optical experiments and for this purpose the efficiency of a monochromator is an important parameter to be known. There are three types of monochromators commercially available. Model-A: Its entrance and exit slits are provided with two arms inclined at an angle of 90 degrees to each other [1], and employs a constant deviation prism. Model-B: It has been provided with entrance and exit slits in line 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 another occasion, in the absence of
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 photodetector. 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 output 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 $I_2T_A$. Subsequently, this beam also suffers a reflection at a plane mirror $P_3$ and reduced to an intensity of $I_2T_Ar_3$. Similarly, the beam $I_1$ after suffering a reflection at a plane mirror $P_1$ is reduced to an intensity of $I_1r_1$. In this case, the ratio $k_1$ (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 the expression,

$$ (I_2T_Ar_3/I_1r_1) = k_1 . \tag{1} $$

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 $I_2r_2$ 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,

$$ (I_2r_2/I_1r_1) = k_2 . \tag{2} $$

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

$$ T_A = (k_1r_2/k_2r_3) \tag{3} $$

$$ T_A = (k_1/k_2) \tag{4} $$

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, a like 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,

$$ (I_2r_2/I_1T_Br_1) = q_1 . \tag{5} $$
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,

$$\frac{I_2}{I_1} = q_2.$$  \hspace{1cm} (6)

Now from Eqs. (5) and (6)

$$T_B = \frac{q_2}{q_1}.$$  \hspace{1cm} (7)

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

$$\frac{I_2}{I_1} = s_2.$$  \hspace{1cm} (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,

$$\frac{I_2}{I_1} = s_1.$$  \hspace{1cm} (9)

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

$$T_C = \frac{s_1}{s_2} \left( \frac{r_2}{r_1} \right)$$

or,

$$T_C = \frac{s_1}{s_2}$$  \hspace{1cm} (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 slit 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 \( \nu_1 \) and \( \nu_2 \) 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 in front 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 monochromate 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 present 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/grating 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.

ACKNOWLEDGEMENTS

The authors are grateful to the Director, National Physical Laboratory, and the Head Physico-Mechanical Standards Division for their permission to publish this paper.
REFERENCES


(Manuscript received in May 24th 1994.)