HIGH PRECISION TECHNIQUE OF MEASURING THE REFLECTANCE OF REFLECTIVE MATERIALS

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Dedicate to my beloved mother

Madam Tan Soo Hwang

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ABSTRACT

A new method of reflectivity measurement is proposed and tested in this Ph.D. study. The method employs fast rotating reference mirror and certain geometry configuration to alternately deliver the light via a sample mirror or by passing it to a photo detector. It has proved to reach a precision of 2×10^{-4} reflectance unit. The precision is at least ten times better than that of conventional reflectometer used in solar energy applications. With good repeatability, the durability test of mirrors is carried out for only one month enabling significant specular reflectance losses of mirrors to be observed instead of more than a year in the conventional case. The reflectometer has provided solutions to few problems that limit the conventional reflectometer. Firstly, the time interval between the collection of reference signal and sample signal is short, therefore, this can reduce the effect due to the changes of environment conditions, particularly, the intensity fluctuation of light source and others. Secondly, by taking advantage of the short measurement time, a large number of readings can be made to suppress the noise level. Thirdly, the value of the reflectance of the reference mirror is not required. In the system, an accurate positioning of laser beam on the photo detector is achieved by a position sensor using a pair of dual cells that acts as an optical lever as well as a position transducer for the feedback system.

ABSTRAK

Teknik baru untuk mengukur pemalar pantulan telah dikemukakan dalam tesis ini. Teknik ini menggunakan cermin rujukan yang boleh berputar dengan laju dan konfigurasi geometri yang tertentu untuk menghantar cahaya ke cermin sample atau terus ke pengesan cahaya secara berselang-seli. Ketepatan pengukuran yang dicapai ialah 2 x 10^{-4} unit pantulan. Keputusan ini adalah sekurang-kurangnya 10 kali ganda lebih baik daripada keputusan yang dicapai oleh pengukur pemalar pantulan konvensional yang digunakan dalam bidang tenaga suria. Dengan kebolehulangan yang baik, ujian ketahanan pemantul suria yang hanya dijalankan sepanjang satu bulan telah dapat memerhatikan pengurangan pemalar pantulan yang jelas berbanding dengan ujian yang sepanjang satu tahun diperlukan bagi keadaan konvensional. Pengukur pemalar pantulan yang baru ini telah menyelesaikan beberapa masalah yang menjadi penghalang kepada pengukur konvensional. Pertama, masa perantaraan semasa mengukur isyarat rujukan dan isyarat sampel telah dipendekkan supaya kesan pengolakan keamatan laser dikurangkan . Kedua, bilangan pengukuran yang banyak dapat dijalankan untuk mengurangkan hingar dalam sistem. Ketiga, pemalar pantulan muktamad bagi cermin rujukan tidak perlu diketahui. Dalam sistem pengukur ini, penempatan sinaran laser yang tepat pada pengesan cahaya dicapai oleh satu pengesan kedudukan yang mengandungi satu pasang pengesan cahaya. Pengesan kedudukan itu boleh berfungsi sebagai tuil optik dan juga sebagai transduser kedudukan untuk sistem suapbalik. Untuk mencapai keputusan yang dinyatakan di atas, selain daripada cara yang pengarang berjaya menggunakan, pengarang juga mengkaji cara lain yang tidak begitu berjaya, sebagai rujukan masa depan.

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LIST OF SYMBOLS

θ	-	Angle of incidence
λ	-	Wavelength
ρ	-	Measured reflectance of sample mirror
ε		Photometric conversion efficiency of photo detector
d	-	Distance from the reference mirror to photo detector
ΔA	-	Area different of reference beam and sample beam
A_r	-	Area of reference beam
A_s	-	Area of sample beam
ΔL	-	Area shifted due to misalignment
α	-	Divergence angle of Gaussian beam
w_0	-	Radius of laser beam waist
z_0	-	Length parameter of Gaussian beam
S	-	Distance of lens from laser beam waist
f_1	-	Focal length of the first lens of beam expander
f_2	-	Focal length of the second lens of the beam expander
$\overline{V}_s$	-	Mean value of sample signal
$\overline{V}_r$	-	Mean value of reference signal
$\overline{V}_b$	-	Mean value of background signal
N		Number of measurements
σ	-	Standard deviation of measurement results

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CHAPTER I

INTRODUCTION

1.1 Introduction

In the age of energy crisis, solar energy as a renewable and environmental friendly energy has gained its importance to become the next alternative energy. High power, high temperature solar concentrator systems generally depend on the use of large area of highly reflective materials. Although second surface silvered float glass mirror has long being recognised to have good solar reflectance, good specularity, good rigidity and long time span etc., it is not commercially competitive due to its weight that require strong structure in heliostat designs. Metallised polymers offer the potential advantages of low cost, lightweight and ease of installation (Berry and Dursch, 1980, Alpert *et. al.* 1990, Alpert *et. al.* 1991 and Schissel *et. al.* 1994). However, metallised polymers suffer from several problems such as unknown lifetime, and low surface abrasion resistant. Much effort has been paid in the search of good protective coating, which has good surface abrasion resistant and high transmittance. At present, researchers still seek for good alternative materials in order to let solar concentrator system commercially attractive. A precise knowledge of the reflectance characteristics of potential solar device materials is required in the choice of materials and to determine the extent of environmentally induced changes in such materials as a function of outdoor exposure conditions and duration.

Specular reflectance loss with time is one of the important determinants of reflective material lifetime. A durable reflective material deteriorates slowly. Hence, the outdoor exposure test period for candidate mirror will depend on the capability of a reflectometer to measure a small change of material reflectance. Presently, the reflectometer used in solar energy applications has measurement uncertainty of 2 x 10^{-3} reflectance unit. The precision level is limited by the fluctuation of light intensity during the interval of measuring reference signal and sample signal (the reflectance is calculated from the ratio of the sample signal to the reference signal). The interval is long because of the need to reinstall the sample mirror for each measurement. This process is necessary because the optical path lengths for both reference beam path and sample beam path should be the same to achieve high accuracy. Due to the low precision achieved for conventional reflectometer, the period of outdoor weatherability test of mirror is usually more than a year. Such a long period of testing has affected the progress of developing solar energy concentrator that can provide inexhaustible energy to mankind.

On the other hand, scientists have thought of an alternative way to accelerate exposure test using weatherometer. But, the accelerated weatherability test does not always reflect actual environmental conditions. For example, Isakson (1972) tested polymethylmethacrylate (PMMA) and polyvinylidene fluoride (VDF) modified with PMMA with accelerated weathering devices and by outdoor exposure. The 12.7 μm thick samples were coated on matte-finished, bright aluminium panels. Nine months exposure in Florida produced only minor band broadening in the IR spectrum for PMMA, while only 31 hours in a Dew Cycle Weatherometer totally obliterated the IR spectrum.

In an effort to find a proper solar beam reflective material for the new invented Non-imaging Focusing Heliostat (Chen *et. al* 2001, and Chen *et. al* 2002), the author and Prof. Dr. Y. T. Chen have proposed and tested a new idea to measure reflectivity with high precision. The merits of the system are:

(a) Fast measurement that reduces the effect of light intensity fluctuations.

(b) Good repeatability without the need to know the reflectance of the reference standard.

Fast measurement can be done because reinstallation of the sample mirror for each measurement is not required in the new experimental setup. A reference mirror, which is attached on a DC motor, can rotate at high speed to direct the laser beam to the desired position. High beam-positioning precision is accomplished by a novel method which apply dual cells as a position sensor. The position sensor acts as an optical lever as well as position transducer for feedback system.

The measurement precision achieved is 2 x 10^{-4} reflectance unit. With this result, a durability test is carried out for a front-coated silver glass mirror and a back-coated aluminised acrylic mirror. Results show that obvious degradations are observed within one-month of exposure. This has greatly shortened the typical outdoor test of more than a year. Therefore, the desired reflective material property can be determined in a short time.

1.2 Objective and Scope of Study

The objective of my study is to carry out specular reflectance measurement at precision level of 10^{-4} reflectance unit for ordinary mirror. The constructed reflectometer will be used in solar collector system for development of high reflectance and long durability reflective material. Although the new reflectometer can be used in other application such as material science to study the optical properties of material, it is beyond the scope of my study. Besides, diffuse reflectance measurement is also beyond the scope of my study because specular reflectance are emphasised in solar collector system.

1.3 Thesis Overview

This thesis is divided into five chapters. Chapter 1 discusses the importance and necessity to have high precision measurement of reflective materials for solar energy applications. Chapter 2 is the literature review section. The theory of specular reflectance is first outlined. Then, various kinds of reflectometers for specular reflectance measurement are given. They are grouped into single-reflection, double-reflection and multiple-reflection systems. However, some of those reflectometers are not suitable for use in durability test. Therefore, a summary is provided together with the discussion of the criteria of reflectometer for used in solar energy field. The following section introduces the reflective material for solar collector system: the silver-coated float glass mirror and thin film reflectors. Glass mirror has long durability whereas thin film reflectors are easier subjected to environmental degradation. Various types of degradation and their protection methods are also given. Finally, two different mirror durability tests are studied, that is, the outdoor weatherability test and accelerated test. Accelerated test can be simulated weatherability test or other specific tests such as the durability test of mirror under the corrosion of acid, abrasion of sand etc. Durability test involves the use of many types of equipment of which reflectometer is the most important instrument.

Chapter 3 describes the principle of the new reflectometer and the experimental setup. Firstly, I will explain that my research work is mainly focused on the precision and repeatability of the reflectivity measurement as long as the accuracy achieved is sufficient for solar energy applications. Then, the principle of the design of the reflectometer is illustrated including all the considerations and calculations. The experimental setup is described in detailed subsequently, which covers the optical scheme, the optical alignment, the electronic circuits and the data acquisition methods. Experimental set up issues such as beam size, uniformity of photo detector, fluctuation of laser intensity, performance of DC motor and design of position sensor are given. The last part of the chapter describes the experimental setup using mechanical stoppers for beam positioning.

Result and analysis are provided in Chapter 4. The first section gives the precision and repeatability achieved by the reflectometer. The verification of the good performance of the constructed reflectometer is confirmed by weatherability test of a silver front-coated mirror and an aluminium back-coated acrylic mirror. The noises of the reflectometer system are analysed in the subsequent section. The major contributions that limit the measurement precision are beam positioning precision, photo detector uniformity and laser intensity fluctuation. The laser intensity fluctuation arose from the laser system itself, the effect of particle flow and the effect of 50 Hz noise.

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