Polarimetry Applications

APPLICATION NOTE

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When the photoelastic modulator (PEM) is used as a polarization analyzer, it is generally useful to use a dual PEM system. A dual PEM system can obtain all four Stokes vectors simultaneously. By using a dual PEM system, the unparalleled high sensitivity, spectral range, and stability of Hinds photoelastic modulators (PEM) can be applied to study polarization.

One of the first uses for a dual PEM system was astronomical polarimetry. Applications can also be found in Stokes Polarimetry and Optical Rotation. Other polarization analysis PEM applications include laser light characterization and magnetic field diagnostics in tokamaks through out the world.

The modulator axes of the two modulators are at 45 degrees, with the polarizer passing axis at 22.5 degrees with each modulator. The angular designations for each modulator are determined by the angular direction of polarized light to which each modulator subsystem is sensitive. The electronic block diagram corresponds to the one given in Figure 1.

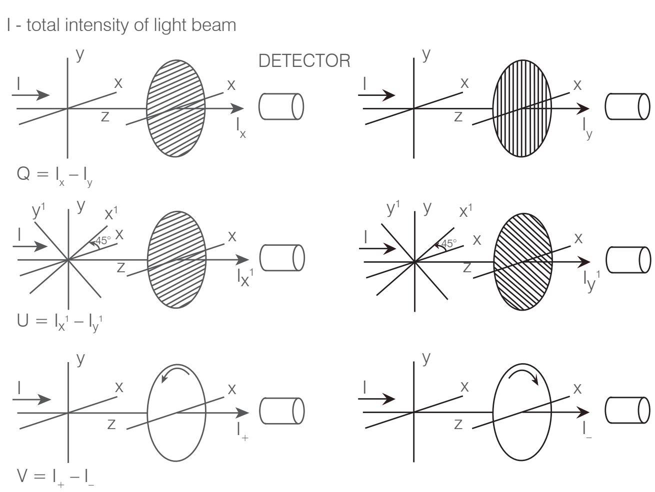

Figure 1. Definition of the Stokes Parameter

A typical block diagram for a dual PEM set-up is shown in Figure 2. This configuration would typically be used as a Stokes polarimeter. F_1 denotes the frequency of the first modulator. F_2 denotes the frequency of the second modulator. The symbol f_1 denotes the reference frequency of the first controller and f2 denotes the reference frequency of the second controller. 1_f represents the modulator frequency and 2f twice the modulator frequency.

The polarization state of a light source is represented by four numerical quantities called the Stokes parameters. These numbers represent the intensities and correspond to the fraction of the light that is linearly polarized and circularly polarized. Light can develop these characteristics after passing through certain devices such as polarized prisms or films and wave plates or it can occur naturally as in starlight. These are defined in Figure 2.

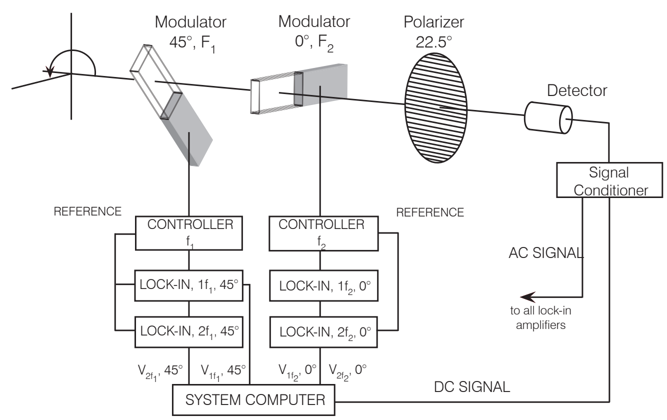

Figure 2. Typical Dual PEM setup

The relationships between the electronic output voltages and the appropriate polarization parameters are given in Table 1.

Hinds Instruments has five standard dual PEM systems for applications that require different useful apertures and measurements in different spectral regions. The dual PEM models are:

I/FS50-60	I/FS47-50	
II/FS20-23	II/FS42-47	II/ZS37-50

The I/FS50-60 and the I/FS47-50 systems are made with fused silica and use the Series I PEM. The Series I PEMs have a rectangular shaped optic with a typical useful aperture of 16 mm. These small systems are useful when the light source has a small beam

Condition: when the peak-to-peak retardation of both PEMs is set at $J_0(\delta 1_0) = J_0(\delta 2_0) = 0$

Normalized Stokes parameters:

J1 and J2 are Bessel functions of the PEM retardation amplitudes S1 and S2

$$Q_N = \frac{Q}{I} = \frac{1}{J_2(\delta 1_0)} \cdot \frac{V_{2f_1}}{V_{DC}}$$

$$U_N = \frac{U}{I} = \frac{1}{J_2(\delta 2_0)} \cdot \frac{V_{2f_2}}{V_{DC}}$$

$$V_N = \frac{V}{I} = \frac{1}{J_2(\delta 1_0)} \cdot \frac{V_{1f_1}}{V_{DC}}$$

Other polarizations parameters:

Degree of Polarization	$DOP = \sqrt{Q_N^2 + U_N^2 + V_N^2}$
Degree of Linear Polarization	$DOLP = \sqrt{Q_N^2 + U_N^2}$
Degree of Circular Polarization	$DOCP = \lvert V_N \rvert$

TABLE 1. RELATIONSHIPS BETWEEN THE ELECTRONIC OUTPUT VOLTAGES AND THE APPROPROATE POLAIRZATION PARAMETERS

diameter. Therefore, if the application for the dual PEM involves a light source consisting of a laser, this is a viable option.

If a larger aperture and/or operation in the IR is required Series II PEMs are preferred. The II/FS20-23 and the II/FS42-47 systems also employ high quality fused silica as the optical material and have a transmission range of 170 nm to 2.6 μm. Both models are completely functional in the UV, visible, and near IR light spectral regions. However, the II/FS20-23 system has the benefit of a very large aperture. This is especially useful if the light source has a large beam diameter or more than one light source is to be observed. This dual PEM is typically used in a Stokes polarimetry system to measure the orientation of the linear component of light emitted from a beam of deuterium atoms injected into tokamak plasma. The II/FS42-47 is also used in Stokes polarimetry measurements and provides a more compact optical head configuration.

The II/ZS37-50 has ZnSe as the optical material. This provides a transmission range from 514 nm to 18 μm. This PEM has applications in the infrared region of the light spectrum. It is used to analyze either a broadband light source or an infrared laser such as the CO_2 laser.

Like all Hinds PEMs, these systems provide the unique benefit of a wide acceptance angle (± 20 degrees or greater), a good transmission for a wide wavelength range, high power handling capabilities, and a high polarization sensitivity. Table 2 compares the technical specifications for all of the Hinds dual PEM systems.

APPLICATIONS FOR DUAL PEM SYSTEMS

Polarization Analysis and Stokes Polarimetry

The most common use for a dual PEM system is to analyze the state of polarization of a light source. There are different ways to represent light polarization. One of these is to use Stokes vectors or parameters (I, Q, U, and V). Using the 1f and 2f signal from each of the modulators, a dual PEM system is able to provide all four of the Stokes parameters simultaneously. In this representation, $I=(I_X + I_Y)$ is the total light intensity. Q is known as the linear preference and is represented $Q=(I_X-I_Y)$. The 45° linear preference is known as U and is shown by $U = I_{45} - I_{45}$ The last component of the vector is $V = I_{rcp}$

TABLE 2: DUAL HEAD SPECIFICATIONS

MODEL	OPTICAL MATERIAL	NOMINAL 1F FREQUENCY	SPECTRAL RANGE	RANGE OF λ/4 RETARDATION[1]	USEFUL APERTURE[2]
II/ZS37-50	ZINC SELENIDE	37 & 50 kHz	550nm - 18μm	2μm - 18μm	14mm
II/FS20-23	FUSED SILICA	20 & 23 kHz	170nm - 2.6μm	170nm - 2μm	45mm
II/FS42-47	FUSED SILICA	42 & 47 kHz	170nm - 2.6μm	1.6μm - 2.6μm	23mm
I/FS50-60	FUSED SILICA	50 & 60 kHz	170nm - 2.6μm	170nm - 2μm	16mm
I/FS47-50	FUSED SILICA	47 & 50 kHz	170nm - 2.6μm	170nm - 2μm	16mm

[1] *$J_0 = 0$*
[2] *Aperture with ≥90% average efficiency (diameter), as per B. Wang "Useful Aperture" Hinds Instruments*

– I_{lcp}, meaning the right circular polarization preference. Any light polarization can be characterized by using these four parameters.

Astronomical Polarimetry

One of the first uses of the photoelastic modulator (PEM) was astronomical polarimetry. Dr. James Kemp, late Professor of Physics at the University of Oregon, used PEMs to study the polarization of light from nearby stars and features on the sun, such as sunspots. The four Stokes parameters (I, Q, U, V) give a complete description of the polarization state of an astronomical object. Dr. Kemp was able to measure degree of polarization down to 10^{-6}.

PEM-based polarimeters typically use a II/FS42-47 PEM system. Detection of the two linear components is made at $2f_1$ and $2f_2$ while the circular component is detected at $1f_1$ or $1f_2$.

Tokamak

Hinds Instruments manufactures a dual PEM system specifically designed for Motional Stark Effect (MSE) diagnostic polarimeters associated with tokamaks. Two octagonal optical element/transducer assemblies, one operating at 20 kHz and the other at 23 kHz, are mounted in a single optical head enclosure. The retardation axes of the two assemblies are at 45 degrees with respect to each other, as required for a PEM-based Stokes polarimeter.

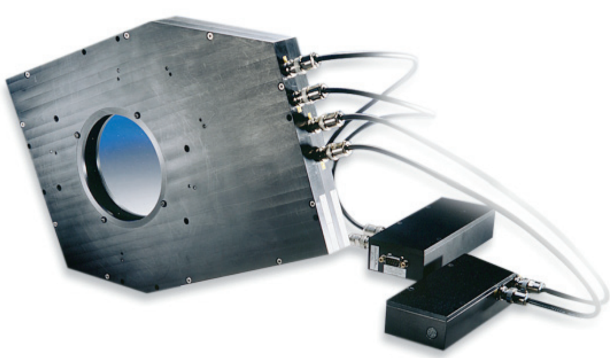

FIGURE 3. DUAL PEM MODEL II/FS20-23

Optical head enclosures are made either from aluminum or from a non-conductive plastic material (e.g. Delrin). This material eliminates eddy currents and strong forces occurring in conductive materials in rapidly changing strong magnetic fields. The head enclosure is made like a clam-shell, with one optical assembly mounted in each half. The two optical elements are separated by only 10 mm. This and the large aperture (100 mm) allow use of a wide range of sighting angles through the PEM optical head.

Dual PEM systems are in use in these tokamaks: TFTR in Princeton, NJ, DIII-D in San Diego, CA, JT-60 in Naka, Japan, JET Joint Undertaking in Abingdon, UK, the Institute for Plasma Research in Gandhinagar, India, and ASDEX Upgrade in Garching, Germany. For more information on this application, please see Hinds Instruments PEM Newsletter #11. A picture of this PEM system can be seen in Figure 3 .

Dual PEM systems provide the capability to make real time polarization analysis measurements. These systems are available in a wide variety of materials and configurations to support many diverse applications. A Hinds sales engineer or application scientist will be glad to explain in more detail any of these options. Please contact us with any questions or comments that you may have.

REFERENCES

1. Kemp, James C. Polarized Light and its Interaction witih Modulating Devices : A Methodology Review, Hinds International, Inc., January 1987.

2. Kliger, Lewis and Randall. Polarized Light in Optics and Spectroscopy, Academic Press, 1990.

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