SPECIAL OPTICS
MANUFACTURE AND DESIGN

TECHNICAL MEMORANDUM TM-8101

Optical Retardation Measurements with the Soleil-Babinet Compensator

1.0 Definition

The Soleil-Babinet Compensator is basically a zero order, crystal quartz waveplate with a variable retardation value. Conventional zero order waveplates (actually "first order" is the technically correct designation) such as the Special Optics 8-8015 Series consist of two quartz plane parallel plates with the optic axis of each plate oriented in the plane of the polished faces. Each plate is aligned optically in series with the optic axis of the second plate rotated 90° with the respect to that of the first.

The net optical path difference, Δ, between the ordinary and extraordinary rays is given by the expression:

$$\Delta = \pm (t_1 - t_2) (n_e - n_o)$$

where t_1 - geometrical thickness of Plate No. 1
t_2 - geometrical thickness of Plate No. 2
and $(n_e - n_o)$ = birefringence of natural quartz, a positive number since $n_e > n_o$

The phase difference in the two rays as they propagate with mutually orthogonal linear vibrations is $2\pi/\lambda$ times the net optical path difference Δ. Therefore, the phase retardation δ of the waveplate is

$$\delta = \pm \frac{2\pi\Delta}{\lambda} = \pm \frac{2\pi}{\lambda} (t_1 - t_2)(n_e - n_o)$$

As in the conventional zero order waveplate, the Soleil-Babinet Compensator has two plates, but one plate actually consists of two wedged elements. Since one of the wedges is translatable, it is possible to vary the thickness t_2. It is important to note that although variable, the selected thickness is uniform over the usable aperture of the device. The range of retardation values at a specific wavelength is determined by the range of variation in t_2.

2.0 Description

The Special Optics Model 8-400 Soleil-Babinet Compensator contains three natural quartz elements as described in section 1.0. One of the two wedged plates is mounted for precise translation normal to the opto-mechanical axis of the compensator.

By adjusting a digital micrometer head, the thickness of the wedge assembly is changed and the translation affecting the change is readable to an accuracy of .001 mm.

The Model 8-400 includes an indexing head with eight detent positions equally spaced at 45° for the rapid and precise adjustments required during calibration and operation. A drum dial and vernier with graduation in 1° increments over 0° - 360° provides added versatility. The Model 8-401 Soleil-Babinet Compensator does not include the calibrated indexing head and is recommended only when a sufficient divided circle mount has previously been purchased.

The usable aperture of both the 8-400 and 8-401 is 10 mm diameter. The natural quartz elements are polished to a low scatter laser grade finish and provide $\lambda/10$ single pass wavefront deformation measured at 632.8 nm. The usable spectral range of the compensator is, of course, limited to the spectral range of natural quartz where absorption is negligible for both e and o-ray. The range of retardation values for a specific wavelength is a function of the prism angle of the two wedged quartz plates and the range of translation. The 8-400 and 8-401 are designed to provide any retardation value from 0 to 2π (or 0 to 1 wave, depending on terminology) over the spectral range of 200-2700 nm.

3.0 Accuracy

The Model 8-400 Soleil-Babinet Compensator is capable of resolving the retardation of an unknown sample to within 0.6 nm which is one thousandth of a wavelength at the He-Ne laser line. It should be noted that such accuracy is dependent upon the operator's ability to calibrate the instrument properly by determining the null position at the 0 and 1 wave values. The null values of visible spectral sources can be determined quite accurately with the human eye. Although somewhat subjective, such an "eyeball" measurement is as good as that performed with most laboratory radiant energy detectors. For non-visible spectral sources, one must obviously rely on a detection system. Minimum leakage through the analyzer at the 0 and 1 wave retardation positions can only be obtained if the spectral bandwidth and beam divergence of the source are minimized as is the case for most commercially available gas and solid state lasers that emit within the acceptable spectral range of the compensator.

When utilized with a grating monochromator as the spectral source, the operator should employ an external lens system to decrease the beam divergence. Since one cannot readily decrease this divergence to a sufficient level, a sensitive detector is recommended for recording the minimum intensity positions. The "eyeball" technique is considered adequate only when the minimum intensity values are true nulls or dark fields.

The Model 8-400 and 8-401 compensators are generally sold without antireflection coatings to avoid the residual birefringence in thin film materials such as magnesium fluoride. In addition, all parts of the compensator package and indexing head are fabricated from non-magnetic materials to prevent residual birefringence due to Faraday or magneto-optic effects.

4.0 Initial Alignment Procedures

4.1 As previously described, the accuracy of the compensator is affected by the characteristics of the light source. The source should therefore emit well collimated, monochromatic light with a known linearly polarized output. If the source is not linearly polarized, a high quality calcite "clean up" polarizer should be utilized.

Position a second high quality polarizer leaving sufficient space for the test sample and compensator and cross this second polarizer or analyzer for complete extinction. Unless extinction of 10-5 is achieved, one should not proceed until more suitable polarizers are introduced.

4.3 Install the Soleil-Babinet Compensator between the polarizer (or polarized laser) and analyzer. Align the compensator so that the reflection from the quartz elements fall back upon the source. This is not a critical alignment but, once made, should not be changed. Any change in alignment will cause the 0λ and 1λ null readings to change.

4.4 Raise the knurled thumb screw and set the indexing head to the 0° position.

4.5 A knurled lock nut is located on the rear surface of the indexing head. Loosen this nut just enough to allow the compensator to rotate. Rotate the compensator until an extinction is reached which should be comparable to that obtained with nothing between the crossed polarizers. Tighten the lock nut so the position of the compensator is fixed with respect to the detent positions of the indexing head. This procedure has oriented the crystallographic axes of the quartz elements at 0° and 90° with respect to the incident light polarization vector.

If, by coincidence, the micrometer head is set near the 0 wave or 1 wave retardation value, there will be minimum light leakage through the analyzer for any rotated position. Such a condition will make it quite difficult for the operator to line up the crystallographic axis with sufficient accuracy. If such a condition exists, simply move the micrometer head 3 to 5 mm in either direction and repeat step 4.5.

4.6 Raise the knurled thumb nut and rotate the indexing head to either the plus or minus 45° mark. Some leakage through the analyzer will now be observed.

4.7 Adjust the micrometer head until the beam passing through the analyzer is extinguished. There will be two settings where such an extinction will occur corresponding to the 0 and 1 wave retardation values. The two micrometer readings where the null values are recorded will, of course, vary with the wavelength of the spectral source. If one is unable to obtain two null values within the range of the micrometer drive, rotate the indexing head through $\pm$ 90° and repeat the procedure. Such a condition may arise if one extinction point occurs at mid-range and the micrometer bottoms before the second null is reached. The compensator may also be tilted about the mounting post axis to change the effective optical path thickness. This technique will shift the micrometer positions at which the null values occur. Unfortunately, once the compensator is tilted about any axis of rotation other than the opto-mechanical axis, the alignment procedure must be repeated from step 4.4.

4.8 Lock all components and make no further adjustments with the exception of the micrometer head and indexing head detents.

5.0 Calibrating the Compensator

5.1 Set the micrometer near the lower limit of travel and then adjust until minimum leakage through the analyzer is obtained. The micrometer will most likely not be at zero when this null is obtained. Record this value.

5.2 Turn the micrometer to a higher value; the transmission through the analyzer will increase, reach a maximum and then decrease to a minimum (about the same extinction as at zero setting). Let us say that the <u>total</u> excursion of the micrometer screw from null to null is 15.124 mm This value corresponds to 1 full order of retardation at the operating wavelength. In other words, you have started with zero retardation at the first null, turned through 1/4, 1/2, 3/4, and then stopped at 1λ. Record the micrometer reading for this second null. The total excursion from null to null corresponds to one wavelength of retardation at that specific spectral line. When a different light source is introduced or whenever the polarizers or compensators (except for previously described allowable adjustments) are moved, it is necessary to repeat all steps of initial alignment and calibration.

6.0 Applications

The Soleil-Babinet Compensator is utilized to either introduce a known phase retardation or to compensate (hence the name) for the phase retardation introduced by the sample. Typical applications are listed as follows:

6.1 To introduce a known retardation to a beam of linearly polarized laser light.

6.2 To analyze a beam with regard to polarization properties.

6.3 To check the accuracy of fixed retardation plates.

6.4 To measure residual birefringence in optical windows and crystals.

6.5 To accurately determine the half wave retardation voltage of Pockels cells.

6.6 To measure birefringence in mineral specimens.

6.7 As a component of an ellipsometer to analyze polarization effects of reflection from surfaces.

6.8 To introduce an optical bias to modulated tunable laser beams.

7.0 Procedure to Introduce a Known Retardation

Once the compensator has been calibrated in accordance with the procedures of sections 4 and 5, any value of retardation can be introduced by adjusting the micrometer head. Remember that the crystallographic axes of the compensator elements are at $\pm 45°$ with respect to the linear polarization vector of the laser source.

Using the example of section 5, the total excursion of the micrometer head is 15.124 mm for one wave retardation at 632.8 nm. To introduce any fraction of a wavelength, multiply the desired fraction by 15.124. Add that value to the zero setting and adjust the micrometer head. For example, to introduce a 1/4 or 1/2 wave retardation, multiply 15.124 by 0.25 and add 3.781 mm to the 0 wave reading.

If the added 1/4 wave is left-handed and right handed was required, simply rotate the indexing head through 90° to effect such a change.

8.0 Determination of an Unknown Retardation

8.1 Insert the unknown component, say a waveplate, between the compensator and analyzer with the compensator set at its 0 wave setting.

8.2 Rotate the unknown about the propagation vector of the laser until transmission through the analyzer is a minimum. This procedure has now aligned the fast or slow axis of the sample waveplate with the laser's incident polarization vector.

8.3 Rotate the unknown sample exactly 45° which will result in transmission through the analyzer. Any calibrated rotary mount, such as angular deviation is noted in the beam reflected back toward the source from the surfaces of the unknown, it implies the unknown is not aligned perpendicular to the incident beam. Such an improper alignment will increase the geometrical thickness of the sample by the cosine of the tilt error. Any variation in the waveplate thickness will, of course, result in a corresponding change in retardation.

8.4 Adjust the compensator toward a higher micrometer setting until a null through the analyzer is obtained. Record this reading and subtract the zero null reading. This excursion, say 4.270 mm, divided by 15.124 mm or .282 is the fraction of a wavelength that was added to (or subtracted from depending on the handedness) the unknown to equal 0 or 1λ retardation at the specific wavelength.

8.5 As a double check, rotate the unknown exactly 90° in either direction. Repeat step 8.4. The new null micrometer setting should give an excursion toward the higher readings of 15.124 mm This number divided by 15.124 equals .718 waves. The result is anticipated because the sense of handedness of the retardation is reversed by a rotation of the sample through 90°.

9.0 References

Jerrard, H.G., "Optical Compensators for Measurements of Elliptical Polarization", JOSA Vol. 38, No. 1, Jan. 1948

Shurcliff, W.A., "Polarized Light", Harvard University Press, Cambridge, Mass. 1962

Driscol, W.G. and Vaughan, W., OSA Handbook of Optics, McGraw-Hill, 1978

Special Optics Bulletin 101-1, "Optical Retardation Plates"
Special Optics Bulletin 101-2, "Laser Polarizers"