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TILT BIAS ANGLE MEASUREMENT WITH IMPROVED SENSITIVITY

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Abstract: The tilt angle, strongly influencing the static as well as the dynamic behaviour of liquid crystal devices often causes problems in time and precision during its measurement. This paper presents a fast and accurate method, based on the magnetic null principle with optical detection. Improved sensitivity of detection of changes in optical transmission ensures reliable measurement of small tilt angles even in thin films of liquid crystals. Theoretical background of the method, details of the mechanical construction and experimental data are reported.

GENERAL : The measurement of the tilt-bias-angle of liquid crystal devices is normally performed by means of optical interference /1,2,6/ as well as by detecting changes of the director configuration induced by external fields; these changes are monitored by capacitive or optical analysis. Detailed discussion of a variety of methods are given by Scheffer and Nehring /3/ and by Toriyama and Suzuki /4/.

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The magnetic null-method, proposed by Scheffer and Nehring /3/, offers direct reading of the tilt-bias angle without knowledge of any material parameters. This technique ensures a small area of measurement and the director pattern itself is not distorted by an electric field as happens during capacitance analysis. However the applicability of this method is drastically reduced as the sensitivity falls to zero if the tilt-bias angle is close to zero or ninety degrees, which is due to the fact, that the laser beam is fixed to a position parallel or perpendicular to the magnetic field. A change of the measurement-device from the perpendicular to the parallel configuration requires holes in the pole pieces of the magnet, an additional glass plate for beam correction and accurate adjustment. For thin layers of liquid crystals (less than 10 microns) and the tilt-bias angle close to zero or ninety degrees the shape of the curve of transmission versus angle of incidence turns broad and shallow (Figure 1) and thus changes in transmission caused by the external field are hardly detectable and the inaccuracy of the measurement increases. Introduction of a variable compensator reduces these basic difficulties but renders the measurement-procedure more time consuming.

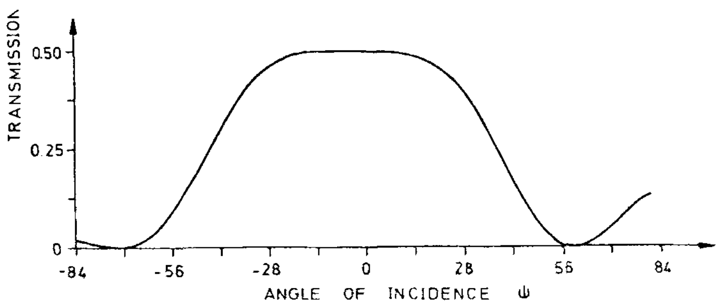

FIGURE 1: Transmission vs. angle of incidence, planar texture, α_0=1 degree, d=12.2 microns, no=1.50, ne=1.63

The transmission of light through a non-twisted liquid crystal layer of thickness d, placed between crossed polarizers and oriented with its principal plane at 45 degrees to the plane of polarization, with arbitrary tilt-bias angle α is given by/7/:

$$T(\psi,\alpha) = \frac{1}{2} \sin^2\{\frac{1}{2} \delta(\psi)\}$$

$$\delta(\psi,\alpha) = 2\pi\frac{d}{\lambda} \{\frac{1}{c^2} (a^2-b^2) \sin\alpha\cdot\cos\alpha\cdot\sin\psi + \frac{1}{c}\sqrt{1-\frac{a^2b^2}{c^2}\sin^2\psi} - \frac{1}{b}\sqrt{1-b^2\sin^2\psi}\} \quad (1)$$

$$a = \frac{1}{ne}, \quad b = \frac{1}{no}, \quad c^2 = a^2\cos^2\alpha + b^2\sin^2\alpha$$

with:
- α : tilt-bias angle
- ψ : angle of incidence
- d : thickness of l.c. layer
- λ : wavelength of transmitted light
- ne: extraorinary refractive index
- no: ordinary refractive index

The principle of the magnetic null-method consists in finding that position where the director and its related physical properties (such as capacitance or optical transmission) are independent of changes of the external field.($\vec{Lo} \parallel \vec{H}$, null-position) Approaching this null-position the decreasing of the field-induced changes in transmission makes their detection quite difficult. The sensitivity of changes in transmission caused by small rotations of the director is given by:

$$\chi(\psi,\alpha_o) = \frac{\Delta T}{\Delta\alpha} = \frac{T_o(\psi,\alpha_o) - T_1(\psi,\alpha_o+\Delta\alpha)}{\Delta\alpha} \quad (2)$$

with:
- T0 :transmission without magnetic field
- Tl : transmission with magnetic field applied
- ne : extraordinary refractive index
- no : ordinary refractive index
- d : thickness of the l.c. layer
- λ : wavelength of transmitted light

The increase of sensitivity in the range around the null-position which is necessary for its accurate determination is achieved by variation of the angle of incidence which remains the only arbitrary parameter.

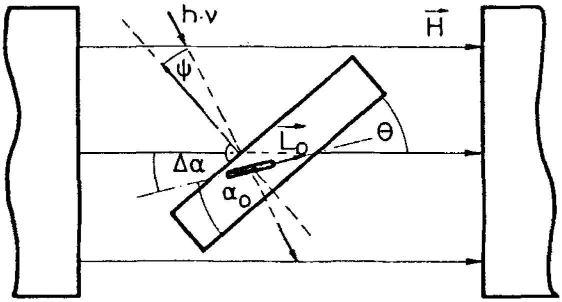

FIGURE 2: Definition of geometry: $\Theta = \alpha_0 + \Delta\alpha$

Figure 3 shows the sensitivity as a function of the angle of incidence; it is obvious that the sesitivity exhibits several local maxima apart from the zero position. These values of the angle of incidence, if kept constant during the measurement, ensure an improved sensitivity for accurately detecting the null position.

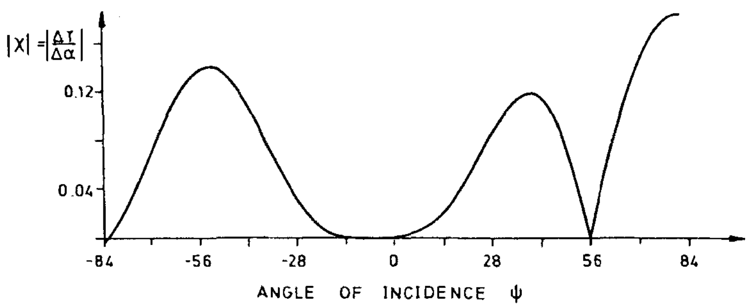

FIGURE 3: Sensitivity $|\chi(\psi)| = \frac{\Delta I}{\Delta\alpha}$, $\alpha_0 = 1^\circ$, $\Delta\alpha = 1^\circ$, $d = 12.2\ \mu$
ne = 1.63, no=1.50

Figure 4 shows the plot of the sensitivity as a function of the angle of incidence with the tilt angle as parameter. Whilst in the case of $\alpha_0 = 0^\circ$ there is always a certain amount of sensitivity in the range of $0^\circ < \psi < 40^\circ$, with increasing tilt-bias angle one has to take care not to choose an angle of the incident beam where the "oscillating" sensitivity equals zero.

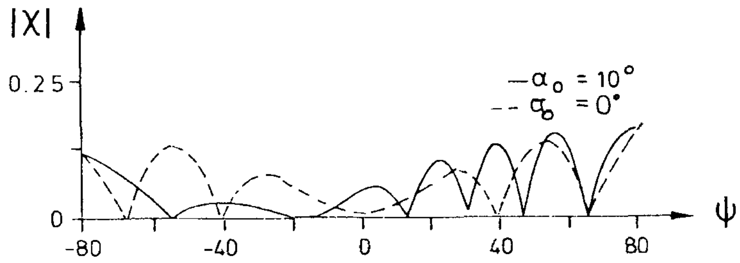

FIGURE 4: Sensitivity $|\chi(\psi)|$, $\alpha_0=0°$, $\alpha_0=10°$, $\Delta\alpha=0.1°$, d=20 μ

The influence of the field induced deformation on the shape of the curve of sensitivity is shown in figure 5.
The angle $\Delta\alpha$ corresponds to the declination of the liquid-crystal molecules effected by the magnetic field. A variation of this declination over two orders causes only a small change in the amount of sensitivity. This is the initial condition for determination of the null-position with adequate accuracy.

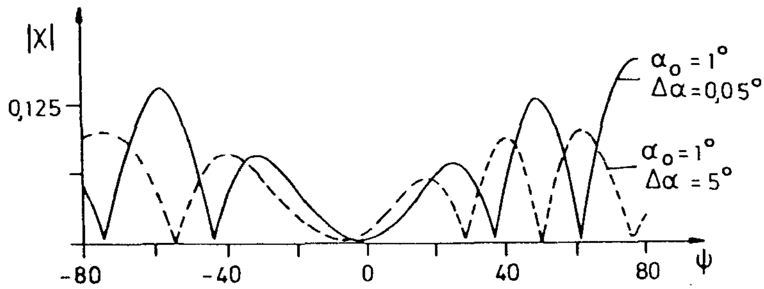

FIGURE 5: Sensitivity $|\chi(\psi)|$, $\Delta\alpha$ =0.05°,5.0°, α_0 =1°, d=20.0 μ

MECHANICAL REALISATION : The light emitting diode and the photo detector are mounted at fixed positions to each other (detector unit) with the possibility of common rotation around the cell to be measured. This provides adjustment of the angle of incidence to an appropriate value of sensitivity. This position then remains fixed and the detection unit together with the cell can be rotated in the magnetic field in order to find the null-position. As light source a FLV 104A light emitting diode with a half- aperture angle of 2 degrees was chosen. Further reduction of the measured spot may be achieved by introducing suitable stops.

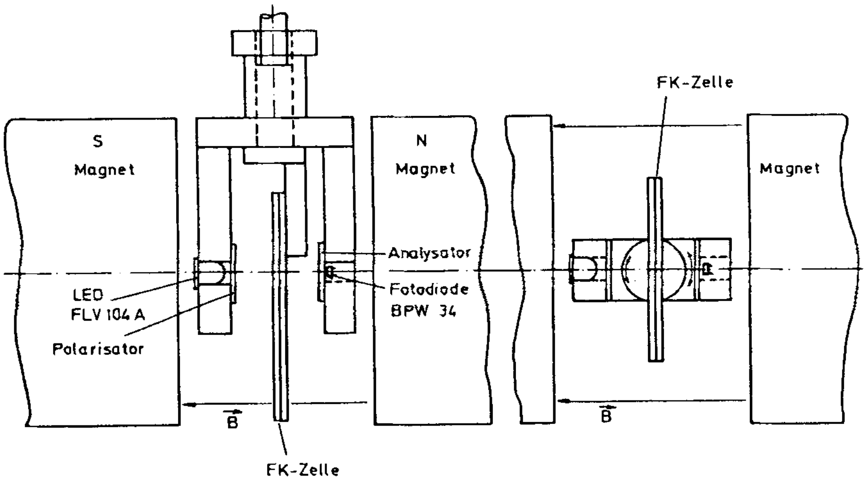

FIGURE 6: Top and side view of the detector unit

The measurement is performed between crossed polarizers with the principal plane at 45 degrees to the director. To take advantage of the improved sensitivity it was necessary to use an incremental angle decoder with a resolution of 0.05 degrees.

PROCEDURE OF MEASUREMENT:

Step 1 : Mounting of the cell to be measured and adjustment of 45 degrees azimuth.

Step 2 : Adjustment of the starting position: the angle between the magnetic field and the surface of the cell should be 0 degrees for planar textures and 90 degrees for homeotropic textures.

Step 3 : Recording of transmission curve $T(\psi)$ with no magnetic field applied for coarse estimation of the tilt-bias angle (symmetry considerations)

Step 4 : Positioning of the cell close to the null-position in order to obtain a field induced director deviation of constant value $\Delta\alpha$.

Step 5 : Variation of the angle of incidence ψ by rotating the detector unit relative to the cell in order to find the null-position of maximum difference of transmission $\Delta T(\psi)$ between the field on and off state.

Step 6 : Rotation of the cell together with fixed detector unit in the magnetic field and search for that position where there is no difference between the field on and off state. The angle between the field direction and the cell surface then equals the tilt-bias angle.

The amount of time needed for one measurement procedure can be drastically reduced by approximating the curve of sensitivity (to be measured in Step 4&5) by the derivative of the transmission with respect to the angle of incidence (as measured in Step 3).

EXPERIMENTAL RESULTS:

We have applied this technique to measure the tilt-bias angle of a PCH-BCH liquid-crystal mixture (product ZLI 1132 by Merck) aligned by a layer of polyimide.
The appropriate angle of incidence ψ_0 , was determined according to step 5 of the measuring routine. Figure 7 shows the curve of the field induced changes in transmission as a function of the angle of incidence; the maxima were found to be at 22.5 and 25 degrees respectivly.

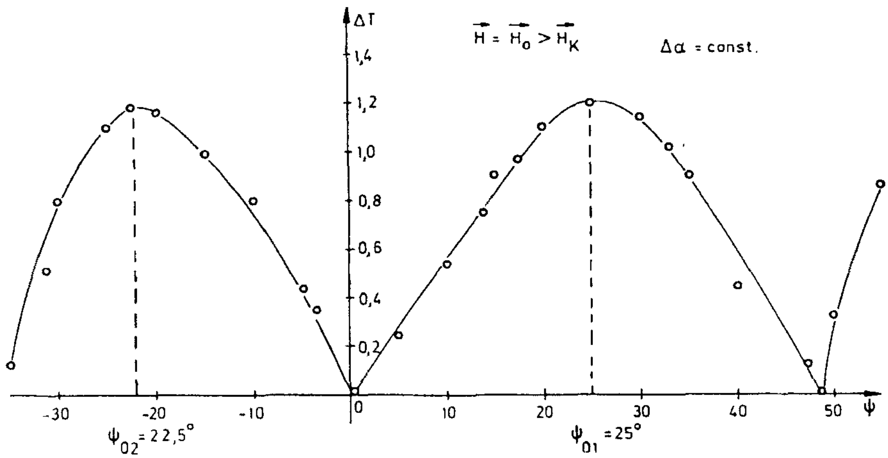

FIGURE 7: Transmission $\Delta T(\psi)$, $\Delta\alpha$ = constant

To point out the advantages of this modified method we compared it to the measurement with the laser beam fixed perpendicular to the magnetic field.

Figure 8 illustrates these difference: it shows the changes in transmission for both conditions of measurement. Curve A (for fixed laser position) exhibits no field induced changes of transmission in a considerable range around the null-position and thus disables an accurate determination of the tilt-bias angle

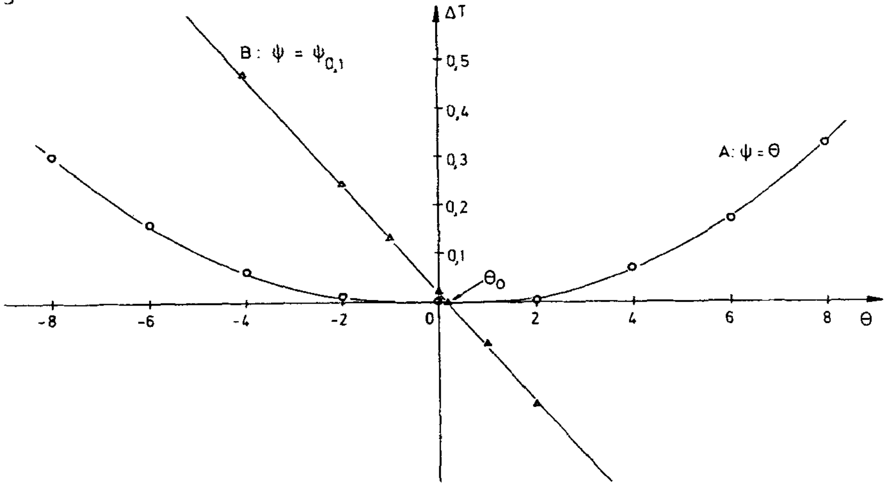

FIGURE 8: Changes in transmission ΔT (Θ)
curve A: $\psi = \Theta$ curve B: $\psi = \psi_{01}$ = const.

Curve B (modified method) shows a linear shape thus enabling linear interpolation and it intersects the Θ -axis at the value of the tilt-bias angle α_0, which in this case was determined to be 0.35 ± 0.05 degrees.

CONCLUSION:

The main advantages of our modified method are:

- improved sensitivity especially in the case of thin layers of liquid-crystals and small tilt-bias angles as induced by polymer films.
- applicability for both quasi-planar and quasi- homeotropic textures
- measurement procedure is simple and fast
- small size of the spot being measured raises possibilities for evaluating tilt-bias angle profile over the cell surface.

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