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Influence of cell and LC parameters on the dynamics of STN liquid crystal displays

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The dynamics of super-twisted nematic (STN) liquid crystal displays have rarely been studied. In this article, the dynamic response of STN is analysed in detail. The evolution of director configuration with time was obtained by solving Ericksen–Leslie hydrodynamic equations. The time varying midlayer tilt angle is presented as a measure of dynamic response. The influence on STN dynamics of cell parameters including pretilt angle, twist angle, cell thickness, and of material parameters including *d*/*p*, K_{22}, K_{33}, were studied.

1. Introduction

Schadt and Helfrich reported twisted nematic (TN) liquid crystal displays (LCDs) in 1971 [1]. They soon found applications in watches and calculators as low information content LCDs. TN displays are not suitable for high information content displays, their contrast ratio is low and the viewing angle narrow when driven at a high multiplexing ratio. In 1985 Scheffer and Nehring, and Waters *et al.* demonstrated the first prototype super-twisted nematic (STN) displays [2, 3]. STN displays have a steep electro-optical response, and can be used for high information displays; their viewing angle and contrast ratio are much improved compared with TN LCDs. STN displays are now used in mobile telephones, personal digital assistance (PDA) and word processors. The response speed of STN LCDs is low, and unsuitable for video application. In industry, a twist angle of 240° is most commonly used for super-twisted liquid crystal display devices.

The static electro-optical response of STN LCDs has been closely studied, but their dynamic behavior is seldom investigated. In the dynamic behaviour of LCDs, the flow of liquid crystal could have an important effect in certain circumstances. For example, the well known optical bounce phenomenon of the TN LCD, which occurs after switching off a high applied voltage, is caused by the backflow effect [4, 5].

In a previous study, the transient director configuration and velocity profile of an STN were given [6]. In this paper, we report a computer simulation study of STN dynamics; 'on' and 'off' voltages are obtained in accordance with the Alt and Pleshko technique. The influence of cell parameters including pretilt angle, twist angle, cell thickness, and of material parameters including *d*/*p*, K_{33} and K_{22} are examined. The transient properties of STN cells are obtained by solving the ericksen–Leslie hydrodynamic equations [7, 8].

2. Description of method

The Ericksen–Leslie hydrodynamic equations are

$$\partial_t(\rho v_i)+\partial_j\left(\rho v_i v_j+p\delta_{i,j}-\sigma^{\mathrm{d}}_{ji}-\sigma^{\mathrm{f}}_{ji}-\sigma'_{ji}\right)=0 \quad (1)$$

$$I\mathrm{d}^2 n_i/\mathrm{d}t^2=\mathbf{h}_i+\mathbf{h}'_i+\gamma n_i \quad (2)$$

where i and j denote x, y, or z components, ρ is the fluid density, v is the fluid velocity, p is the hydrostatic pressure, σ^{d} is the stress tensor from elastic distortion, σ^{f} is the stress tensor induced by electric and magnetic fields, σ' is the viscous stress tensor, $\mathbf{h}$ is the molecular field from elastic free energy, $\mathbf{h}'$ is the viscous molecular field, I is the rotational inertial density of the fluid, γ is a Lagrangian mutiplier and n is the unit vector of liquid crystal director. In this work, the problem is limited to the one-dimensional case, and all the variables depend on z and t. The boundary conditions are those at the substrates, the velocity components vanish and the director is fixed and time-independent. The explicit expressions for the various quantities can be found in the continuum theory of Ericksen and Leslie [7, 8].

To simulate the dynamics behaviour of STN displays, we solved the equation of Ericksen–Leslie hydrodynamic equation and then obtained the transient director distribution. The inertial terms in the equation were neglected in the simulation because their influence

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is very small in comparison with the viscous term. Since there are very few measurements of all the viscosity coefficients, here we use the five Leslie viscosity constants for MBBA [5, 9]. $\alpha_1=0.0359$, $\alpha_2=-0.4283$, $\alpha_3=-0.0066$, $\alpha_4=0.4598$, $\alpha_5=0.2559\,\mathrm{g\,cm^{-1}\,s^{-1}}$; $\alpha_6=\alpha_2+\alpha_3+\alpha_5$ (Onsager's relation).

The STN displays are addressed using root-mean-square (rms) voltage alt and Pleshko techniques [10].

The selection and non-selection voltages are

$$V_s^2=(1/N)V_o^2+[(N-1)/N](1/b)^2V_0^2 \quad (3)$$

$$V_{ns}^2=(1/N)[(b-2)/b]^2V_o^2+[(N-1)/N](1/b)^2V_o^2 \quad (4)$$

where V_o is the operating voltage, b is the bias and N is the number of rows of electrodes.

The maximum ratio of V_s and V_{ns} is obtained when $b=\sqrt{N}+1$.

$$a_{max}=\frac{V_s}{V_{ns}}=\left[\frac{(\sqrt{N}+1)}{(\sqrt{N}-1)}\right]^{\frac{1}{2}}. \quad (5)$$

Breddels and van Sprang [11] derived an expression for a reduced characteristic voltage $V_=$ where the mid-layer tilt angle becomes identical with the pretilt angle θ_o.

$$V_==\frac{U_=}{U_0}=\left(\left\{\left[2\left(\frac{K_{33}}{K_{11}}-\frac{K_{22}}{K_{11}}\right)\cos 2\theta_0-\frac{K_{33}}{K_{11}}\right]\frac{\phi}{\pi}+4\frac{K_{22}}{K_{11}}\frac{d}{p}\right\}\frac{\phi}{\pi}\right)^{\frac{1}{2}} \quad (6)$$

$$U_o=\pi\left(\frac{K_{11}}{\varepsilon_0\Delta\varepsilon}\right)^{\frac{1}{2}} \quad (7)$$

where K_{11}, K_{22} and K_{33} are the splay, twist and bend elastic constants, respectively, $\Delta\varepsilon$ is the dielectric constant anisotropy ($\Delta\varepsilon=\varepsilon_\parallel-\varepsilon_\perp$), ϕ is the twist angle, θ_o is the pretilt angle, d is the cell thickness and p is the intrinsic pitch of the liquid crystal. $U_=$ is the actual voltage where the midlayer tilt angle becomes identical with the pretilt angle θ_o.

The $V_=$ can be adopted as the non-selection voltage V_{ns}; the operating voltage V_o and the selection voltage V_s can then be calculated. The STN liquid crystal display is switched between V_{ns} and V_s. For convenience, 'switching on' means STN switched from V_{ns} to V_s; 'switching off' means STN switched from V_s to V_{ns}.

3. Results

An STN device having a twist angle of 240°, pretilt angle 5°, cell gap $d=6.0\,\mu m$, $K_{11}=1.24\times10^{-6}$ dyn, $K_{22}=0.6\times10^{-6}$ dyn, $K_{33}=1.71\times10^{-6}$ dyn, $\varepsilon_\parallel=13.8$ and $\varepsilon_\perp=6.6$ is assumed. These cell and material parameter values are used unless stated specifically otherwise. The liquid crystal layer has a left-handed twist, the multiplicity of the STN is 32.

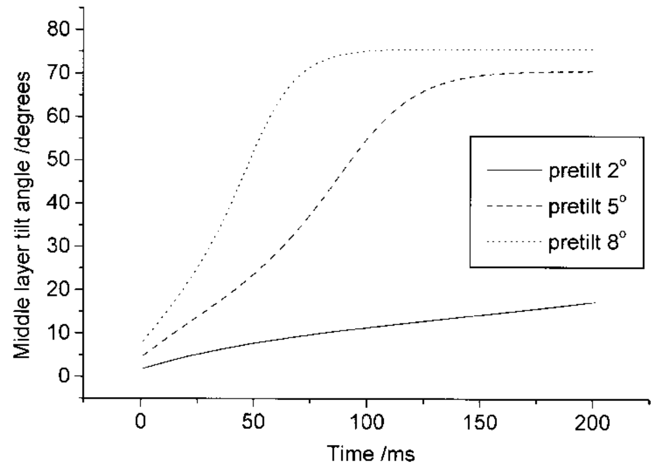

Figure 1. Variation of middle layer tilt angle with time for different pretilt angles upon switching on.

According to equation (6), $U_==2.01$ V, so V_{ns} is equal to 2.01 V. The V_s can be calculated by using equation (5); $V_s=2.38$.

Figure 1 shows the middle layer tilt angle for different pretilt angles as a function of time after switching on. Figure 2 shows the middle layer tilt angle for different pretilt angle as a function of time after switching off. It is reasonable to use the time-varying middle layer tilt angle as a measure of the dynamic response of the STN cells. The rise time T_r is defined as the time required to reach 90% of the maximum middle layer tilt angle. The fall time T_f is defined as the time required to reach the point where the middle layer tilt is 10% above its minimum. From figure 1, the rise time T_r shortens as the pretilt angle increases. From figure 2, the fall

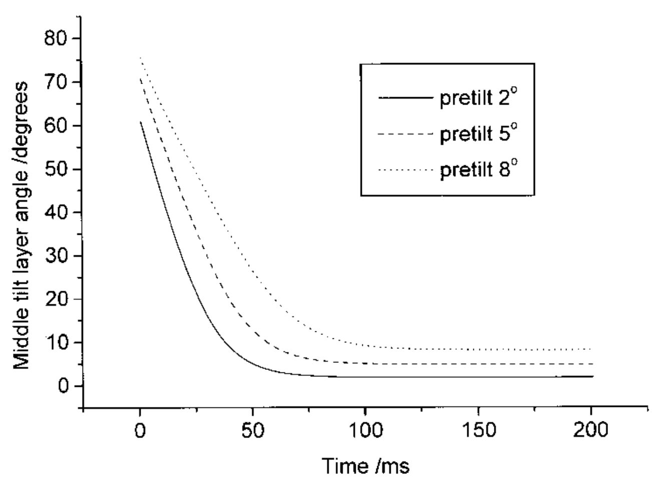

Figure 2. Variation of middle layer tilt angle with time for different pretilt angles upon switching off.

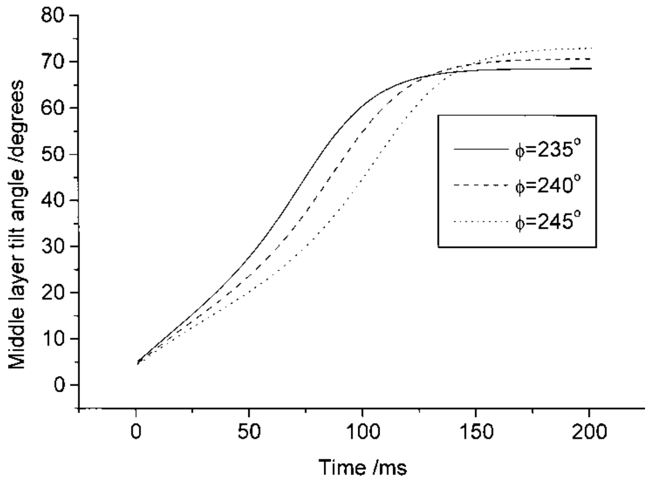

Figure 3. Variation of middle layer tilt angle with time for different twist angles upon switching on.

time T_f increases as the pretilt angle increases. It is interesting that a small pretilt angle greatly increases the rise time. In fact an STN device with a twist angle of 2° needs more than 500 ms to reach an equilibrium state.

To study the effect of twist angle on the dynamic response of STN devices, three STN devices were considered with twist angles of 235°, 240° and 245°. Figure 3 shows the middle layer tilt angle for different twist angles as a function of time after switching on. Figure 4 shows the middle layer tilt angle for different twist angles as a function of time after switching off. From figure 3, the rise time T_r increases as the twist angle increases. From figure 4, the fall time T_f changes very little as the twist angle increases.

For an STN device having twist angle 240° and pretilt angle 5°, the effect of cell thickness was studied

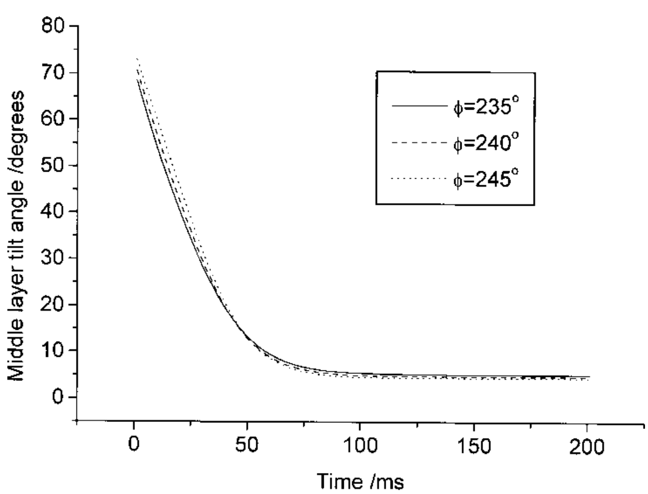

Figure 4. Variation of middle layer tilt angle with time for different twist angles upon switching off.

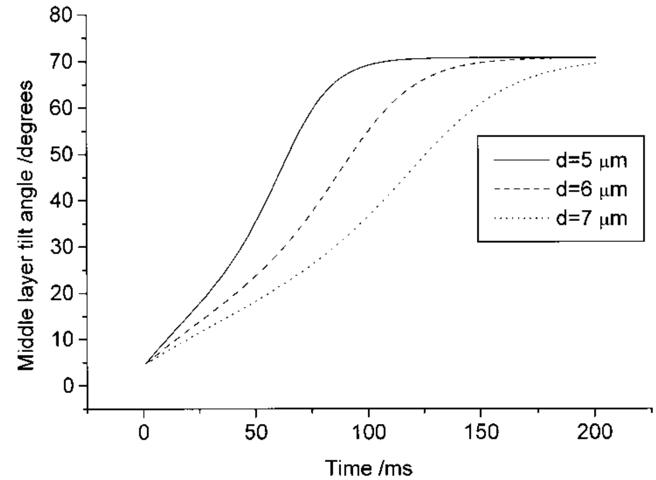

Figure 5. Variation of middle layer tilt angle with time for different gaps upon switching on.

for different cell gaps. Figure 5 shows the middle layer tilt angle for different cell gaps as a function of time after switching on. Figure 6 shows the middle layer tilt angle for different cell gaps as a function of time after switching off. As cell thickness increases, the rise time T_r and the fall time T_f increase greatly.

Figure 7 shows the middle layer tilt angle for different *d*/*p* values as a function of time after switching on. Figure 8 shows the middle layer tilt angle for different *d*/*p* values as a function of time after switching off. From figure 7, the rise time T_r increases as the *d*/*p* value increases. From figure 8, the fall time T_f decreases as the *d*/*p* value increases.

To study the effect of K_{22} on the dynamic response of STN devices, a STN device having twist angle 240°, pretilt angle 5°, and *d*/*p* value 0.55 was considered. The

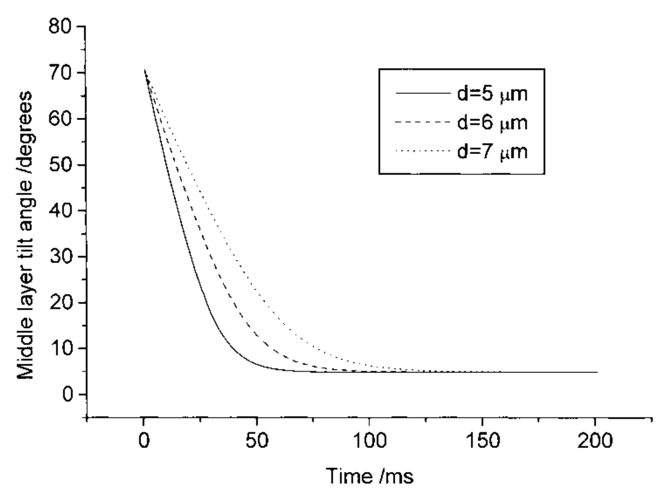

Figure 6. Variation of middle layer tilt angle with time for different gaps upon switching off.

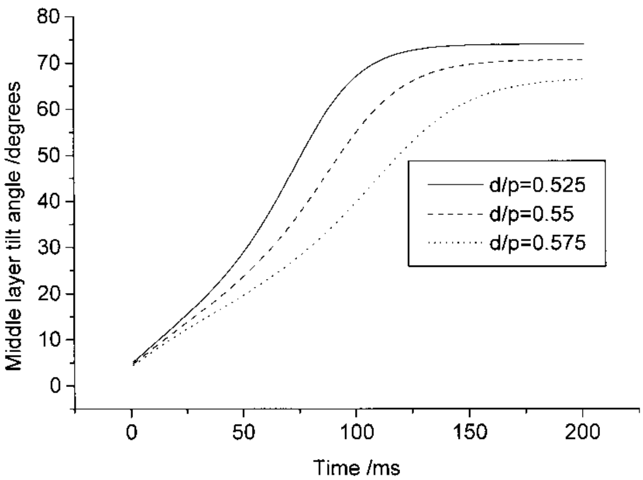

Figure 7. Variation of middle layer tilt angle with time for different *d*/*p* values upon switching on.

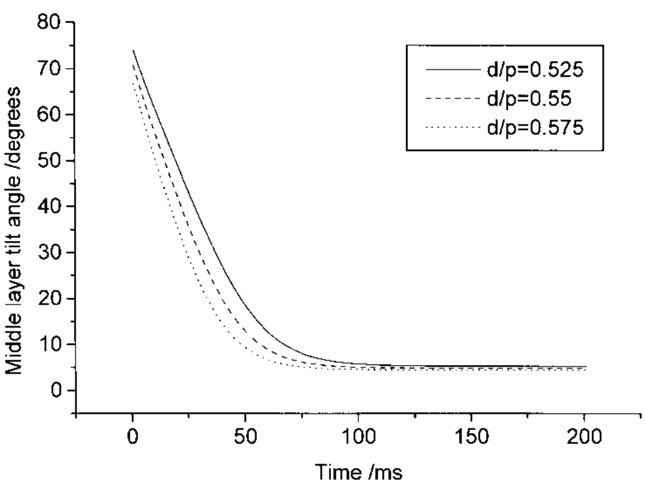

Figure 8. Variation of middle layer tilt angle with time for different *d*/*p* values upon switching off.

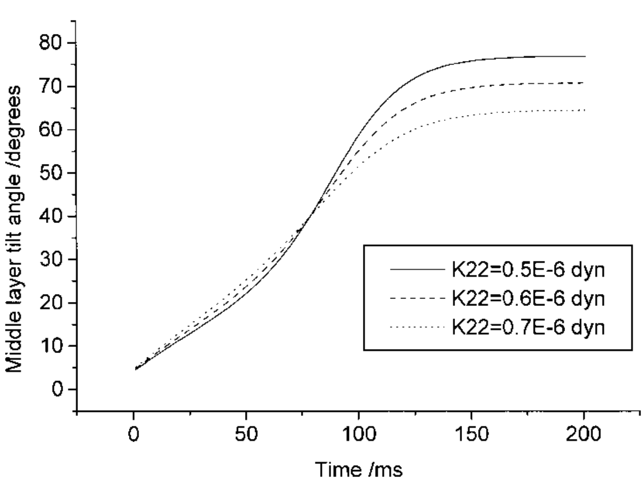

Figure 9. Variation of middle layer tilt angle with time for different K_{22} values upon switching on.

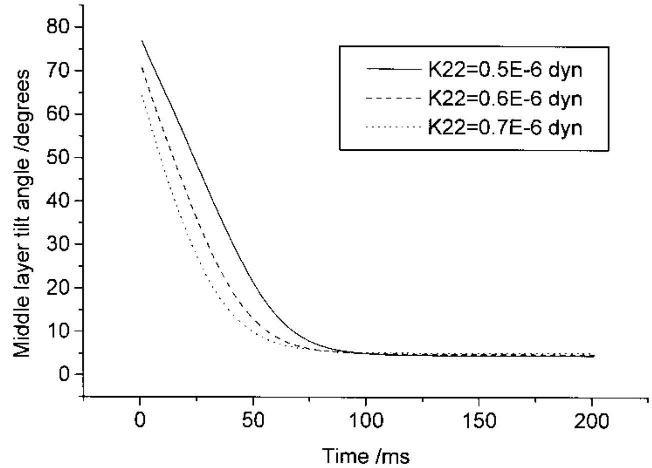

Figure 10. Variation of middle layer tilt angle with time for different K_{22} values upon switching off.

influence of K_{22} on the dynamic response was studied. Figure 9 shows the middle layer tilt angle for different K_{22} as a function of time after switching on. Figure 10 shows the middle layer tilt angle for different K_{22} as a function of time after switching off. From figure 9, as K_{22} increases, the rise time T_r decreases; from figure 10, as K_{22} increases, the fall time decreases.

Using the same STN device, by changing value of K_{33}, Its influence on the dynamic response of the STN is studied. Figure 11 shows the middle layer tilt angle for different K_{33} as a function of time after switching on. Figure 12 shows the middle layer tilt angle for different K_{33} as a function of time after switching off. From figure 11, as K_{33} increases, the rise time T_r increases; from figure 12, as K_{33} increases, the fall time T_f decreases.

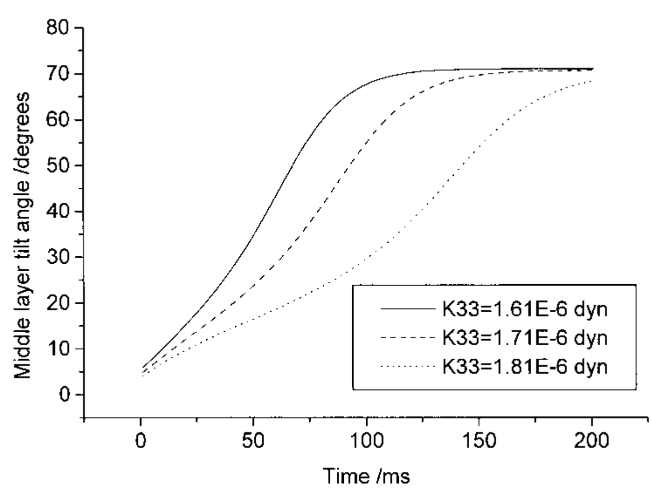

Figure 11. Variation of middle layer tilt angle with time for different K_{33} values upon switching on.

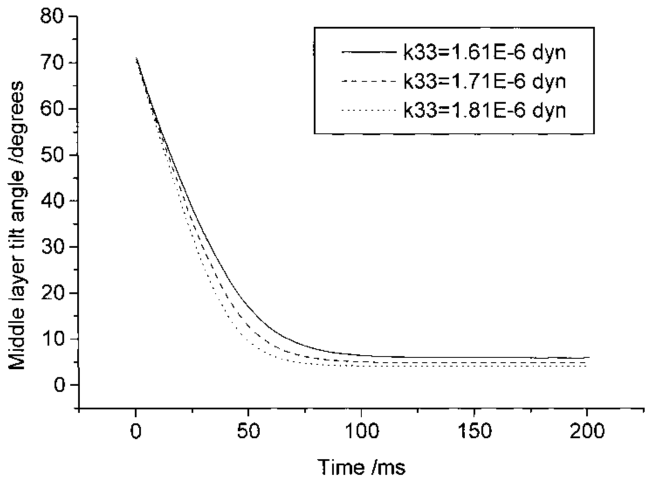

Figure 12. Variation of middle layer tilt angle with time for different K_{33} values upon switching off.

4. Conclusions

We have investigated the dynamics of STN cells by solving the Eriksen–Leslie hydrodynamic equations. The effects of pretilt angle, twist angle, cell thickness, and material parameters including *d*/*p*, K_{22} and K_{33} on the dynamic response were investigated. The variation of middle layer tilt angle with time was used to measure the dynamic response of STN cells.

Generally, pretilt angle, cell thickness, *d*/*p*, and K_{33} have a significant influence on both the rise time and fall time. The twist angle mainly affects the rise time; K_{22} has an obvious influence on the fall time. The effects of *d*/*p* value, pretilt angle and K_{33} on the dynamic response are interesting; the response time shows a reverse trend for the voltage switched on or off, as *d*/*p*, pretilt angle, or K_{33} increases. Increasing cell thickness increases both rise time and fall time.

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