## 2. Theory

Under the action of an alternating electric field generated by a high-frequency signal source (frequency about 10 MHz), the piezoelectric ceramic sheet (PZT) undergoes periodic compression and elongation vibrations. Its propagation in the liquid forms an ultrasonic wave. The sound pressure causes the local part of the liquid periodically expanded and compressed, which makes the density of the liquid form a periodic distribution in the wave propagation direction. The refractive index is also distributed in the same way, forming the so-called sparse and dense waves.

If a parallel light beam passes through the liquid perpendicular to the direction of ultrasound propagation at this time, the light beam will be diffracted. The structure of the density distribution formed by the ultrasonic field is moving forward in the liquid with a style of a travelling wave. In order to make the experimental conditions easy to realize and the diffraction phenomenon easy to be stably observed, in this experiment, a stable standing wave is formed in a liquid tank with limited dimensions. The amplitude of the standing wave can reach twice that of the travelling wave.

After a standing wave is formed, at a certain time *t*, the particles on both sides of a node of the standing wave squeeze to the node that makes the vicinity of the node a dense particle region. After half a period, $t + T / 2$, the particles on both sides of this node again disperse to the left and right that makes the vicinity of this node a sparse particle region. Figure 1 shows the changes in amplitude *y*, liquid density distribution, and refractive index *n* at *t* and $t + T / 2$ (*T* is the ultrasonic vibration period) of the ultrasonic wave.

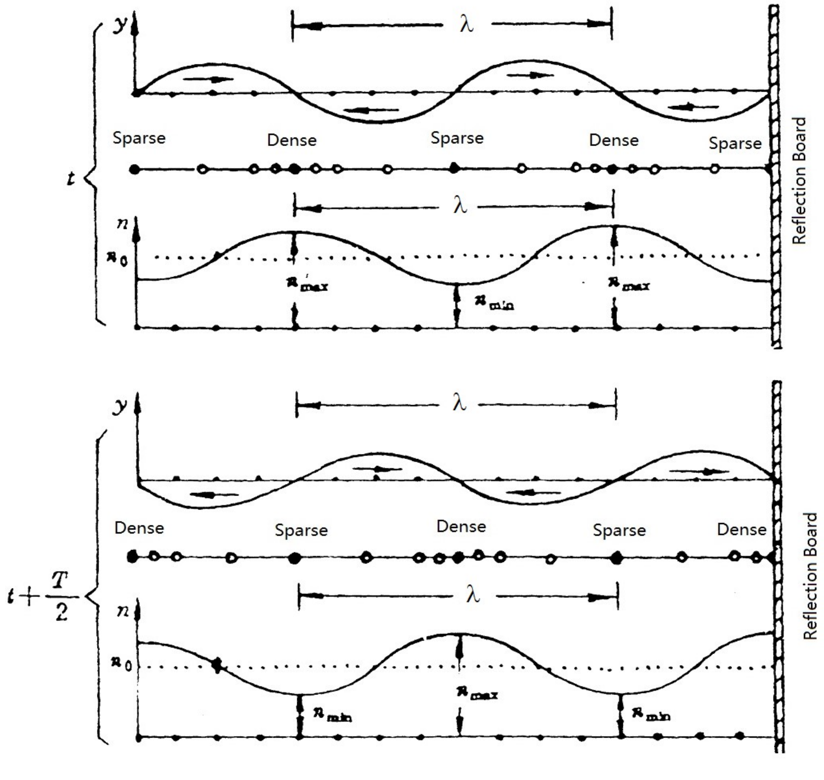

Figure 1 Formation of the ultrasonic grating

From Figure 1, it can be seen that the nature of the ultrasonic grating is that at a certain time $t$, the distance between two adjacent dense regions is $d$, which is the wavelength of the travelling wave propagating in the liquid, and after half a period, $t + T / 2$, the position of all such areas drift by a distance of $d /2$, and at other times, the wave phenomenon disappears completely.

The structure formed by the ultrasonic wave is not visually observable. When a light beam passes through the ultrasonic field, the observed results are dark stripes seen at the nodes (opaque) and bright stripes seen at the antinodes (transparent). The pitch of the bright and dark stripes is half of the wavelength of the sound wave, which is $d / 2$. When a parallel light beam of wavelength $\lambda$ passes through the ultrasonic grating, the positions of the light diffraction orders are determined by the grating equation.

$$d \sin \phi_k = k\lambda \quad (K = 0, 1, 2, ...). \tag{1}$$

The optical path diagram is shown in Figure 2.

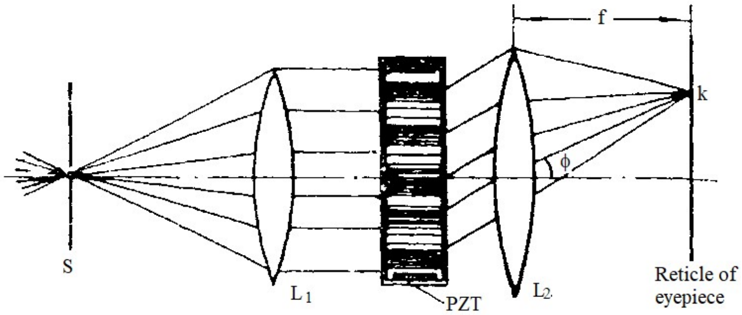

Figure 2 Schematic of experimental optical path of ultrasonic grating diffraction

Since the angle $\phi$ is very small, it can be approximated as:

$$\sin \phi_k = l_k / f \ , \tag{2}$$

where is the distance from the diffraction *zero*th order to the *k*th order, and *f* is the focal length of the lens $L_2$. So the wavelength $d$ of the ultrasonic wave is:

$$d = k\lambda / \sin \phi_k = k\lambda f / l_k \ . \tag{3}$$

Ultrasonic wave propagation speed in liquid is:

$$V=d\upsilon, \tag{4}$$

where $\upsilon$ is the frequency of the ultrasonic signal source.