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OPTICAL MEASURING CONVERTER OF LIQUID LEVEL

Analysis of the basic optical methods of measuring the liquid level is conducted. A new optical measuring transducer of liquid level, the sensitive elements of which are made from the dielectric with the negative index of refraction, has been proposed.

Key words: *optical method, level, measuring converter of liquid level, waveguide, negative index of refraction, sensetive element, spectrum.*

Introduction. The level of liquid measuring is an actual problem of environment condition control. Choosing of device of the liquid level measuring depends foremost on its characteristics, terms of storage and characteristics of the environment.

Prior information sources analysis. In the conditions of high–pressure, low or high temperature, explosive or fire risk working environment the most widespread methods of measuring liquid level are mechanical, electromechanical methods on the basis of measuring resistance at direct and alternative current, thermal method, ultrasonic etc. But these methods need application of additional efforts to provide normal operation of devices in specific terms that make them more expensive. Therefore for measurement of liquid level with a stationary surface optical methods are utilized.

Non–invasive optical methods are based on the reflection of light from the surface of liquid. For example, known optical liquid level measuring device in vessels , which contains a gauge bar, connected by the bottom end to the float for raising or lowering with the liquid level [1]. Contact optical methods are based on light propagation across optical waveguide which is immersed in the liquid. For example, liquid content gauge based on pulse method of particles selection while flight [2].

The drawback of non–invasive methods is high error of measuring, and contact methods disadvantage is narrow band of the measured value, which is limited by the length of sensitive element.

The goal of the work – is the development of liquid content gauge of high accuracy and sensitiveness with the expanded range of measurements in difficult specific conditions .

Materials and results of investigations. For the solution of the given task it is necessary to formulate the characteristics of sensitive element which would satisfy the following conditions:

1) sensitive element of L length is a dielectric, which has a refractive index n_1 and a cladding with a refractive index n_2;

2) sensitive element is partly immersed in liquid with a refractive index n3 , at the distance h ; aboveliquid there is gaseous medium with refractive index $n_3^/$;

3) optical radiation of P_0^* power is supplied to the end face of sensitive element, initial power P^* is registered on the opposite end of sensitive element.

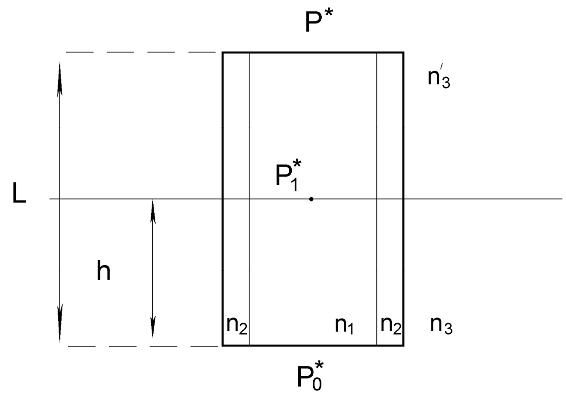

Fig. 1. The structure of a sensitive element detector

This structure of sensitive element is already known, since it was published earlier. [3]. But the difference of the offered device is that the core of waveguide is made of material which has a negative refractive index. Specific characteristics of materials with negative refractive index are: negative refraction, simultaneously negative electricand magnetic permeabilities, antiparallelism of cluster and phase speeds [4].

Sensitive element is conventionally divided in two components, which are in different environments. Power of the component placed in liquid, is defined as:

$$P_1^* = P_0^* \cdot e^{-2\alpha h}. \tag{1}$$

Power of component, placed in the gas, accordingly as:

$$P^* = P_1^* \cdot e^{-2\alpha'(L-h)}, \tag{2}$$

where α, α' are coefficients of light, propagating a waveguide located intwo environments.

The total power of light of that part of the element which is on the boundary of two environments is written as:

$$P^* = P_0^* \cdot e^{2h(\alpha'-\alpha)-2\alpha' L}. \tag{3}$$

Extinction coefficients α and α' are defined as imaginary parts of propagation constant, obtained while solution of characteristic equation of the offered waveguide, correspondingly for liquid and gaseous environments. Characteristic equation of the three–layered flat waveguide looks like:

$$\frac{m_3}{m_2} k_2 \tan(k_2 d) \pm \frac{m_3}{m_1} k_2 \tan^{\pm 1}(k_1 L) \pm k_3 \frac{k_1}{k_2} \frac{m_2}{m_1} \tan(k_2 d) \tan^{\pm 1}(k_1 L) - k_3 = 0, \tag{4}$$

where $k_1^2 = k^2 n_1^2 - h^2$, h – propagation constant, $n_1 = \sqrt{\varepsilon_1 \mu_1}$ – refractive index of core, $k_2^2 = k^2 n_2^2 - h^2$, $n_2 = \sqrt{\varepsilon_2 \mu_2} + i\alpha_2$ – refractive index of cladding, α_2 – extinction coefficient of light in the cladding, $k_3^2 = h^2 - k^2 n_3^2$, $n_3 = \sqrt{\varepsilon_3 \mu_3}$ – refractive index of the environment, $k = \frac{2\pi}{\lambda}$ – wave-number of free space, λ – wavelength, $2L$ – geometrical dimentions of the core, d – geometrical dimentions of the cladding.

The extinction coefficient of light in the core is taken such that in comparison with α, α' and α_2, they can be neglected. The values α, α',obtained while solution of equation (4), are substituted into equation (3) and dependence of power at the output of waveguide on liquid level is constructed. On the basis of the obtained characteristic equation dependence is constructed for the waveguide, the core of which has NRI and for classic waveguide the core of which has simultaneously positive values magnetic and dielectric permittivities (we will name such material as material with positive refractive index , PRI).

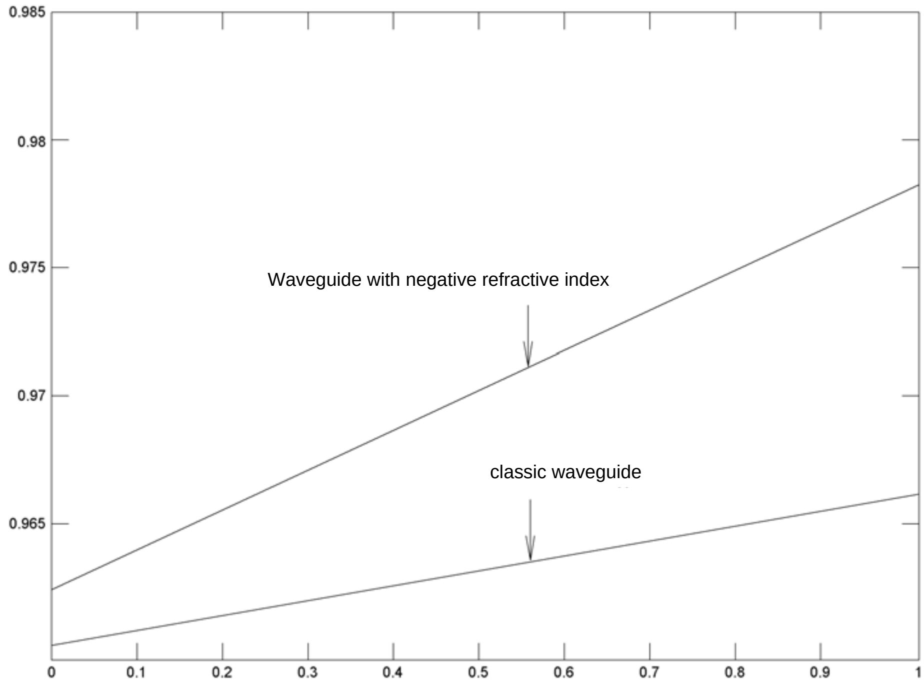

Fig. 2. Dependence of initial power of light on liquid liquid

The slope of dependence for a waveguide with NRI of core is higher than for a waveguide with PRI, therefore sensitivity of detectors based on such waveguides will be higher. As it was shown in [5], two–layered waveguides with NRI of core have special mode composition. For investigation of mode composition of the offered three–layered structure it is necessary to build dependence of the given frequency:

$$V = 2kL\sqrt{n_1^2 - n_3^2}\ , \tag{5}$$

from normalized of propagation:

$$b = \frac{\frac{h}{k} - n_3}{n_1 - n_3}. \tag{6}$$

While construction of dependence parameter V changes at the expence of n_3 parameter – refractive index of the environment.

The cutoff of the second mode occurs at $V = V_2$ and $b = 0$:

$$b = \frac{\frac{h}{k} - n_3}{n_1 - n_3} = 0 \Rightarrow h_2 = kn_3\ ,$$

where h_2 – propagation constant, at which a cutoff of the second mode occurs. Substituting this value into characteristic equation (4), the obtained equation will be written as:

$$\frac{m_3}{m_2}k_2\tan(k_2 d) \pm \frac{m_3}{m_1}k_2\tan^{\pm 1}(k_1 L) = 0\ , \tag{7}$$

where, $k_2^2 = k^2 n_2^2 - k^2 n_3^2$.

Solving this equation relatively variable n_3, at all other preset parameters we will obtain such valueRI of the environment at which the cutoff of the second mode occurs in a waveguide. Having defined by the obtained solution the resulted frequency, we will define the value $V_2 = 2.132$ which, regardless of waveguide provides the cutoff of the second mode.

Presence in a waveguide with NRI of the core of radiation non-transmission band, while supplying at its input of non–monochrome light, provides interruption of radiation spectrum at its output (Fig. 3).

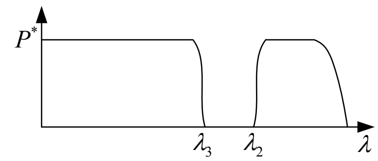

Fig. 3. Spectrum of radiation at the output of waveguide with NRI

In Fig. 3 λ_2 and λ_3 are wavelengths, corresponding to the resulted frequencies V_2 and V_3. Proceeding from the obtained value of the resulted frequency at the moment of second mode cutoff and formula (5), dependence between the wave–length on which the cutoff of the second mode will be provided in the given waveguide from NRI of external environment $\lambda_2 = f(n_3)$ is established:

$$\lambda_2 = \frac{2\pi}{V_2} L\sqrt{n_1^2 - n_3^2} = 2.947L\sqrt{n_1^2 - n_3^2}\ . \tag{8}$$

Values of cutoff wavelengths as it is seen from equation (8), depend on refractive indices of liquid and gaseous environment and do not depend on liquid level. Thus, from the initial spectrum the value of wavelength λ_2 is defined, by which NRI of external environment n_3 is defined according to the suggested dependence. It allows to neglect component errors, appearing due to the impact of temperature and pressure on the optical characteristics of external environments and waveguide itself. Substituting the obtained value of n_3 in characteristic equation and solving it, we obtain complex constant of propagation ,the imaginary part of which is the dispersion coefficient: α and α' depending on the environment a waveguide is in, i. e. depending on n_3. As cutoff wavelength depends on the environment a waveguide is in, i.e. if we place it on the boundary line of two environments an initial spectrum will look like:

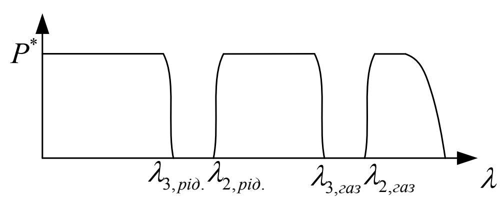

Fig. 4. Initial spectrum of sensitive element which is on the boundary line of two environments

For enlargement of measurement band level gauge consists of several series connected sensitive elements (Fig. 5). Parameters of each sensitive elements are chosen in such a way that areas of light non-transmission were different. This allows to register light flux which passes across all sensitive elements and to separate optical information from each of them. Therefore having connected in series n waveguides, so that each waveguide had its unique band $\lambda_{3,liq.} ... \lambda_{2,gas.}$ and passing across them non–monochrome light , at the output we will obtain the following spectrum (Fig.6).

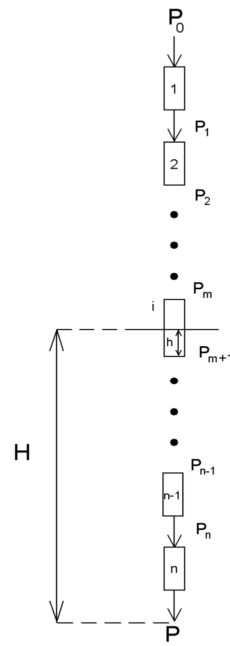

Fig.5. Architecture framework of level gauge

Having defined by initial spectrum the values of wavelengths $\lambda_{2,liq.}^{n}$ and $\lambda_{2,gas.}^{1}$, by the formula (8) RI of liquid and gas are defined correspondingly, which are substituted in characteristic equation for definition of α and α'. Knowing the number of detector *i* from the obtained spectrum, which is on the boundary line of two environments, we define actual liquid level.

The calculation of level gauge powers, taking into account that refractive indices of components which are in different environments will be different, looks like:

$$P_m = P_o \cdot e^{-2mL\alpha 1}, \tag{9}$$

$$P = P_{m+1} \cdot e^{-2(n-(m+1))L\alpha 2}. \tag{10}$$

Thus,

$$P_{m+1} = \frac{P}{e^{-2(n-(m+1))L\alpha 2}}, \tag{11}$$

where *m* is a number of sensitive elements in gaseous environment, *n* is a total number of sensitive elements the level gauge consists of .

Taking into account the formula (3) equation of transformation equation will be :

$$h = \frac{\ln\left(\frac{P_m}{P_{m+1}}\right) + 2L\alpha_2}{2(\alpha_2 - \alpha_1)}. \tag{12}$$

Total liquid level in a vessel is calculated by the formula:

$$H = L \cdot (n - (m+1)) + h. \tag{13}$$

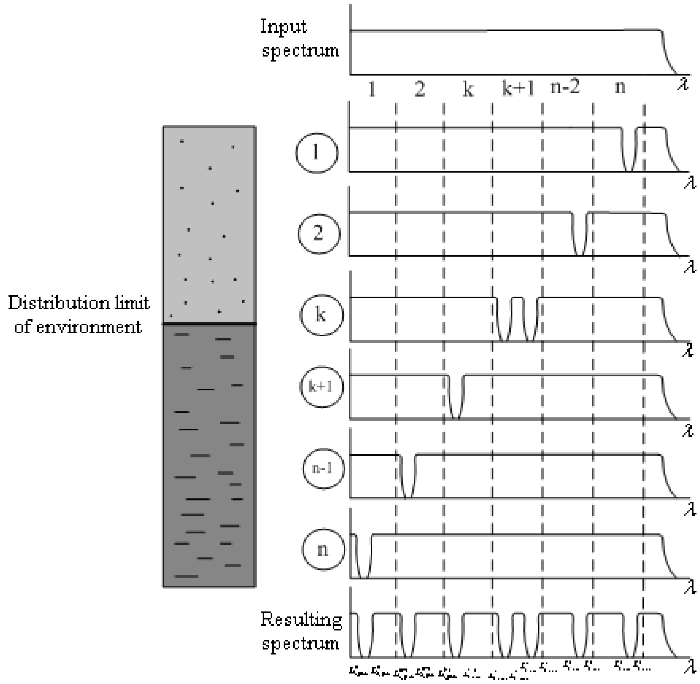

Fig. 6. Resulting spectrum of level gauge

Conclusions. Optical measuring transducer of liquid level, sensitive elements of which are manufactured from a dielectric with negative refractive index is offered. As a result of investigation accuracy of the device was enhanced due to elimination of temperature and pressure impact on optical characteristics of waveguide materials and external environments, the band of measuring range is expanded as a result of increasing the number of sensitive elements and sensitivity of the device is improved.

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