Simulation of High-Sensitivity Hydrophone Based on ANSYS

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Abstract—**Fiber optical hydrophone with high sensitivity attracts more and more attentions in recent years. In this paper, the packaging structures of the hydrophone are simulated based on ANSYS, finite element analysis software. Polyurethane is adopted to design a cylindrical hydrophone and an ellipsoidal hydrophone. By improving packaging structure of sensing-head, the acoustic sensing-index is increased. Experiment Results show that the sensitivity of hydrophone after packaging is 40 times of bare fiber.**

Keyword—hydrophone; acoustic pressure sensitivity; finite element

I. PRINCIPLE

As is known that, the relative shift of the Bragg wavelength of a FBG is related to the axial strain applied to the grating as follows [1]

$$\Delta\lambda / \lambda = (1 - P_e)\varepsilon \qquad (1)$$

Where P_e is the effective photoelastic coefficient of the fiber glass with ε the axial strain.

The effective photoelastic coefficient P_e is defined as:

$$P_e = n_{eff}^2 [P_{12} - v(P_{11} + P_{12})] / 2 \qquad (2)$$

Where n_{eff} is the effective refractive index of the guide mode with v the Poisson ratio, P_{11}、P_{12} the photoelatic coefficient.

For a typical silica fiber, $n_{eff} = 1.46$, $v = 0.16$, $P_{11} = 0.12$, $P_{12} = 0.27$, and, hence, we have $P_e = 0.22$.

And the axial strain ε along the FBG under an applied pressure P is given by

$$\varepsilon = -P(1 - 2\mu) / E \qquad (3)$$

Where μ is the Poisson ratio of the polymer with E the Young's modulus [2].

Combined formulas (1) and (3)

$$\Delta\lambda / \lambda = -(1 - P_e)(1 - 2\mu)P / E \qquad (4)$$

For the encapsulation structure of the hydrophone, the pressure sensitivity is related with the Poisson ratio and Young's modulus of the polymer. The smaller the Poisson ratio and Young's modulus, the higher the pressure sensitivity.

II. FINITE ELEMENT SIMULATION BASED ON ANSYS

Finite Element Method [3], FEM in short, is used more and more widely in recent years and becomes one of the most important ways to resolve computational mechanics.

FEM is a method for dividing up a very complicated problem into small elements that can be solved in relation to each other. The finite element method [4] is a good choice for solving partial differential equations over complicated domains. ANSYS, based on finite element method, offers a comprehensive range of engineering simulation solution sets providing access to virtually any field of engineering simulation that a design process requires. In this paper, structural mechanics、modal analysis and harmonic analysis are adopted.

A. Simulation of Young's modulus and Poisson ratio

An encapsulation structure model is established with diameter of 4mm, length of 50mm and density of 2200 kg/m^3. The mesh generation is automatic in ANSYS, and we use the method to generate 30672 nodes and 14998 elements as following
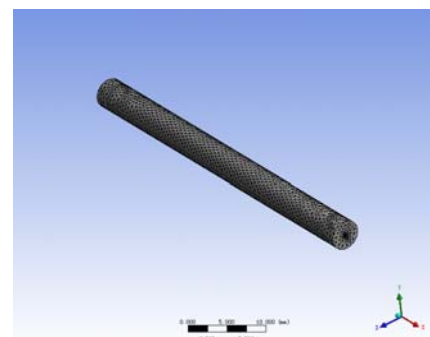

Figure 1 Meshing in ANSYS

The relationship between different Young's modulus、

different Poisson ratio and axial strain is given, respectively, as follows
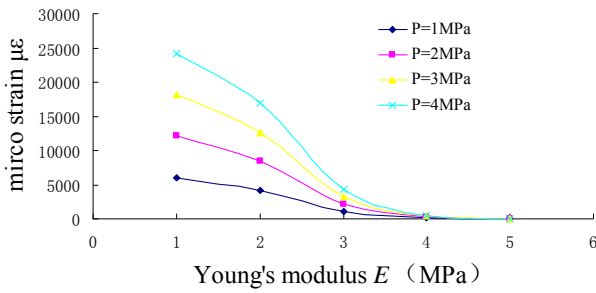

Figure 2 Relationship between Young's modulus and micro strain
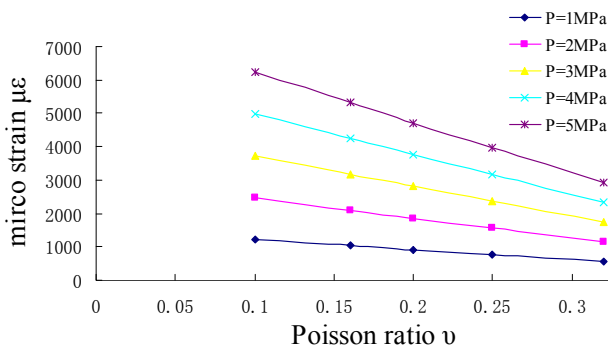

Figure 3 Relationship between Poisson ratio and micro strain

It shows that for hydrophone with encapsulation structure, the axial strain along the FBG is in inverse ratio to Young's modulus and Poisson ratio of polymer. So packaging material with smaller Young's modulus and Poisson ratio is be proposed for the smaller Young's modulus and Poisson ratio, the higher the strain under the same pressure.

B. Structral Mechanics Simulation of Encapsulation Structure of Polyurethane Based on ANSYS

In according to above simulation results, polyurethane, with Young's modulus $E = 125MPa$ 、 Poisson ratio $v = 0.32$ and density $\rho = 100kg/m^2$, is proposed to packaging. In this paper, a cylinder shape hydrophone and a spindle shape hydrophone are designed respectively while the structures are shown in figure 4 and figure 5.

Figure 4 The Cylinder Encapsulation Structure

Figure 5 The Spindle Encapsulation Structure

The hydrophone after packaging is more sensitivity to static pressure than bare fiber.
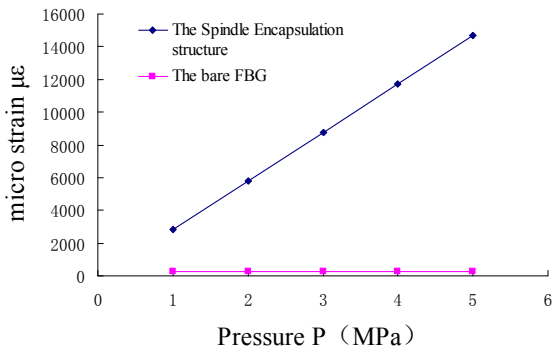

Figure 6 Comparison of Micro-strain between after packaging and before packaging under different pressure
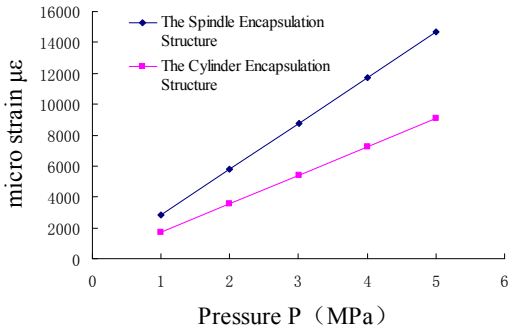

Figure 7 Comparison of Micro-strain between the Spindle Encapsulation Structure and the Cylinder one under different pressure

C. Modal Analysis of the Hydrophone

A modal analysis [5] is a technique used to determine the vibration characteristics of the hydrophone. In structural engineering, modal analysis uses the overall mass and stiffness of the hydrophone to find the various periods at which it will naturally resonate. Generally, the hydrophone works between 0 to 10 *kHz* which demands the first resonance frequency greater in order to far away from working frequency. But if the working frequency is too far away from the resonance frequency, the sensitivity will be decreased. Therefore, it needs to be considered simultaneously.

According to the Hamilton Principle [6], for the harmonic motion in ANSYS, we have

$$([\bar{K}] - \omega^2[\bar{M}])[U] = [\bar{P}]V \qquad (5)$$

$$[\bar{P}]'[U] + C_0 V = Q$$

In freedom condition, we have the dynamic equation as follows

$$([\bar{K}] - \omega^2[\bar{M}])[U] = 0 \qquad (6)$$

Where $[\bar{K}]$ is the stiffness matrix and $[\bar{M}]$ the mass matrix.

The empty ellipse hydrophone owns a very low resonance frequency so we fill it full of Silica in order to enhance its first resonance frequency. The first resonance frequency of hydrophone full of Silica is 14946HZ.

D. Experiment Results

Measuring system was established with M-Z interferometer for pressure sensitivity. By experiment, the pressure sensitivity after packaging is 40dB larger than before packaging for the cylindial shape encapsulation structure. The comparison on phase sensitivity to acoustic pressure between after packaging and before packaging is shown in figure 8.
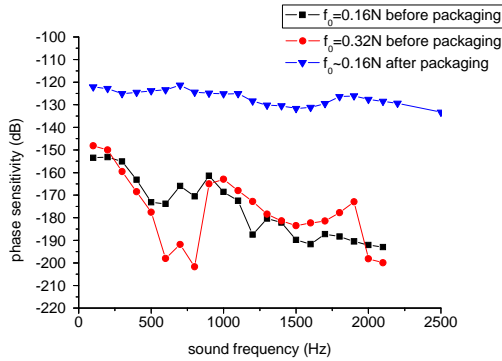

Figure 8 Comparison of phase sensitivity between the packaging hydrophone and the bare FBG

Meanwhile, the hydrophone of splindial shape encapsulation structure was compared with the cylinder one.
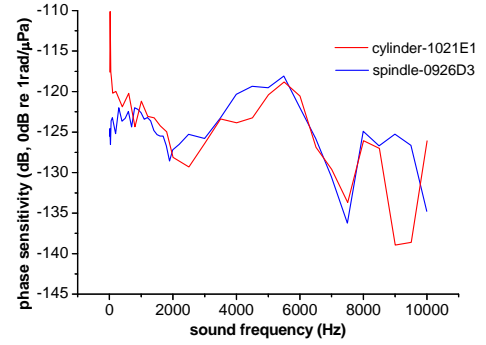

Figure 9 Comparison of phase sensitivity between the Spindle Encapsulation Structure and the Cylinder

The testing results indicate that the hydrophone of splindle is 3dB higher than the cylinder one.

III. CONCLUSION

In this paper, ANSYS was used to simulate the encapsulation structure of hydrophone in order to enhance its acoustic pressure sensitivity. Polyurethane was adopted to package the hydrophone and two hydrophones were made with one cylinder shape and the other splindle shape. The experiment shows that after packaging, the acoustic pressure sensitivity was higer than before packaging. In the future, new structure of polyurethane will be designed to furture enhance the acoustic pressure sensitivity.

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