Proceedings of the 11th
KACC, October 1996

DESIGNING CYLINDER PRESSURE TRANSDUCER OF 0~3.0 *MPA*

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Abstracts The frequency-pressure relationship of the cylinder, within 0 ~ 3.0*Mpa*, is studied by making use of the finite element method (FEM). Based on numerical calculations of FEM and the actual working conditions of the cylinder pressure transducer, this paper presents the optimizing results of the length, the radius and the thickness of the cylinder. Moreover, this paper gives some more important points on designing the whole structure of the cylinder and on reality of the transducer system. The obtained results are of important theoretical bases for developing the cylinder pressure transducer of 0 ~ 3.0*Mpa*.

Keywords Cylinder, Resonator, Pressure Transducer, Finite Element Method, Designing

1. INTRODUCTION

As compared to the conventional pressure transducer, the resonant cylinder pressure transducer has following advantages: direct digital output (without A/D), long team stability, low hysteresis, and high repeatability[1,3]. Nowadays, the regular cylinder pressure transducer of 0 ~ 0.3*Mpa* has been used in Air Date Computer on board of flight, the calibrator equipment on ground, pressure controller, and etc. The above transducer of 0 ~ 0.3*Mpa* with 0.02%F.S. accuracy can be manufactured in Britain, American, Russian and China. They represent the highest level in aeronautical measuring area. But the transducer of 0 ~ 0.3*Mpa* can not satisfy the urgent demand of precise measurement of larger pressure. Only the British Solartron Company can manufacture a fewer cylinder transducer for measuring large pressure, such as 0 ~ 3.0*Mpa*. On the other hand, it is hard to find any paper to discuss related technical problems in open publication. The objective of this paper is to solve the designing cylinder pressure transducer of 0 ~ 3.0*Mpa*. Firstly, we present some laws of the frequency-pressure relationship of the cylinder at low frequency ranges, by making use of FEM. Then, according to structure of the cylinder, we give the actual designing optimization of the geometric structural parameters of the cylinder and the realization project of the transducer system.

Fig. 1 shows the structural sketch of the cylinder for measuring the pressure. The effective length, mean radius and thickness are L, R and H respectively; The bottom end is clamped while the top end is a round diaphragm whose thickness is h. P is the pressure difference between inner and outer of the cylinder. Young's modulus, density and poisson ratio are E, ρ and μ respectively.

The free vibration of the cylinder is a typical mechanical problem[2], but the research on its characteristics of vibration, was seldom appeared in open publication, under the large pressure. Especially the above cylinder is used for measuring large pressure of 0 ~ 3.0*Mpa*. As space is limited, it is impossible for us to present the finite element equations in this paper.

2. CALCULATION AND DISCUSSION OF FREQUENCY-PRESSURE RELATIONSHIP

The cylinder is made of *Ni-Span C*, Young's modulus, density and poisson ratio are $E = 1.911 \times 10^{11} pa$, $\rho = 7.85 \times 10^3 Kg/m^3$ and $\mu = 0.3$ respectively.

Define $f_{n,m}(P)\,[Hz]$ as the natural frequency of the cylinder for pressure P, (n,m) mode, where n is the circumferential wave number, m is the longitudinal half wave number. Thus $f_{n,m}(0)$ $[Hz]$ is the natural frequency for pressure $P = 0$.

Define $\beta_{n,m} = [f_{n,m}(P) - f_{n,m}(0)]/f_{n,m}(0)$ [%] as the relative variation of the natural frequency of the cylinder within $(0, P)$

Table 1 shows the natural frequencies of the cylinder within lower frequency range, $f_{2,1}(0)$, $f_{3,1}(0)$, $f_{4,1}(0)$, $f_{5,1}(0)$ for different thickness H, and $L = 60mm$, $R = 11mm$

Table 2 shows the relative variation of the natural frequency of the cylinder within $(0,3.0)Mpa$, $\beta_{2,1}$, $\beta_{3,1}$, $\beta_{4,1}$, $\beta_{5,1}$ corresponding to table 1.

Table 3 shows the natural frequencies of the cylinder within lower frequency range, $f_{2,1}(0)$, $f_{3,1}(0)$, $f_{4,1}(0)$, $f_{5,1}(0)$ for different length L, and $H = 0.3mm$, $R = 11mm$

Table 4 shows the relative variation of the natural frequency of the cylinder within $(0,3.0)Mpa$, $\beta_{2,1}$, $\beta_{3,1}$, $\beta_{4,1}$, $\beta_{5,1}$ corresponding to table 3.

Table 5 shows the natural frequencies of the cylinder within lower frequency range, $f_{2,1}(0)$, $f_{3,1}(0)$, $f_{4,1}(0)$, $f_{5,1}(0)$ for different radius R, and $H = 0.3mm$, $L = 60mm$.

Table 6 shows the relative variation of the natural frequency of the cylinder within $(0,3.0)Mpa$, $\beta_{2,1}$, $\beta_{3,1}$, $\beta_{4,1}$, $\beta_{5,1}$ corresponding to table 5.

From the above tables, the following results can be obtained within the parameter spaces discussed:

- $f_{n,1}(0)$ increases with increasing *H*, and the bigger *n*, the greater increasing trend; $\beta_{n,1}$ decreases with increasing *H*, and the bigger *n*, the greater decreasing trend.
- $f_{n,1}(0)$ decreases with increasing *L*, and the bigger *n*, the less decreasing trend; $\beta_{n,1}$ increases with increasing *L*, and the bigger *n*, the less increasing trend.
- $f_{2,1}(0)$ increases with increasing *R*, $\beta_{2,1}$ decreases with increasing *R*. On the other hand, as $n \geq 3$, $f_{n,1}(0)$ decreases with increasing *R*, and the bigger *n*, the greater decreasing trend; $\beta_{n,1}$ increases with increasing *R*, and the bigger *n*, the more increasing trend.

3. DESIGNING THE CYLINDER FOR MEASURING PRESSURE 0~3.0 *MPA*

3.1 Exciting means and the vibration mode

We select the electric-magnetic unit as the exciting and detecting means for the resonator cylinder pressure transducer. Thus the vibration mode is (4,1). See Fig. 2.

3.2 Strength of the cylinder

The cylinder's maximum stress is *PR/H*, which is yielded by pressure *P*. Then the following equation must be satisfied in order to make the cylinder in stable working condition

$$P_{\max} R/H \leq [\sigma]/K \tag{1}$$

Where P_{max} is the maximum measurand pressure, $[\sigma]$ is the permitted stress. K is the safety coefficient.

We select *Ni-Span C* to fabricate the cylinder, thus $[\sigma] = 4.5 \times 10^8\ pa$. As we select K=3.5, the maximum pressure P_{max} =3.0*Mpa*, the minimum thickness H are as 0.21, 0.233 and 0.257 mm corresponding to the radius R as are 9, 10 and 11 mm respectively.

3.3 The ratio of H/R

It should be guaranteed for cylinder to be a thin shell, thus the following equation must be satisfied

$$H/R \leq 1/30 \tag{2}$$

The maximum thickness H are as 0.3, 0.333 and 0.367 mm corresponding to the radius R as are 9, 10 and 11 mm respectively.

3.4 The relative variation of the natural frequency

The relative variation of the natural frequency of resonator is one of the important indexes for resonant transducer. Generally, the relative variation of the natural frequency can be selected within 15 ~ 25 %.

3.5 *Relative relationship of different vibration mode*

When we select the electric-magnetic unit as the exciting and detecting means for the resonator cylinder pressure transducer, the actual working vibration only is mode (4,1). Thus the frequencies range of vibration mode (4,1) should be guaranteed in an isolated condition within the full pressure measuring range (see also Fig. 3).

3.6 Round diaphragm at the top end

Designing principle of the thickness of the round diaphragm at the top end is the minimum frequency of the diaphragm is as much as twice of the working frequencies of the cylinder within the full measuring range.

The minimum frequency of a round diaphragm with clamped boundary condition can be written as[4]

$$\Omega_{min} = \frac{10.21h}{2\pi R^2}\sqrt{\frac{E}{12(1-\mu^2)\rho}} \quad [Hz] \tag{3}$$

3.7 Designing parameters of the cylinder

Based on the above calculating, analyzing and discussing, we present the designing parameters of the cylinder for measuring 0 ~ 3.0*Mpa*.

L=60 mm, R=11 mm, H=0.3 mm.

Thus, the natural frequency range of the cylinder is 9059 ~ 10981*Hz* as the measurand pressure range is 0 ~ 3.0*Mpa*. The relative variation of the natural frequency is 21.215 %. Fig. 3 shows graphs of $f_{2,1}$, $f_{3,1}$, $f_{4,1}$, $f_{5,1}$ within the pressure range of 0 ~ 3.0*Mpa*. Moreover, the minimum thickness h at the top end can be determined as 1.095 mm from equation (3).

4. CONCLUSION

This paper presents the designing parameters of the cylinder resonator for measuring pressure of 0 ~ 3.0*Mpa*. It is of important theory bases for developing the cylinder pressure transducer of 0 ~ 3.0*Mpa*.

5. ACKNOWLEDGMENT

The authors would like to thank Dr. Yoon Kang Sup, M.Sc. Chang Yu Shin, and their classmates in Mechatronics Lab. at Pusan National University. With their help, the layout of this paper is finished smoothly.

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TABLE 1. $f_{n,1}(0)$ for different H($R = 11mm, L = 60mm$)

$H\,(mm)$	$n=2$	$n=3$	$n=4$	$n=5$
0.28	6859	5646	8492	13225
0.29	6876	5769	8775	13691
0.30	6893	5894	9059	14157
0.31	6912	6020	9344	14624
0.32	6930	6148	9629	15091

TABLE 2. $\beta_{n,1}$ for different H ($R = 11mm, L = 60mm$)

$H\,(mm)$	$n=2$	$n=3$	$n=4$	$n=5$
0.28	6.279	27.853	25.394	18.023
0.29	6.040	25.969	23.185	16.360
0.30	5.815	24.236	21.215	14.890
0.31	5.605	22.641	19.453	13.587
0.32	5.406	21.172	17.874	12.428

TABLE 3. $f_{n,1}(0)$ for different L($R = 11mm, H = 0.3mm$)

$L\,(mm)$	$n=2$	$n=3$	$n=4$	$n=5$
50	9090	6874	9408	14333
55	7875	6308	9202	14291
60	6893	5894	9059	14157

TABLE 4. $\beta_{n,1}$ for different L($R = 11mm, H = 0.3mm$)

$L\,(mm)$	$n=2$	$n=3$	$n=4$	$n=5$
50	3.522	18.501	19.899	14.596
55	4.562	21.523	20.664	14.773
60	5.815	24.236	21.215	14.890

TABLE 5. $f_{n,1}(0)$ for different R($L = 60mm, H = 0.3mm$)

$R\,(mm)$	$n=2$	$n=3$	$n=4$	$n=5$
9	6363	7529	13148	21011
10	6610	6527	10778	17046
11	6893	5894	9059	14157

TABLE 6. $\beta_{n,1}$ for different R($L = 60mm, H = 0.3mm$)

$R\,(mm)$	$n=2$	$n=3$	$n=4$	$n=5$
9	8.007	18.465	12.740	8.496
10	6.816	21.870	16.784	11.463
11	5.815	24.236	21.215	14.890

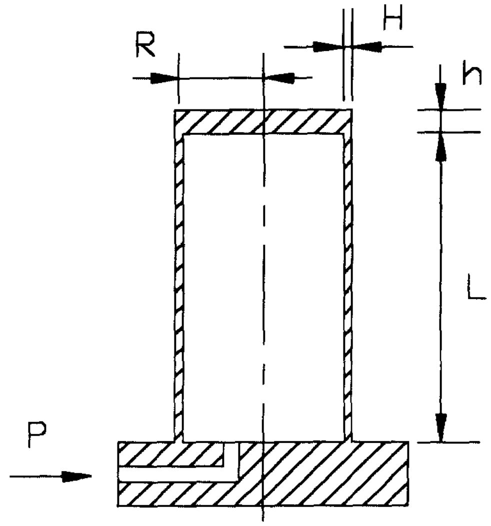

Fig. 1 The sketch of the cylinder

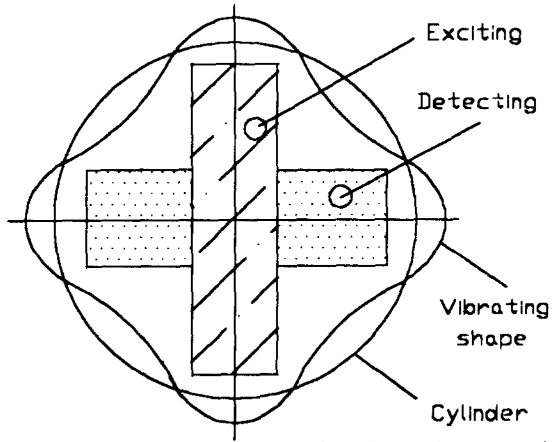

Fig. 2. Circumferential vibrating shape and the scheme of the exciting/detecting means

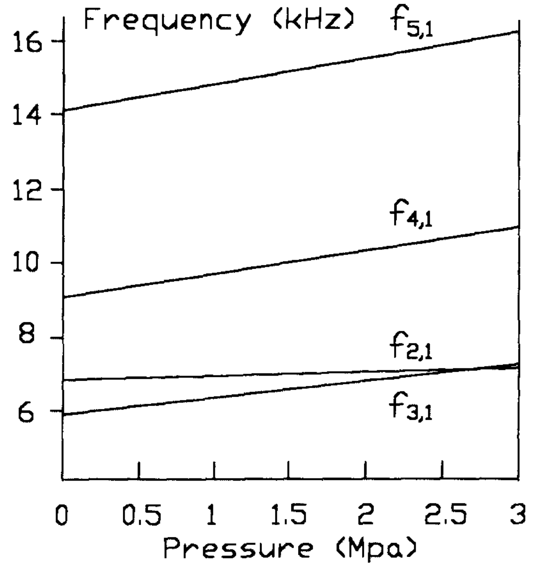

Fig.3 Frequency-pressure relationship