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# Model Analysis of Cymbal Generator Under Different Working Conditions

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**ABSTRACT :** *In order to study the influence for natural frequency under different constraint conditions of Cymbal transducer. Through the use of ANSYS and SIMULATION with finite element method, the Cymbal transducer can be applied on different constraints and load conditions, calculation and analysis to obtain the modal under the specific natural frequencies and mode shapes. Which in the free and non free conditions yield stress limits are in the security domain, the modal analysis results of vibration mode and natural frequency shows that suitable for large load under low frequency vibration of train vibration load, the load in order to study, under low frequency vibration Cymbal transducer can provide simulation support for energy recovery applications.*

**KEYWORDS** *CYMBAL TRANSDUCER , MODEL ANALYSIS, INHERENT FREQUENCY, MODE OF VIBRATION, FINITE ELEMENT METHOD*

## I. INTRODUCTION

Cymbal transducer is made up by two cymbal shaped metal cap and piezoelectric ceramic sheet with bonding pressure of combination which has small volume, light weight, can bear large load. The cymbal metal caps can be low impedance, high bending axial deformation transformation for pressure electric ceramic wafer of high impedance, the path toward the expansion deformation[1].

The vibration mode is the inherent and the overall characteristic of the elastic structure.. Through the modal analysis method which can figure out the structure in a susceptible to frequency range of each order of the main modal characteristics can be predicted structure in this frequency band on external or internal various vibration sources of the actual vibration response. Therefore, the modal analysis is the important method for the structural dynamic design and the fault diagnosis of the equipment.

In this paper the Cymbal transducer can under the force constraint condition is analyzed. According to the boundary stress constraints, the modal analysis using finite element analysis software, comparative analysis of Cymbal transducer can device of train vibration energy recovery provide structural support analysis.

## II. CYMBAL TRANSDUCER

Cymbal transducer is a miniaturized V crooked device which is composed of a piezoelectric ceramic sheet, epoxy resin and metal end cap structure, the 3D entity model as shown in Figure 1.

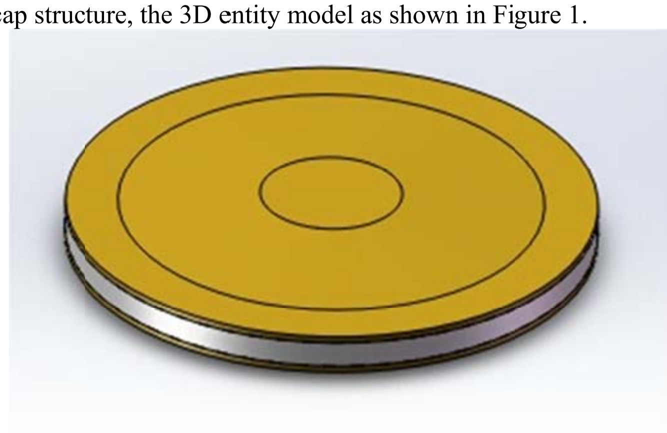


Figure 1. 3D entity model of Cymbal transducer

### 2.1 Introduction about the construction

As shown in section view 2, the Cymbal harvester consists of two pieces of cymbal brass metal caps and circular piezoelectric ceramic piece by epoxy resin adhesive. The thickness of metal cap is $t_m$; The thickness of Piezoelectric ceramic plate is $t_p$; The Radius of Top circle of metal cap is $R_1$; The Radius of Inner bottom circle of metal cap is $R_2$; The Radius of bottom circle of metal cap is $R_3$; The height of Lumen height of metal cap is $h$;

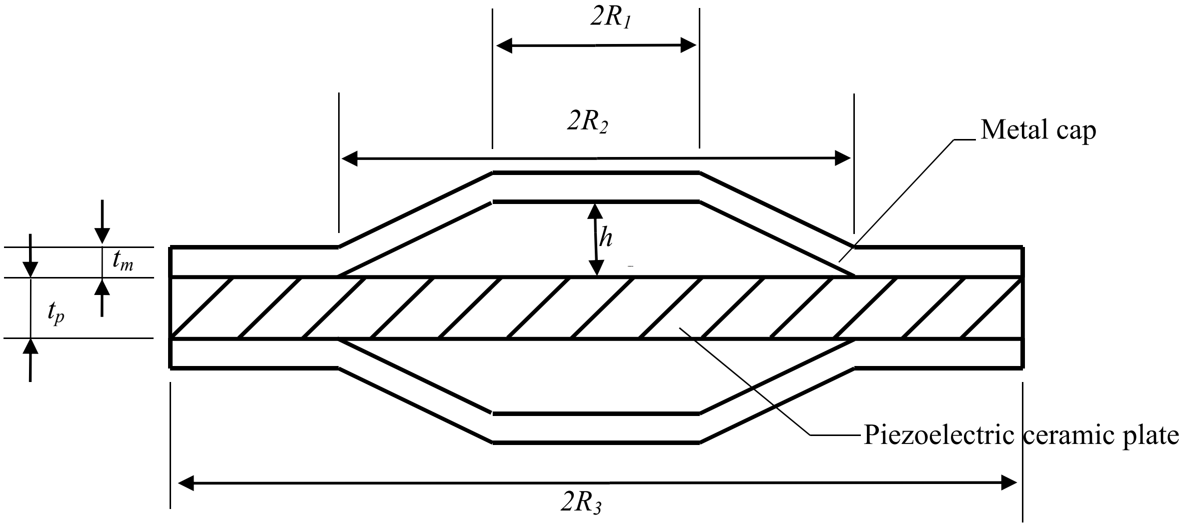



Figure 2. Structure display of Cymbal

### 2.2 Power generation principle

When the metal cap is subjected to the external axial load, the movement displacement and the radial and axial stretching of the piezoelectric ceramic piece have a certain functional relationship[2]. When the external axial vibration is Cymbal transducer to receiving device of metal end cap and a metal end cap to produce bending vibration, due to the coupling between the metal end cap and a piezoelectric ceramic disk, external axial load by metal end caps buffer and converted into electric vibrator radial compressive stress and the vibrator to produce radial vibration, due to the pressure on the piezoelectric effect of piezoelectric ceramic, alternating external vibration the cymbal transducer an alternating electric field is generated, which is to achieve the transformation of the external source of vibration excitation energy[3].

Because of its special hollow metal cap structure, which applied in the metal cap on the top end of the axial stress can conversion of piezoelectric ceramic sheet of radial pressure should force and axial stress, which makes the $d_{31}$ and $d_{33}$ mode piezoelectric constant pressure are equivalent pressure constant play a role, the effect of pressure dielectric constant is higher than that of single mode under the pressure of piezoelectric ceramic $d_{31}$ and $d_{33}$, $d_{31}$ radial vibration mode, thus increasing the mechanical and electrical conversion efficiency[4].

## III. CYMBAL TRANSDUCER MODAL ANALYSIS

According to the literatures of[5-6],Taking with structure parameters of piezoelectric constant high equivalent of Cymbal transducer. Its parameters are as follows: Table 1.

The Metal cap's material is brass. Piezoelectric ceramic pieces of material is PZT-5H. The Binder between them is YH-896 which is applies to the bonding of metal and ceramic. It has the advantages of bonding strength, impact resistance, high temperature resistance, wear resistance and the shock effect is ideal .

### 3.1 Selection of parameters for adhesive material

In the metal cap and the piezoelectric ceramic binder selection, according to the characteristics of the metal and ceramic bond and the need of extra high bonding strength, impact resistance, high temperature resistance, wear resistance, shockproof effect ideal binder. One of the suitable for this is the P-51, P-14, 7-2315 epoxy adhesive, YH-896 and so on.YH-896 compared with several other binder, with moderate viscosity colloid, strong tensile strength, shear strength. So choose YH-896 as bonded metal cap and the pressure piezoelectric electric ceramic material. The material parameters of adhesive YH-896 are listed in Table 1.

Table 1. Adhesive parameters

| Item | Parameter | Unit |
|---|---|---|
| Type | YH-896 | / |
| Viscosity | 10±5 | / |
| Strength of extension | ≥160±10 | $kg/cm^2$ |
| Shear strength | ≥150±10 | $kg/cm^2$ |
| Shelf life | 12 months | / |
| Density | 980 | $kg/m^3$ |
| Curing speed | 10-30s | / |
| Modulus of elasticity | 2.5 | Gpa |
| Relative permittivity | 3 | / |
| Poisson ratio | 0.36 | / |

Note: The above performance data is typical in laboratory environment temperature of 25 degree and the humidity of 70% of the measured data, only use the customer reference does not guarantee is a particular environment can reach all the data of the customer please when in use, to test data shall prevail.

For the piezoelectric ceramic transducer are PZT-5A, PZT-5H, PZT-4, PVDF and etc. The PZT-5H compared to other materials with higher equivalent pressure constant, obtain good positive piezoelectric effect, can obtain higher energy conversion rate, so in Cymbal transducer can structure select PZT-5H as the pressure of piezoelectric materials.

**3.2 Cymbal transducer material parameters**

Phase compared to steel 45#, aluminum alloy, copper and other materials, brass with high stiffness and Young's modulus, suitable for work in low frequency and high load conditions, and suitable for relatively high conductivity. Here is a selection of brass as the material of the metal end caps.

By the literatures of [5-6],Under the train running condition of high and low frequency load environment, need to design appropriate cymbal piezoelectric device structure, so Cymbal transducer can the material parameters and structural parameters are listed in Table 2.

Table 2. Cymbal transducer parameters

| Parameter | Item | | Unit |
|---|---|---|---|
| | Metal cap | PZT-5H | |
| Density ρ | 8900 | 7500 | $Kg/m^3$ |
| Poisson ratio μ | 0.35 | 0.28 | / |
| Modulus of elasticity | 112 | 102 | Gpa |
| Radius of bottom circle | 15 | 15 | mm |
| Radius of Top circle Top circle diameter | 4 | / | mm |
| Radius of Inner bottom circle | 12 | / | mm |
| Height of Lumen | 0.3 | / | mm |
| Thickness of Metal cap | 0.4 | / | mm |
| thickness of PZT-5H | / | 1 | mm |
| Thermal conductivity | / | 1.5 | W/(m • k) |

Table 3. PZT5-H piezoelectric parameters

| Item | Parameter | Unit |
|---|---|---|
| Relative permittivity matrix $\left[\varepsilon/\varepsilon_0\right]$ | $\begin{pmatrix} 1730 & 0 & 0 \\ 0 & 1730 & 0 \\ 0 & 0 & 1730 \end{pmatrix}$ | / |
| Piezoelectric constant matrix $[d]$ | $\begin{pmatrix} 0 & 0 & 0 & 0 & 584 & 0 \\ 0 & 0 & 0 & 584 & 0 & 0 \\ -171 & -171 & 374 & 0 & 0 & 0 \end{pmatrix}$ | $10^{-12}$C/N |
| Piezoelectric flexible constant matrix $[s]$ | $\begin{pmatrix} 16.4 & -5.74 & -7.22 & 0 & 0 & 0 \\ -5.74 & 16.4 & -7.22 & 0 & 0 & 0 \\ -7.22 & -7.22 & 18.8 & 0 & 0 & 0 \\ 0 & 0 & 0 & 47.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 47.5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 47.5 \end{pmatrix}$ | $10^{-12}$m/V |

Note: the vacuum or static permittivity of $\varepsilon_0$ on the upper table is vacuum. $\varepsilon_0 = 8.85\times10^{-12} F/m$

## IV. MODAL ANALYSIS OF CYMBAL TRANSDUCER

Modal analysis is used to analyze the vibration characteristics of the structure, that is, to determine the natural frequencies and vibration modes of the structure, it is the harmonic response analysis, dynamic analysis and spectrum analysis and the other dynamics analysis based.

Modal analysis is used to determine the natural frequency of the system and corresponding mode shapes, the system's basic modes and natural frequencies is transient dynamic analysis, harmonic response analysis and the other dynamic analysis based. Will usually designers need to the vibration mode of the design for the first mode and will be the first order mode and other modes of vibration frequency interval as far as possible to increase, to ensure that the energy harvesting device for the stability of the structure, and the resonant frequency of the first mode of prisoners to the response has important influence.

### 4.1 The establishment and calculation of the finite element model of Cymbal transducer

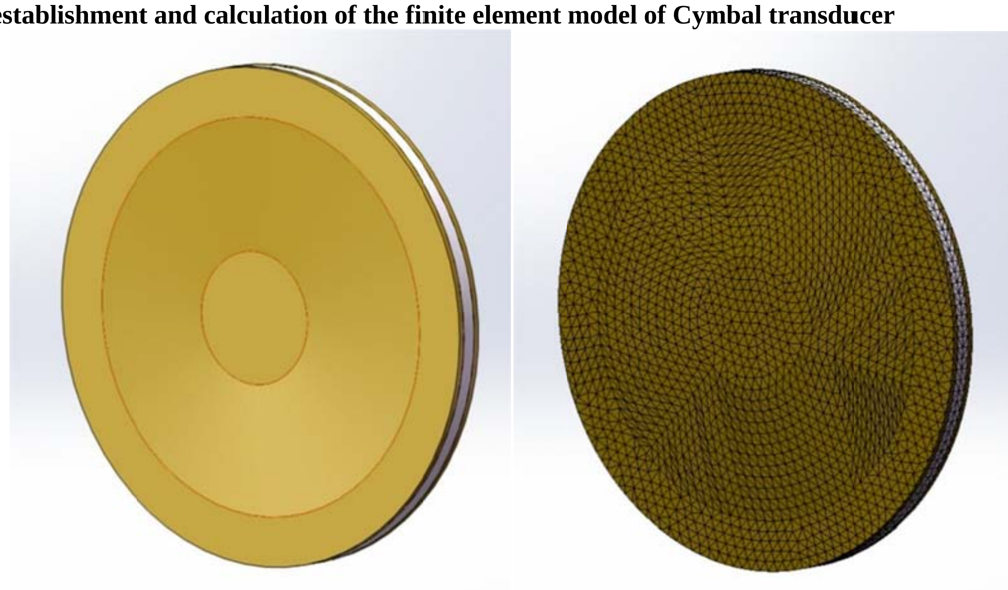


Figure 3. Cymbal transducer sub entity model and grid model diagram

### 4.2 Define material properties and set parameters

According to the prisoners in front of the cymbal is the definition of material parameters, finite element model of material property parameters, selection of Analysis Settings set Max modes to find (the maximum modal number) value of 6. In the mesh in the properties grid settings for fine.

#### 4.2.1 Natural frequency of free state

With the Cymbal transducer under free state, without any constraints, only analysis of order 6. After simulation with ANSYS and simulation by 10 times analysis mean values obtained natural frequencies of modal analysis and the finite element method is carried out vibration modal analysis, modal shape and natural frequency of, reduce the size of the natural frequency can effectively use the vertical resonance capture as much as possible to the vibration energy of Cymbal transducer. The modal analysis of the first order to the sixth order modes is shown in Figure 4 and table 4.The mode state is shown in Figure 5.

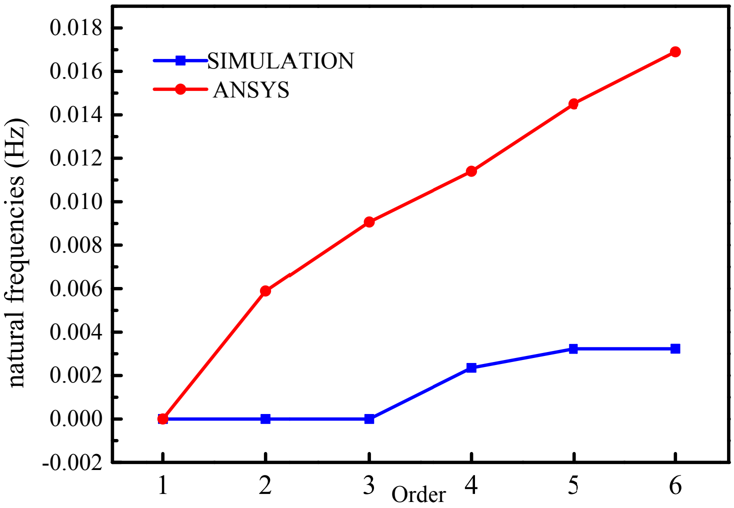


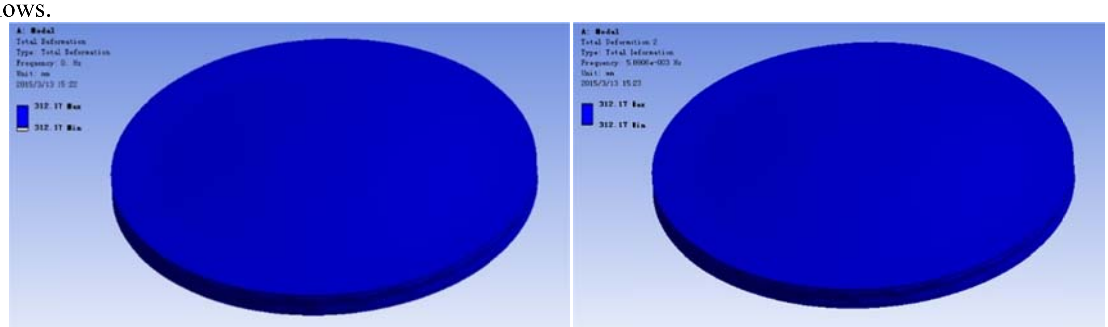

Figure 4. Results of modal analysis in free state

Table 4. Natural frequencies of a free state

| Order | SIMULATION（Hz） | ANSYS（Hz） |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0 | 5.8906e-003 |
| 3 | 3.3539e-009 | 8.0661e-003 |
| 4 | 0.0023546 | 0.0134 |
| 5 | 0.0032262 | 0.0195 |
| 6 | 0.0032324 | 0.0209 |

Because of the difference between those two software of finite element calculation method of immanent algorithm, resulting in these two software in analysis of natural frequency differences, in the first three order the results are basically the same, in the realistic environment of third order frequency is more significance.

Because in practice, the reference value is more of the fourth order, so only a fourth of the first four modes, as follows.



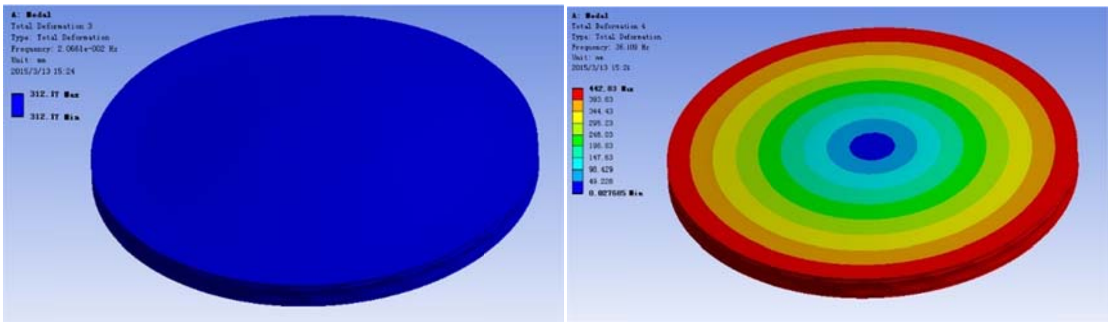


Figure 5. Vibration state of the first to fourth mode under free state

In the free state, pressure electric dipole resonance frequency is low, four steps were below 100Hz, but in the actual environment, piezoelectric vibrator is in a non free state, exist a series of constraints. Therefore, the study of non free state constraint modal analysis more reference significance.

### 4.2.2 Non free state

Practical working environment, piezoelectric streak in the circular groove by vertical load, under forced vibration, therefore defined constraints is fixed under the bottom of the metal cap constraints and other parts in free state, do not impose any constraints, on the metal cap, pressure PZT-5H piezoelectric ceramics and the gold belongs to cap defined as rigid connection, the load was applied on the metal crown round face, load 190N and stacked gravity load.

Finite element calculations, as shown in Figure 7 and table 5. According to the results of the data in Figure 6, the stress yield limit and the stress in the safety range of the brass.

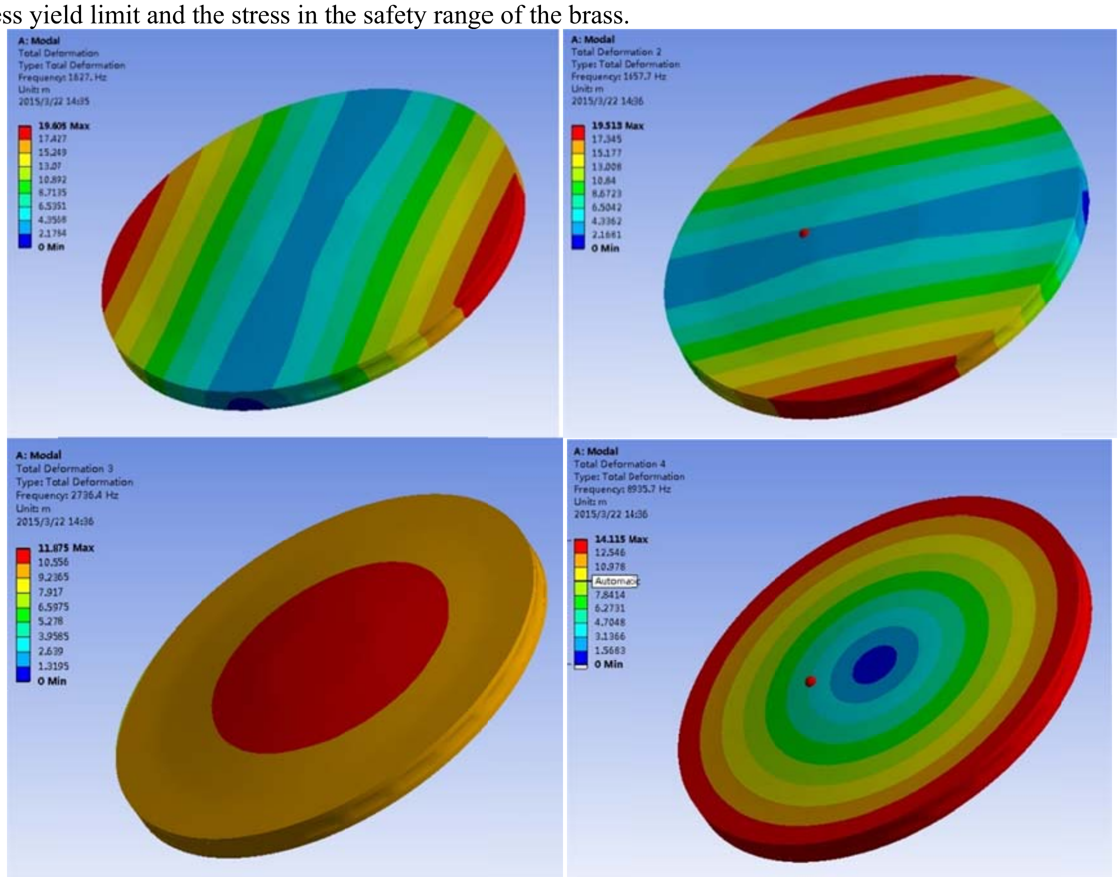



Figure 6. Mode shapes of the first to fourth mode under non free state

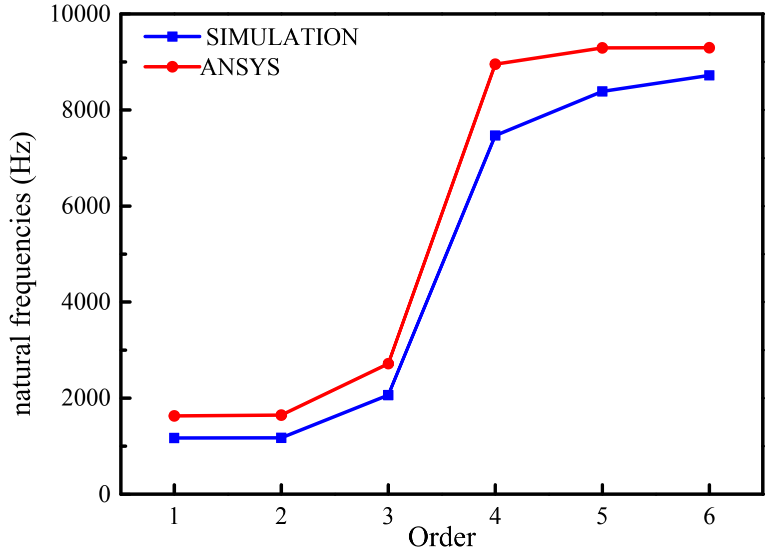



Figure 7. Results of modal analysis

Table 5. Results of modal analysis

| Order | SIMULATION（Hz） | ANSYS（Hz） |
|---|---|---|
| 1 | 1168.4 | 1629.7 |
| 2 | 1171.2 | 1645.5 |
| 3 | 2062 | 2716.2 |
| 4 | 7468.4 | 8955.6 |
| 5 | 8387.7 | 9293.4 |
| 6 | 8721.6 | 9296.6 |

In the ree state, two software simulation results have little difference. Between 7% - 12%, pressure of the first order natural frequency of the electric dipole reached 1168.4Hz, and in the actual environment, environmental vibration frequency multi around 100Hz and reduce harvesting is first-order natural frequency of the natural frequency at or near ambient vibration frequency on the vibration of energy recovery has important significance.

## V. CONCLUSION

The cymbal piezoelectric device as the rail vibration energy recovery technology as a new confession of micro energy, will be able to train running environment of track vertical to the vibration energy conversion into electrical energy, as some low power electronic components and sensor power supply, has important theoretical significance and economic value in use. In this paper, an important unit of the Cymbal piezoelectric energy recovery technology is a finite element study.

The finite element method and ANSYS workbench14.0 software, simulation software to analyze the design of Cymbal transducer is, and analysis the first vibration modal and calculate the resonant frequency. Maximum average displacement amplitude of the actual working condition of the first order vibration mode, with two software calculation for resonant frequency compared, the relative deviation of less than 7. 00% its resonance frequency 1168.4Hz, far higher than the actual environment vibration frequency. Experimental results show that the engineering application significance to solve the Cymbal transducer. To get a good piezoelectric effect, should be optimized in haversters results.

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