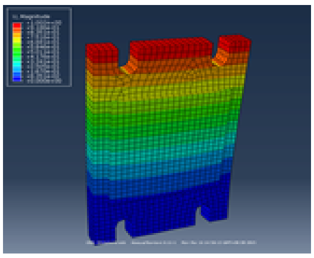
driving force, and its vibration characteristics directly affect the performance of the system. In order to make a more intuitive analysis of the dynamic characteristics of the piezoelectric vibrator and to predict the vibration shape of the system at first, the vibration modal analysis of the piezoelectric vibrator is carried out by using the finite element analysis software ABAQUS. The parameters of piezoelectric vibrators are as follows:

The parameters of piezoelectric ceramics: density $\rho_p = 7.5 \times 10^3 kg/m^3$, dielectric constant matrix ($\varepsilon \times 10^{-9} F/m$), piezoelectric constant matrix ($e \times C/m^2$), piezoelectric elastic coefficient matrix ($c \times 10^{10} N/m^2$) respectively as:

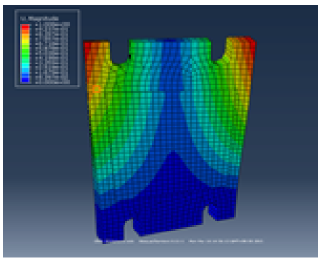
$$\varepsilon = \begin{bmatrix} 7.124 & 0 & 0 \\ 0 & 7.124 & 0 \\ 0 & 0 & 5.841 \end{bmatrix} \quad e = \begin{bmatrix} 0 & 0 & 4.1 \\ 0 & 0 & 4.1 \\ 0 & 0 & 14.1 \\ 0 & 0 & 0 \\ 0 & 10.5 & 0 \\ 10.5 & 0 & 0 \end{bmatrix} \quad c = \begin{bmatrix} 13.2 & 7.1 & 7.3 & 0 & 0 & 0 \\ 7.1 & 13.2 & 7.3 & 0 & 0 & 0 \\ 7.3 & 7.3 & 11.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.6 \end{bmatrix}$$

The material parameters of the metal substrate (65Mn) of piezoelectric vibrators are: density $\rho_{65Mn} = 7.85 \times 10^3 kg/m^3$, modulus of elasticity $E_{65Mn} = 2.06 \times 10^{11} Pa$, Poisson ratio $\mu_{65Mn} = 0.3$.

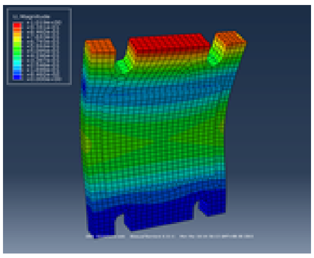
Through simulation modal analysis, the four vibration modes of the piezoelectric vibrator are obtained, as shown in figure 2. From the vibration mode nephogram, it can be seen that the first order vibration mode is the flexural vibration along the length direction; the second order vibration mode is torsional vibration; the third order vibration mode and the fourth order vibration mode are messy and meaningless. From the system working form, the piezoelectric vibrator operates in the two order mode.



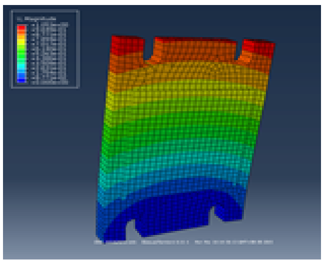
First order vibration modes vibration mode



b) Second order vibration mode



c) Third order vibration modes



d) Fourth order vibration mode

Figure 2: Modal of piezoelectric vibrator

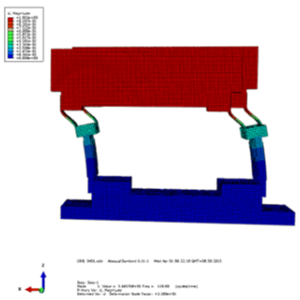
2.3 Whole machine modal analysis

The system is tested by simulation software. The grid is divided, the boundary conditions are set up, and the material parameters of each part of the system are set up. The first five order vibration modes and the modal frequencies of the conveying system are obtained, as shown in Figure 3. Materials and parameters of each part of the vibration conveying system are shown in Table 1, which mainly include 65Mn spring steel, 45 steel and hard aluminum alloys.

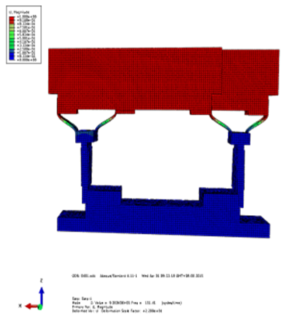
Table 1: Materials and Parameters of Each Part of the Conveying System

Name	Material Science	density kg/m^3	Modulus of elasticity Gpa	Poisson ratio
Piezoelectric vibrator	Piezoelectric ceramics	7600	63	0.32
Support spring	65Mn	7800	197	0.28
base	45#	7850	196	0.27
top plate	Duralium	2700	75	0.33

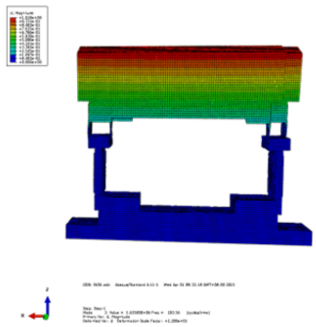
From the modal images can be seen in the first order vibration shape for pure bending vibration, second order vibration shape and torsional vibration, natural frequency is 151.4Hz, third stage, fourth stage and fifth modes rather messy. The second order vibration mode agrees well with the simulation analysis of the vibration modes of the piezoelectric vibrator, so the conveyor operates normally in the second order torsional mode.



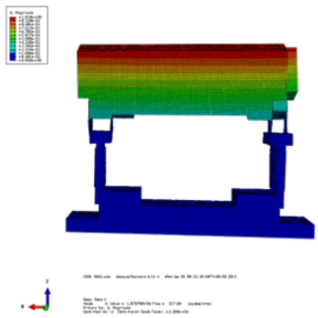
a) First order vibration model



b) Second order vibration model



c) Third order vibration model



d) Fourth order vibration model

e) Fifth order vibration model

Figure 3: Vibration pattern nephogram of the whole machine

EIGENVALUE OUTPUT

MODE NO	EIGENVALUE	FREQUENCY (RAD/TIME)	FREQUENCY (CYCLES/TIME)	GENERALIZED MASS	COMPOSITE
1	5.66576E+05	752.71	119.80	3.17316E-03	0.0000
2	9.05040E+05	951.34	151.41	3.12035E-03	0.0000
3	1.63580E+06	1279.0	203.56	1.61291E-03	0.0000
4	1.87079E+06	1367.8	217.69	1.56038E-03	0.0000
5	3.00246E+07	5479.5	872.08	5.84501E-04	0.0000
6	3.28445E+07	5731.0	912.12	9.89157E-04	0.0000
7	4.67164E+07	6834.9	1087.8	9.04348E-04	0.0000
8	5.78407E+07	7605.3	1210.4	2.26491E-04	0.0000
9	8.09112E+07	8995.1	1431.6	2.72650E-03	0.0000
10	1.41524E+08	11896.	1893.4	6.55422E-04	0.0000

Figure 4: Modal frequency of system order

2.3.1 Working principle

From the analysis of vibration modal simulation of piezoelectric vibrator and conveyor system, we know that, the bimorph piezoelectric vibrator under the action of alternating signals, can torsional alternating deformation occur, and make the supporting spring produce elastic deformation, to drive the top plate and double track vibration level approximation. As the linear conveyor in the two-vibration mode of piezoelectric bimorph, one end of which is connected with the supporting spring do exist torsional vibration, friction between the material and the material disc, the piezoelectric vibrator is less than the return reverse forward acceleration, so the material and material by friction between the discs to move forward, because the top two vibration phase instead, so as to realize the two top conveying cycle. The special design of the straight track enables the material to be screened and arranged throughout its cycle, and the final material is delivered to the specified docking device in a specified manner.

3. EXPERIMENTAL METHOD

This experiment uses M3 metal small nut as the system test object, the method is to measure the material in the straight track double track entire movement time which consumed. In order to ensure the accuracy of the experimental results, the average value method is adopted, that is, each experiment is repeated five times without changing the experimental environment and parameters, and the algebraic average of the five measurements is obtained. In order to express the speed of feeding more visually, the measured data is converted to the number of materials transported in unit time.

The actual determination method of conveying speed: the conveyor is fixed on the bench and is connected with the piezoelectric controller. After the power is switched on, adjust to proper voltage and frequency, and cause the conveyor to resonate. Measuring the time, it takes for the material to move from one end of the straight track to the other. Finally, the relationship between the feeding speed and the voltage and frequency is plotted. The test device is shown in figure 5.

The actual measuring method of system amplitude: using laser micrometer to measure amplitude, firstly, the conveyer is fixed on the experimental platform, connected with the piezoelectric controller, and connected with the power supply. Through the piezoelectric controller to change the driving frequency and voltage, point the laser head to the measuring point, measure the amplitude of the selected frequency value or voltage value, record the data, draw the relationship curve, and test the device as shown in figure 6.

Figure 5: Speed test device diagram test

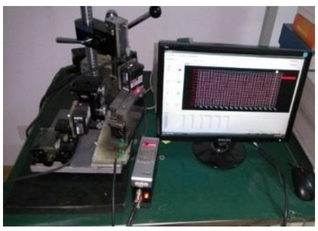


Figure 6: device of amplitude

3.1 Conveyor frequency characteristic

Drive the voltage to 200V, change the drive frequency of the system, in the second phase of the conveyor frequency near the natural frequency to measure the speed of transmission, the measurement results shown in figure 7. At the same time, the amplitude changes of the conveyer under this process are measured by laser micrometer, and the measurement result is shown in figure 8.

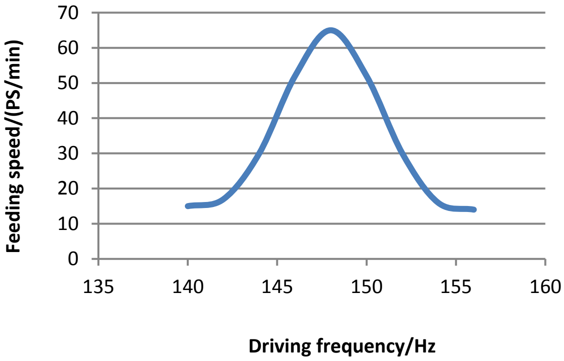


Figure 7: Relationship between drive frequency and conveying speed

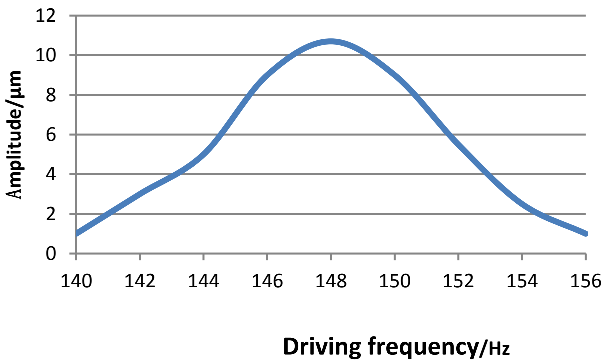


Figure 8: Relationship between drive frequency and system amplitude

As can be seen from Figure 7, the conveying speed of the conveyor is affected by the driving frequency. When the driving frequency is near 148Hz, the speed of the conveyor two tracks is maximum, reaching 65 /min, at which time the system reaches a resonance state. When the driving frequency deviates from the resonant frequency, the conveying speed decreases obviously.

As can be seen from figure 8, the trend of the amplitude curve is similar to that of the transport velocity curve. When the driving frequency reaches 148Hz, the amplitude reaches the maximum value of 11 mu m. When the driving frequency deviates from the resonant frequency, the amplitude of the conveyor is obviously decreased, and the frequency domain and the conveying speed are almost the same.

3.2 Conveyor voltage characteristic

First, the voltage of the piezoelectric controller is tuned to the resonant frequency 148Hz, the voltage is zero, and the voltage increases at 20V each to determine the corresponding speed of delivery, that is, the time from the end of the rail to the other end of the material. Then, the track vibration amplitudes of different voltages are tested in turn by means of a laser micrometer, and the curves of voltage versus speed and amplitude are obtained, as shown in Figure 9 and figure 10, respectively.

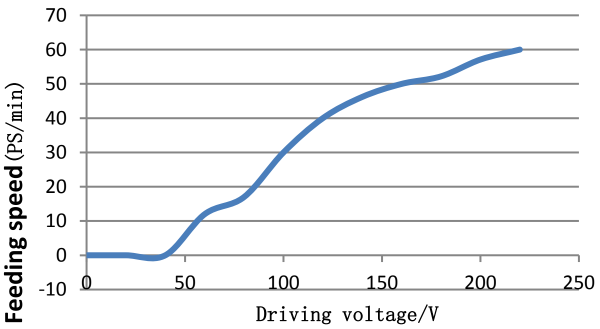


Figure 9: Relationship between transmission speed and driving voltage

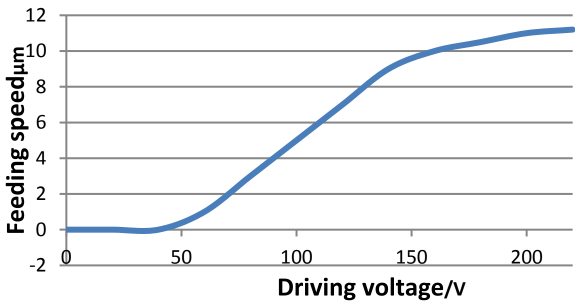


Figure 10: Relationship between amplitude and driving voltage

As can be seen from Fig. 9, when the voltage is extremely low, the conveyor feed rate is almost 0, and cannot be fed. When the voltage increases, the feed capacity of the conveyor increases gradually. With the increase of the voltage, the feed rate also increases, and its relationship is approximately linear increase. When the voltage increases to 200V, the transport speed is 54 /min.

As can be seen from Fig. 10, when the voltage of the piezoelectric controller is very low, the conveyor is almost free of vibration, and the data measured by the laser micrometer is very small and can be neglected. When the voltage reaches a certain value, the vibration amplitude of the conveyor begins to increase, but the amplitude is still small and can hardly be fed at this time. When the voltage continues to increase, the amplitude continues to increase, and the feeding capacity increases gradually, and basically linearly. When the voltage is increased to 200V, the amplitude is 13μm.

3.3 Consistency of conveying speed

In order to ensure the material transportation, the conveyor also needs to investigate the consistency of the material speed of the two-straight track. That is the natural frequency of the driving frequency conveyor reached two modes, the two-track speed difference must be maintained in a certain range, otherwise the material cannot achieve effective circulation in a straight line, prone to accumulation of clogging, conveying performance conveyor.

The first driving voltage to 200V conveyor, while driving near the frequency to two order natural frequency, frequency characteristics in the frequency domain are effective, feeding and discharging test track rail transportation speed, the test results are as follows:

Table 2: Data Sheet for Track Speed Consistency of Incoming and Outgoing Tracks

frequency（Hz） speed（ps/min）	141	143	145	147	149	151	153	155	157
Feed track	16	18	31	53	66	49	24	9	6
Discharge track	7	10	25	50	65	54	32	17	15
Velocity difference	9	8	6	5	4	5	8	8	9

As can be seen from the above table, when the driving frequency reaches the natural frequency near the two orders, the speed uniformity of the conveyor is the best. When the driving frequency deviates from the two-order natural frequency, its consistency becomes worse and worse, and the speed of the feeding track decreases gradually, and the speed of the discharge track gradually increases.

4. CONCLUSION

A reciprocating double track linear piezoelectric conveyor is designed in this paper. The system of the rectangular piezoelectric vibrator and the whole machine works in the second stage mode, and the natural frequency of the second stage is 151.4Hz. It has a certain error with the resonance frequency 148Hz of the experimental test, but basically agrees with it. The experimental tests show that the conveying speed and amplitude increase with the increase of voltage. With the increase of the driving frequency, the system increases first and then decreases, and the system works better under resonance. At the same time, the consistency of the two linear orbits is tested. The results show that the two linear track agrees well in the resonance state. When the deviation from the resonance interval, the consistency is poor.

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