A Study on the Metal Tube Type Ultrasonic Motor (MTTUSM)

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***Abstract*—The main motivation of this study hopes to understand the characteristic of the metal tube type ultrasonic motor (MTTUSM) through simple components, different driving or operation ways, its characteristic includes the rotational speed, driving phase angle and the relation of operation time and temperature rise. And hopes it can be applied to drive the small-scale optics lens mould or precision fixed position system. According to the experimental results, the maximum rotational speed is 2,075rpm under conditions of 140V_{p-p} driving voltage, 62kHz resonance frequency, 60^0 phase angle and 0.5mm thickness of piezoelectric ceramic slice. In addition, the speed that rising temperature is in direct proportion to the thickness of the piezoelectric ceramic and driving voltage. The temperature rises to 66.7^0C from 20^0C under conditions of 140V_{p-p} driving voltage, 62kHz, 90^0 driving phase angle and piezoelectric ceramic of 12mm*2mm*0.5mm size. At last, the MTTUSM is applied to push the optics lens, finds its biggest thrust is 420mN under conditions of 140V_{p-p} driving voltage, screw of M2 size and piezoelectric ceramic of 12mm*2mm*0.4mm size.**

Keywords: Metal Tube Type Ultrasonic Motor (MTTUSM), Rotational Speed, Driving Phase Angle, Driving Voltage, Optics Lens Mould.

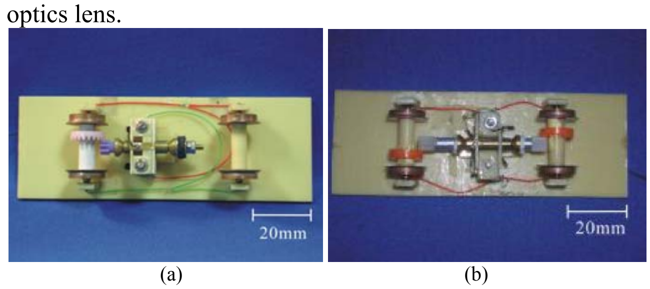
I. INTRODUCTION

Up to today, a series of ultrasonic motor was developed out since 1995[1]. This kind of USM burns metal tube of titanium altogether together with piezoelectric ceramic powder. Then spread four slices of silver electrodes separately on the piezoelectric ceramic. Among them, the paring into a cone form within both ends of the metal tube. Putting rotor and rod in metal tube finally can become a kind of simple motor. While using, so long as exert driving voltage and resonance frequency to the electrode, the rotation that can let the rotor be fast. And the motor can in the precise systems extensive application. Certainly, its size, driving voltage, driving frequency and the largest rotational speed, torsion, thrust or load ability that can be reached receiving much concern too. Such as, an ultrasonic motor using bending cylindrical transducer based on PZT thin film, the maximum rotational speed is 295rpm under conditions of 33V_{p-p} driving voltage and 105.5kHz driving frequency. And its external diameter is 2.4mm, the internal diameter is 1.9mm and the length is 10mm [1]. Next year, the motor of the same size, its driving voltage is reduced to 25V_{p-p}, and the rotational speed improves to 545rpm [2]. By 1998, the motor of the same size, its driving voltage is reduced to 15Vp-p even more, and the rotational speed is up to 880rpm [3]. By 1999, the motor of the same size cooperates with different components, and its driving voltage improves to 100Vp-p, driving frequency is reduced to 85kHz. But it is under the condition of 650rpm rotational speed, can produce the torsion of 0.22mNm [4]. So far, we can find the performance of above-mentioned ultrasonic motors very excellent.

After 2002, a **MTTUSM** come out the development successively [5-6]. This kind of USM sticks the piezoelectric ceramic slice on both sides of metal tube. In addition, its composition and operation mode are unanimous in the above-mentioned motor. Its size of the metal tube type ultrasonic motor is separately 2.4mm external diameter, 1.6mm internal diameter and 10mm length. Its maximum rotational speed, torsion and efficiency are separately 573rpm, 1.8mNm and 25% under conditions of 100V_{p-p} driving voltage, 69.5kHz and 60mW. Next year, Its length shortens to 6mm. And under the condition of the same driving voltage, its maximum rotational speed, torsion and efficiency are reduced to 430rpm, 0.5mNm and 16% respectively. Obviously its performance is influenced by metal tube length.

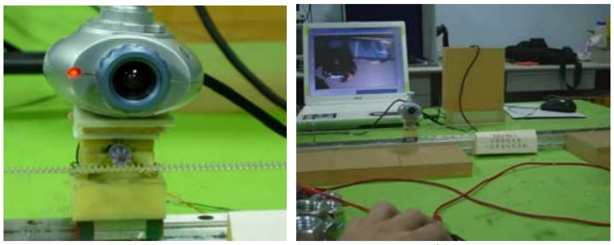
In recent years, the **MTTUSM** is tried to be made into the small-scale piezoelectric train, shows as Fig. 1 [7-8]. For the double round driving, the maximum travel speed is 261mm/s under conditions of 100V_{p-p} driving voltage and 51kHz, shows as Fig. 1(a) [7]. And for the four wheels driving, the maximum travel speed is 249mm/s under conditions of 100V_{p-p} driving voltage and 53.4kHz, shows as Fig. 1(b) [8].

In addition, this **MTTUSM** can be applied to the monitoring system, shows as Fig. 2. It is made by Piezo Lab of Cheng Shiu University of Taiwan. Its main structure includes the **MTTUSM**, the gear wheel, the rack, base, slide rail and optics lens. The **MTTUSM** can carry the fast movement back and forth on the rack and slide rail of the optics lens.



(a) (b)

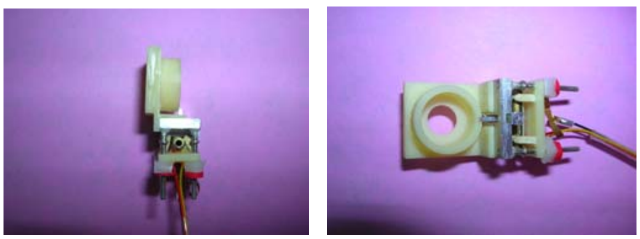
Figure 1. The back view of the small-scale piezoelectric train's prototype; (a) double round driving [7] and (b) four wheels driving [8].



(a) (b)

Figure 2. For MTTUSM on the monitoring system; (a) close shot and (b) distant view (From Piezo Lab of Cheng Shiu University of Taiwan).

Another kind of small-scale optics lens mould came out by the metal tube type USM development too, shows as Fig. 3. The small-scale optics lens mould is studied by Sunnytec Electronics Co., LTD of Taiwan. The distance of movement of this optics lens mould can exceed above 3mm at least. Among them the diameter of the optics lens is smaller than 10mm.



(a) (b)

Figure 3. For MTTUSM on the optics lens mould; (a) right side view and (b) front view (Taiwan (R.O.C.) Patent No. I265375, November 01, 2006).

As for this paper, there is mainly discussing various kinds of performance and application of the metal tube type USM. It will be applied to in new-type optics lens mould, its analysis of performance including driving voltage, rotational speed, phase angle, rising temperature and thrust, etc., shows as Fig. 4.

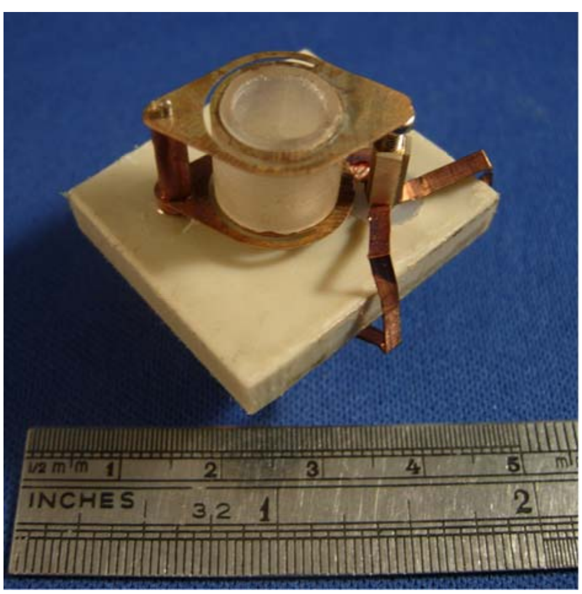


Figure 4. An optics lens mould's prototype that a kind of application the MTTUSM made.

II. Composition and Operation Principle

In this paper, the metal tube type USM (MTTUSM) is mainly used in optics lens mould, show as Fig. 4-5. Its main structure of the optics lens mould includes a shell (top cover and base), two elastic components (reed and pillar), optics lens and the MTTUSM (metal tube, piezoelectric ceramic slice, driving part and screw). When the MTTUSM is droved, the metal tube will be deformed, and cause the screw to rotate and move upwards or downwards, shows as Fig. 6. And the screw moved upwards will withstand the reed of the elastic component, will drive optics lens to do the vertical movement from head to foot by this. While doing the vertical movement that rises or drops in the rotor of MTTUSM, the elastic component can prevent the optics lens from tilting, shows as Fig. 7.

The deformation relational expression of MTTUSM in Fig. 6, can express:

$$x = X_m \sin(\omega t + \phi)\,. \tag{1}$$

$$y = Y_m \cos(\omega t + \phi)\,. \tag{2}$$

Where

$$X_m = c_x d_{33} V_{p-p}\,. \tag{3}$$

$$Y_m = c_y d_{33} V_{p-p}\,. \tag{4}$$

Or can show into an oval orbit equation from Eq.(1)-(2):

$$\left(\frac{x}{X_m}\right)^2 + \left(\frac{y}{Y_m}\right)^2 = 1\,. \tag{5}$$

Where x and y represents horizontal and vertical direction out of deformation or displacement separately. And X_m and Y_m represents the amplitude of the horizontal and vertical direction separately. ω representatives driving angle velocity or driving frequency ($2\pi f$). And ϕ representatives driving phase angle. Where c_x and c_y represents horizontal and vertical direction out of revise coefficient separately. d_{33} representatives piezoelectric constant of d-form. V_{p-p} representatives driving voltage by peak to peak.

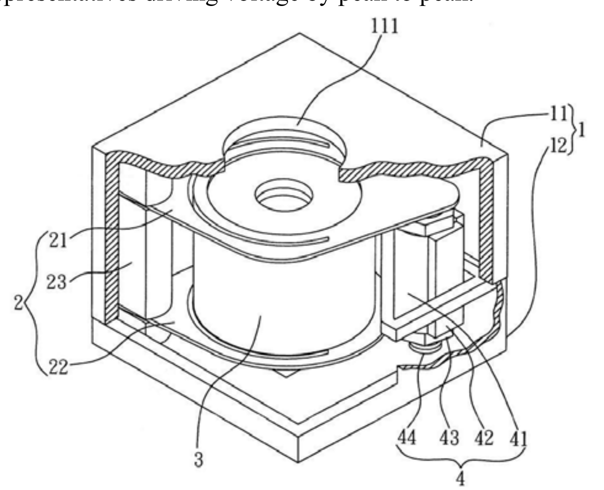


Figure 5. The composition of the optics lens mould.

TABLE I. EXPLANATION OF SYMBOLS OF THE OPTICS LENS MOULD

Symbol	Explanation
1	Shell
11	Top cover
111	Punch
12	Base
2	Elastic component
21	Reed
22	Reed
23	Pillar
3	Optics lens
4	MTTUSM
41	Metal tube
42	Piezoelectric ceramic slice
43	Driving part
44	Screw

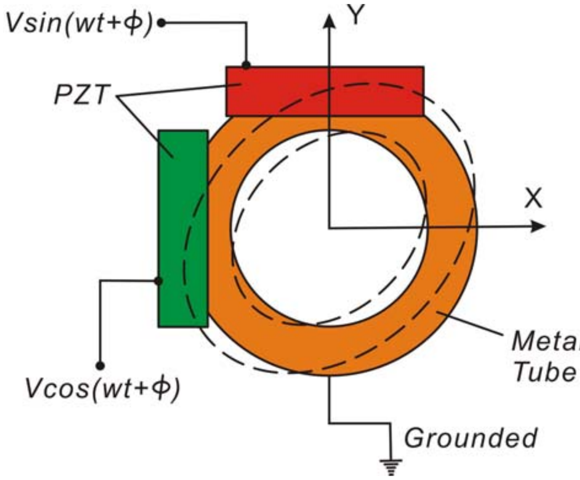


Figure 6. The operation principle of the MTTUSM.

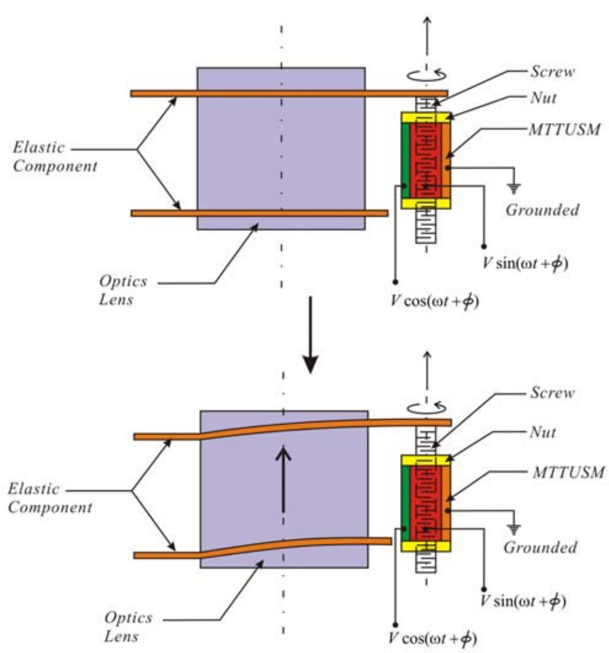


Figure 7. The operation principle of the new type optics lens mould.

III. SIMULATION

Shows as Fig. 8, we can find the best vibration mode of different MTTUSM by ANSYS code simulation. And can help us to find the best positions or nodes that install the motor.

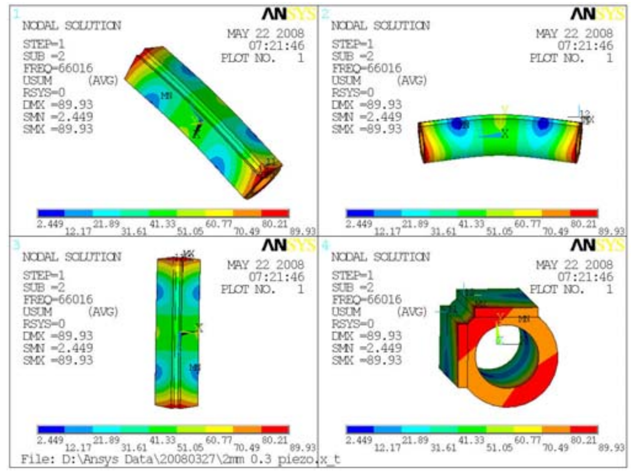


Figure 8. The modal simulation analysis of MTTUSM.

Shows as Fig. 9, we can find the optimum design form of the elastic component by ANSYS code simulation too, but will not cause the optics lens to produce tilting in moving.

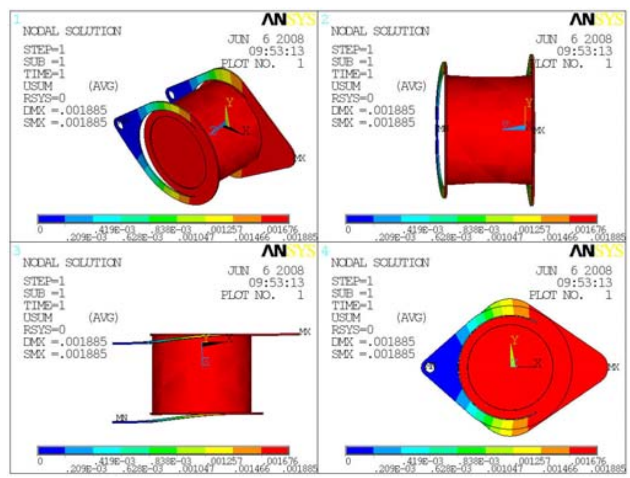


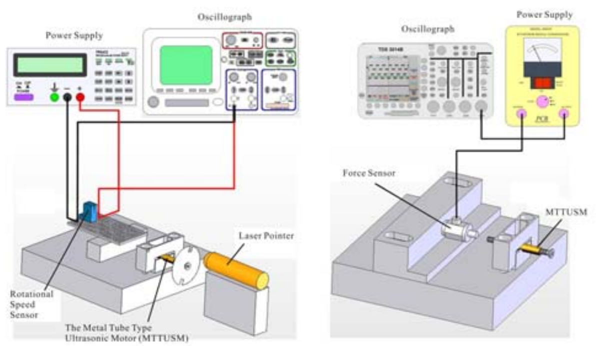
Figure 9. The deformation simulation analysis of the optics lens mould.

IV. EXPERIMENT

First, we can find the best driving frequency of MTTUSM by impedance analysis instrument (Agilent 4294A).

Second, we can find the maximum rotational speed of MTTUSM by rotational speed sensor under conditions of different driving voltages (60~100$V_{p\text{-}p}$), shows as Fig.10(a). In addition, only if stick thermal sensor on MTTUSM, we can measure the temperature change under different operation conditions.

Finally, we can find the thrust of MTTUSM by force sensor under different conditions, shows as Fig.10(b).



(a) (b)

Figure 10. Test the experiment structure of MTTUSM; (a) rotational speed testing and (b) thrust testing.

IV. RESULTS AND DISCUSSION

According to the results of experiments, we find:

(1)Under condition of different driving phase angle, the best top three rotational speed of the MTUSM is 60^0, 45^0 and 30^0 respectively, shows as Fig. 11.

(2) Under conditions of $140V_{p-p}$ driving voltage, 62kHz driving frequency and 90^0 driving phase angle, the rising temperature is in direct proportion to thickness of piezoelectric ceramic slice, shows as Fig. 12.

(3)Under conditions of different driving voltage, 62kHz driving frequency and 90^0 driving phase angle, the thrust is in inverse proportion to thickness of reed, shows as Fig. 13.

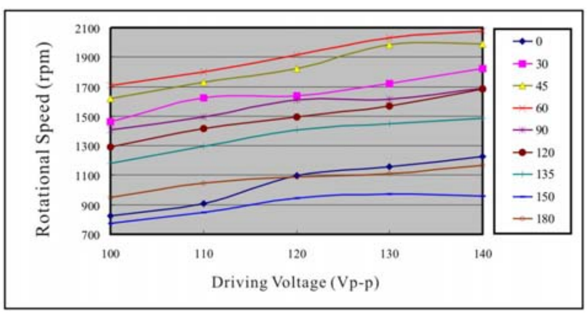


Figure 11. The relation between the rotational speed of MTTUSM and driving voltage under condition of different driving phase angle.

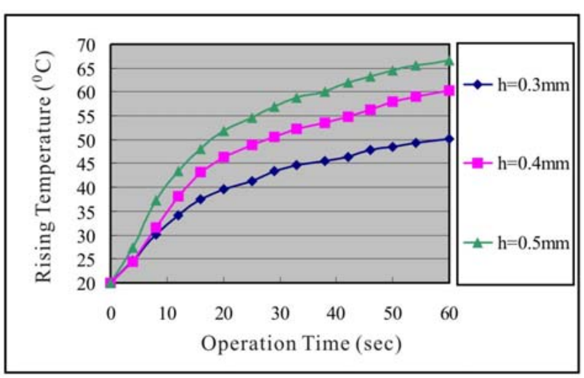


Figure 12. The relation between the rising temperature of MTTUSM and operation time under conditions of $140V_{p-p}$, 62kHz and 90^0 driving phase angle.

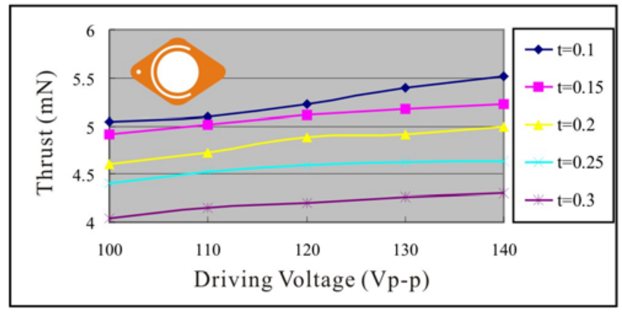


Figure 13. The relation between the thrust of MTTUSM and driving voltage under condition of different thickness of reed.

V. CONCLUSION

In this paper, we can utilize simulation (ANSYS code) and experiments to find the best driving mode or condition of the MTTUSM or optics lens mould. According to the experimental results, we find that so long as choose proper reed, driving voltage, driving frequency and driving phase angle, then MTTUSM, on having enough thrust to promote optics lens mould to move vertically. In addition, we find MTTUSM unsuitable to be used in the system operated for a long time too, because rising temperature is too high will influence the systematic normal running. But, use MTTUSM in optics lens mould with shorter operating time, the problem of the rising temperature can be neglected.

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