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Effects of Ultrasonic Motor Stator Teeth Height on Start Reliability

Abstract: As a new type of motor, the traveling wave type rotary ultrasonic motors (TRUM) have a wide range of applications. However, the friction between stator and rotor leads to its poor start reliability, which retards the progress of application of ultrasonic motors. Sometimes TRUMs which are widely used cannot start after storage. Height of tooth of the ultrasonic motor's stator is one of the factors affecting TRUM's start stabilizing. In this paper, combined with the ultrasonic motor running mechanism, the factors that affect TRUM's start reliability are studied. Model of ultrasonic motor stator tooth height is analyzed by finite element analysis (FEA). Five TRUMs with different tooth heights are fabricated and measured. A TRUM with 1.85 mm tooth height can start properly in humidity 90%, but ultrasonic motors with 1.8–1.9 mm tooth height cannot start properly under the same conditions.

Keywords: ultrasonic motors, startup reliability, tooth height, running mechanism

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Introduction

Ultrasonic motors (USMs) are a new type of motors, which apply piezoelectric vibration and frictional force as the driving source. USMs exhibit a great deal of advantage compared to the conventional electromagnetic motors, e.g., superior force/mass ratio, improved direct drive capability, high holding torque while power off, feasibility of a fully non-magnetic motor design and direct drive without speed reduction gears. USMs offer several outstanding characteristics, whereas some USMs which have been saved for some time after manufacturing cannot start properly. The nonlinear vibration of the stator contributes to the startup unreliability. Starting up from an upper frequency is an effective method to improve the reliability (Huafeng, Qingjun, and Chao 2013). Several factors on the start of USM, such as USM's work and contact parameters, friction materials and state of the environment, are studied (Weiwei 2010). In order to maintain the start stability, the effects of stator teeth are analyzed in this paper. And different tooth heights of the USM that affect start stability are verified by experiment.

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Mechanism of Startup on Teeth

Structural Parameters of Stator

USM stator dimensions greatly affect the performance of the motor, and the main structural parameters include stator tooth height, tooth width, alveolar width, stator diameter, thickness of the piezoelectric ceramic, thickness of the elastic support, support position and width.

The role of the stator teeth is to enlarge the stator vibration amplitude. Thus, stator tooth height of traveling wave rotary ultrasonic motor (TRUM) has an impact on performance. The output power of motors with teeth is greater than that of motors without teeth. No-load speed of TRUM with teeth has greatly improved. The bending vibration of the stator teeth of the stator metal elastomer is effectively converted into the driving tangential movement of the motor rotor, so that tooth height is an important design parameter. It affects the start stability of TRUMs.

Traveling Wave Rotary Ultrasonic Motors Stator Modal Analysis

TRUM stator size restricts stator tooth height. The ratio of stator teeth height h_t and stator metal body height h_m is (Chunsheng 2011)

Table 1: Parameters of ultrasonic motor.

Test number	Material of stator	Number of teeth	Height of the stator	Inside diameter of stator	Outside diameter of stator	Stator teeth height
1	Copper alloy	72	4.3	22	60	1.8
2	Copper alloy	72	4.3	22	60	1.85
3	Copper alloy	72	4.3	22	60	1.9
4	Copper alloy	72	4.3	22	60	1.95
5	Copper alloy	72	4.3	22	60	2.0

$$h_t = (0.375 \sim 0.444) \times h_m \quad [1]$$

In this study, the stator metal body height h_m was 4.3 mm.

According to eq. [1], the stator teeth height h_t was $h_t = 1.6875–1.998$ mm. The heights of the stator teeth $h_t = 1.8–2.0$ mm were selected and analyzed. In order to analyze the impact of the stator teeth height on startup stability, the other parameters stayed unchanged except stator teeth height. The other parameters are shown in Table 1.

The circumferential movement of the points on the stator's teeth contributes to driving the rotor, while in the start of TRUM, the circumferential force component produced by contacting both the stator tooth and rotor under the pre-pressure can drive the rotor. Thereby, the deformation of stator tooth that is big enough can make the horizontal movement of the points on the stator tooth and transmit it reliably to the rotor. The horizontal movement makes the stator and rotor teeth produce the circumferential force, so that the circumferential force component can come into better use for start reliability.

The TRUM modal was analyzed using ANSYS. TRUM with stator tooth height $h_t = 1.8$ mm modal is shown in Figure 1. The frequency was 53.034 kHz.

USM with stator tooth height $h_t = 1.85$ mm modal is shown in Figure 2. The frequency was 52.735 kHz. The deformation of stator tooth here was greater than deformation in Figure 1.

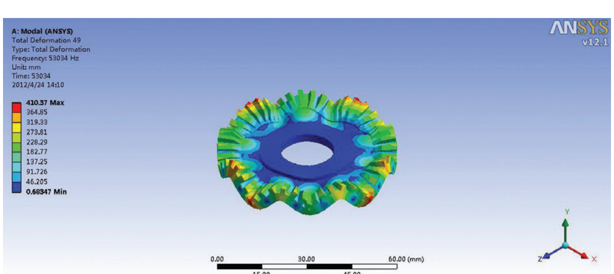

Figure 1: Mode of stator at stator tooth height 1.8 mm.

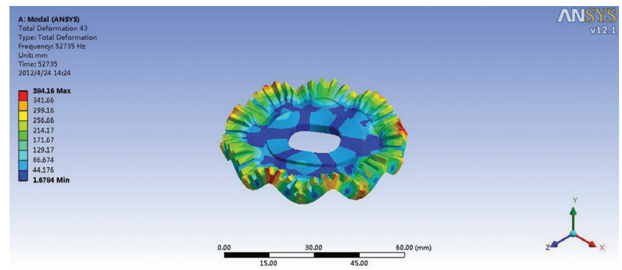

Figure 2: Mode of stator at stator tooth height 1.85 mm.

USM with stator tooth height $h_t = 1.9$ mm modal is shown in Figure 3. The frequency was 50.64 kHz.

USM with stator tooth height $h_t = 1.95$ mm modal is shown in Figure 4. The frequency was 49.485 kHz.

USM with stator tooth height $h_t = 2.0$ mm modal is shown in Figure 5. The frequency was 48.309 kHz. The deformation of stator tooth was smallest.

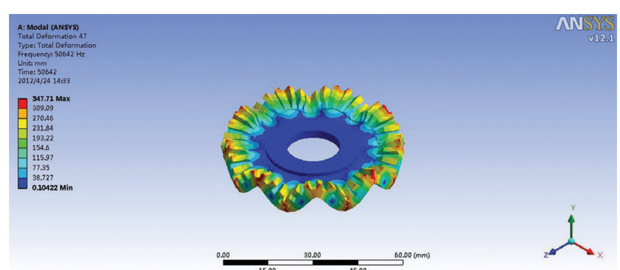

Figure 3: Mode of stator at stator tooth height 1.9 mm.

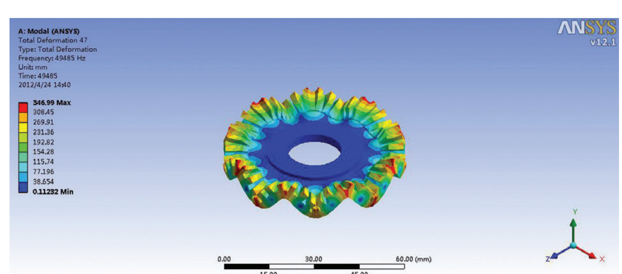

Figure 4: Mode of stator at stator tooth height 1.95 mm.

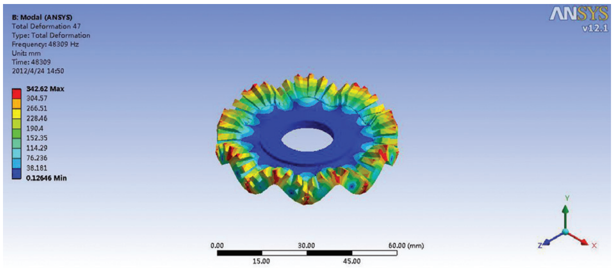

Figure 5: Mode of stator at stator tooth height 2 mm.

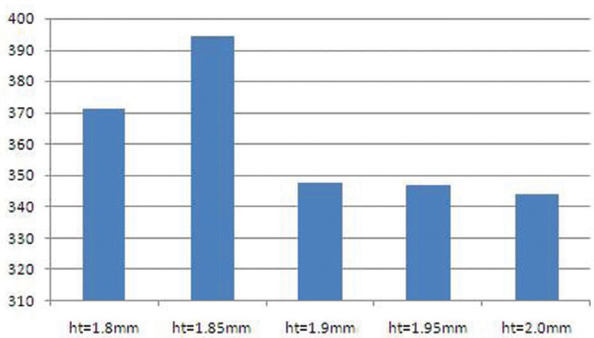

Figure 6: Deformation at various stator tooth heights.

From the above analysis, the stator deformations are shown in Figure 6.

With the deepening of the stator tooth height, the stator amplitude changes non-linearly. From 1.8 to 1.85, the amplitude increases. With an increase of tooth depth from 1.9 to 2.0, the amplitude becomes smaller. The increase of maximum amplitude of stator improves the starting reliability.

Experimental Verification

Rotation of stator of USM was transferred to the rotor through the friction material. Effect of humidity in the friction on material mechanical properties is obvious. There are many kinds of friction materials of USM. At present, the friction material widely used is mostly polytetrafluoroethylene (PTFE) or epoxy resin that can be classified into polymer material. The main components of test samples of friction material for USM are epoxy resin, graphite, aluminum oxide and PTFE (Zheng-Nian, Qing-Jun, and Chun-Sheng 2010; Qing-Jun, Zhi-Yuan, and Wei 2007). As the humidity increased, the material strength and elastic modulus decreased. The influence of humidity on small deformation modulus is more obvious (Gao Fei, Yi Lan, and Dong-Hui 2003; Gao Fei, Yi Lan, and Jing 2004). It has little effect on the large deformation modulus. The relationship between humidity and modulus of elasticity is closely linear. With the humidity increased, the effect of humidity on the modulus is weakened. The USM cannot start up properly because of the effect of humidity on the friction material.

In order to test the USM start reliability, the USM (TRUM-60) that was manufactured by Chunsheng ultrasonic motor company was tested. USM drive frequency is 40.9221 KHz. USM drive frequency voltage is 196 V that is shown in Figure 7. The USM can be started normally.

The USM was placed in the humidity test chamber. Humidity was set to 90%, temperature was set to 22°C for 24 h, which is shown in Figure 8. The USM did not start normally.

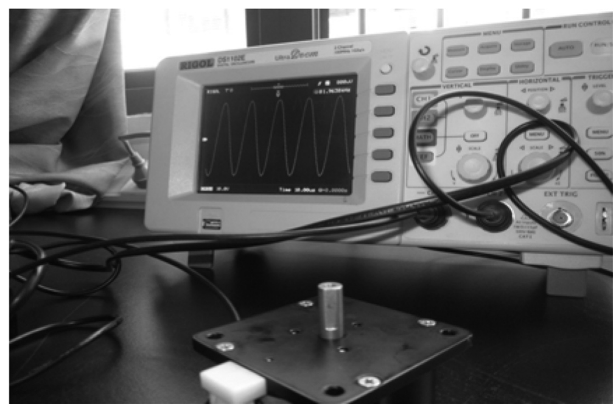

Figure 7: Ultrasonic motor normal startup.

Figure 8: Setup of humidity test.

According to the analysis in Section “Experimental Verification,” the increase of maximum amplitude of stator improves the starting reliability. We increase the stator teeth height to improve start reliability of USM. The stator teeth height was changed from 1.8 mm to 1.95 mm as shown in Figure 9. When the height was 1.85 mm, that

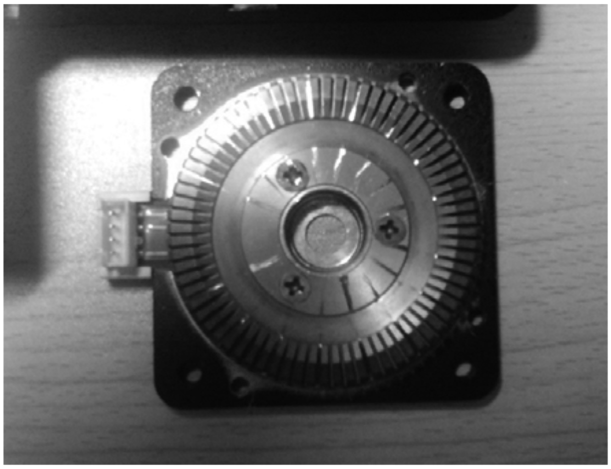

Figure 9: Ultrasonic motor stator tooth height.

USM could start up normally. The speed of the USM became smaller. The no-load speed dropped from 134 rpm to 126 rpm.

Conclusion

We analyzed the effect of humidity on the startup of USM. Combined with the USM running mechanism, the factors that affect TRUM's start reliability are studied. The USM stator tooth height that affects USM startup stability is analyzed. USMs get different startup stability by gradually increasing the tooth height in experiments. We conclude that suitable tooth height can improve startup stability.

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