Ultrasonics 56 (2015) 303–307

Contents lists available at ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

Experimental investigation on sandwich structure ring-type ultrasonic motor

Taijiang Peng *, Hongyan Shi, Xiong Liang, Feng Luo, Xiaoyu Wu

Shenzhen Key Laboratory of Advanced Manufacturing Technology for Mold & Die, College of Mechatronics and Control Engineering, Shenzhen University, Shenzhen 518060, China

ARTICLE INFO

Article history:
Received 20 May 2014
Received in revised form 31 July 2014
Accepted 12 August 2014
Available online 27 August 2014

Keywords:
Ring-type USM
Sandwich structure USM
Stator ring
Piezoelectric ceramics
Modal analysis

ABSTRACT

This paper presents a manufacture method for a sandwich structure Ultrasonic Motor (USM) and experiment. Two pieces of rotor clamped on a stator, and a stainless steel disk-spring is bonded on the hollow rotor disk to provide the press by a nut assembled on the shaft. The stator is made of a double-side Printed-Circuit Board (PCB) which is sawed out the ring in the center and connected on the board with three legs. On each side of the ring surface, there are electrodes connected at the same position via through hole. The three layer drive circuit for sine, cosine, and ground signal is connected on the board through each leg. There are many piezoelectric components (PZT) bonded between two electrodes and fill soldering tin on each electrode. Then PZT is welded on PCB by reflow soldering. Finally, rub the gibbous soldering tin down to the position of PZT surface makes sure the surface contacts with rotor evenly. The welding process can also be completed by Surface Mounted Technology (SMT). A prototype motor is manufactured by this method. Two B_{03} model shapes of the stator are obtained by the finite element analysis and the optimal frequency of the motor is 56.375 kHz measured by impedance instrument. The theoretical analysis is conducted for the relationship between the revolving speed of the USM and thickness of stator ring, number of the travelling waves, PZT amplitude, frequency and the other parameters. The experiment result shows that the maximum revolving speed is 116RPM and the maximum torque is 25 N mm, when the actuate voltage is 200VAC.

1. Introduction

USM [1–3] is a functional actuator, which makes the stator vibrating within the ultrasonic frequency domain, actualizing the revolving/linear movement and the torque/force through the friction between stator and rotor by the converse piezoelectric effect of the piezoelectric ceramic material. It is characterized with high power density, compact structure, no electromagnetic interference, good controllability of the output performance, high control accuracy, easy to direct drive, etc. Therefore, it can realize to drive without transmission system, and has been successfully applied in optical autofocus system, precise positioning table, light path controller, instrumentation, medical equipment and other applications.

The USM proposed in recent years usually utilizes the piezoelectric ceramics ring (PZT ring) vibrating to form the actuating ability. The common pattern of divisional polarization [4–8] is shown as Fig. 1, (a) is two-phase divisional polarization and (b) is equally divisional polarization. No matter which polarization pattern of the PZT ring utilized, the manufacturing process of the PZT ring is complex and leading lower yields. In order to enlarge the circumferential vibration amplitude of the points on stator surface, many evenly distributed teeth need to be machined on the metal substrate of stator [1–3,9–13]. Moreover, when gluing the PZT ring on substrate surface which opposites to the teeth side, the division boundaries on the PZT ring surface shall be aligned with the tooth slots [2]. These increase lots of the manufacture difficulty.

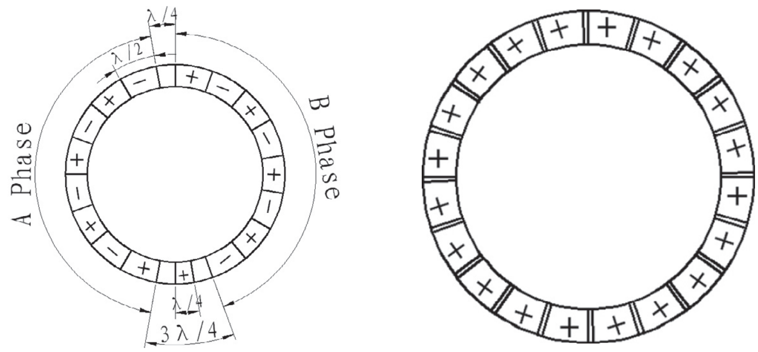
This paper presents a manufacture method for a sandwich structure USM which is composed of two pieces of rotor clamped on a stator. The stator could be fabricated with Surface Mounted Technology (SMT). A prototype of this kind USM has been manufactured and experimented on the performance.

2. Design principle of the sandwich structure USM

The structure diagram of sandwich structure USM is shown in Fig. 2. It is mainly composed of a pre-tightening nut (1), two pieces of rotor disc (2), stator (3) and shaft (4). Adjusting the nut position along the shaft can change the pressure provided by the disk-spring (9) which glued on the hollow rotor disc. Meanwhile, ensuring the two rotor discs are clamped reliably on the stator.

* Corresponding author.
E-mail address: pengtj@szu.edu.cn (T. Peng).

http://dx.doi.org/10.1016/j.ultras.2014.08.014
0041-624X/



(a) Two-phase divisional polarization (b) Equally divisional polarization

Fig. 1. Polarization pattern of PZT ring.

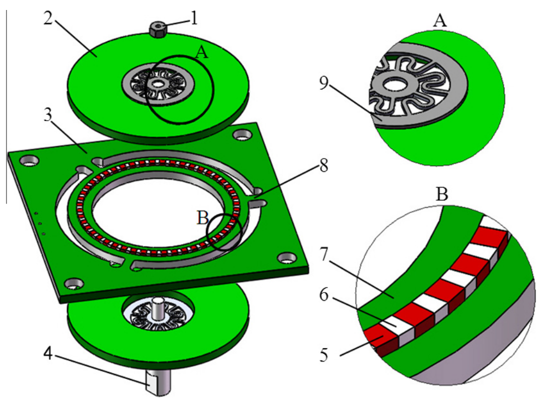


Fig. 2. Structure diagram of sandwich structure USM.

The stator is made of a double-sided PCB with three layers (Sine signal layer, Cosine signal layer, and Ground signal layer) and many PZT components (5). There are a ring (7) in the center of PCB and three legs (8) connecting the ring with the board. And there are many electrodes uniformly distributed on both sides of the ring and divided into three groups to supply sine, cosine and ground signals for PZT component respectively. The two opposite electrodes are connected via through hole. Many PZT components are uniformly bonded between two electrodes firstly and soldering tin (6) filled on electrode. Then PZT components are welded on PCB by reflow soldering. The PZT components and the soldering tin become a raised ring on the PCB ring (7), as scale-up view B shown in Fig. 3. Finally, rub the gibbous soldering tin down to the position of the PZT surface makes sure the raised ring surface contacts the rotor disc evenly.

2.1. Design principle for the stator

As mentioned above, the stator is the key part of sandwich structure USM. The PZT components and the soldering tin become a raised ring on each side of PCB which contacts rotor disc. It is different from the stator applied in ring-type USM at present.

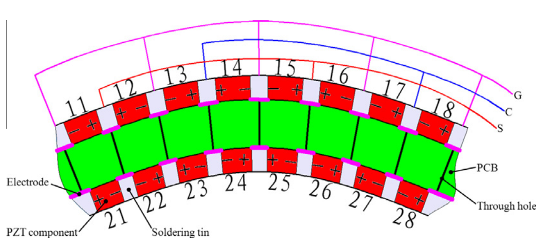


Fig. 3. Deformation schematic of half-wave length stator ring.

The structure of the stator is shown in Fig. 3 in half travelling wave length. Where "+" and "−" signs represent the polarize electric field, so the polarize direction of PZT components is from "+" to "−". The arrangement principle of bond PZT components on PCB as shown in Fig. 3 as: Each PZT component in the upside group (11–18) and underside group (21–28) is bonded with the epoxy glue between every two electrodes. The polarizing directions of each two adjacent PZT components on each side are opposite, and also the polarizing directions of each two PZT components at the same position on double sides are opposite. The electrodes are divided into three groups (including S for Sine signal, C for Cosine signal, G for GND signal) which are connected according to the wiring rules shown in Fig. 3 at each layer supplying the power for the PZT component. The electrodes are connected with signals are S, G, C, and G in turn.

Based on the operating characteristics and deformation rules of PZT, the arrangement of PZT components and the wiring rule illuminated shown in Fig. 3, it can be seen that: at the first half period of $0 - T/2$, PZT components 11–18 expand, while PZT components 21–28 contract at this segment, which makes the stator ring deformed upward like "$\frown$" shown in Fig. 3, and the next segment deformed downward like "$\smile$" ; at the next half period of $T/2 - T$, PZT components 11–18 contract, while PZT components 21–28 expand at this segment, which makes the stator ring deformed downward like "$\smile$", and the next segment deformed upward like "$\frown$". This is the deformation principle along a wavelength range of the stator ring. Therefore, assuming that the intermediate diameter of the stator ring is R, the travelling wave length is λ, PZT component length (along the polarize direction) is a, the gap between each two PZT components is b, then:

$$\begin{cases} 2\pi R = k\lambda \\ 16(a+b) = \lambda \end{cases} \tag{1}$$

where k is the number of the travelling waves along the stator ring, $k = 1, 2, 3\ldots$

According to Eq. (1), the stator structure size can be determined easily.

2.2. Vibration modal of the stator

There are three legs connecting the stator ring with the board, and the structure of the stator in this paper is different from the stator used at present, so it is necessary to establish the stator model constructed by the method above and import the stator model into ANSYS software to analyze the vibrating model. The material parameters are shown in Table 1.