DEVELOPMENT OF A MICRO SCREW THREAD AND A MICRO GEAR
COILED EXTRA FINE WIRES

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1. Introduction

Micro-mechanical parts for a micro-machine are mostly produced by two methods of a photolithography\(^1\)\(^2\) or an ultra-precise milling\(^3\). If we choose the photolithography method to make the micro parts, we can produce a lot of the micro-mechanical parts at a time like IC manufacturing; also, the parts are fabricated into the micro-machines through the processes of multi-layered deposition/electroforming and etching of sacrificial layers. However, the parts are shaped into a planar figure with constant thickness, and their materials are selected from a few materials example of poly-silicon or tungsten. Moreover, the method requires photolithography equipments for IC manufacturing systems; besides, their equipments must be kept in a clean room. The price of the lithography equipments is over several million dollars and running cost for the clean room runs up to considerable sum. Therefore, the researchers working on the development of the micro-machines which parts are produced by the photolithography method are only a handful of researchers in a few research institutes.

If we choose the ultra-precise milling method to make the micro parts, we can produce only one micro part in one manufacturing cycle; also, the part is not fabricated into the micro-machine. Nevertheless, the micro part is shaped into three-dimensional shape by CNC (computerized numerical control) machine tool with CAD/CAM system, and their materials are selected from many materials. However, the method requires a super-precision CNC machining center to enable to control five-axis machining simultaneously; besides, the CNC machining center needs diamond tools which cutting edges are fabricated to special profiles with the accuracy of sub-micrometer. The price of the super-precision CNC machining center is over several million dollars. Therefore, advanced researches for the micro-machine which parts are produced by the ultra-precise milling method are carried on the shoulders of limited researchers.

Many researchers and engineers wait for the third method to developed micro-mechanical parts with simple and inexpensive processes and without special equipments. A novel method to make the micro mechanical parts utilized extra fine wires was thought up\(^4\). In this paper, a micro mechanical system composed by the micro-screw and the micro-nut is developed, and an external micro gear and an internal micro gear utilized extra fine wires are developed, also rotations of gear trains are confirmed by experiments.

2. Micro screw and Micro nut utilized extra fine wires

The micro screw utilized extra fine wires and the standard screw of M1.2 are shown in figure 1. The micro screw is made by brazing an extra fine wire which is coiled around a needle pin. The micro screw has following dimensions; its major diameter is 0.6 millimeters, its pitch is 0.1 millimeters (i.e. 100 micrometers), and its length of threaded portion is 14 millimeters. Just for reference, the standard screw of M1.2 has following dimensions; major diameter is 1.2 millimeters, its pitch is 0.25 millimeters (i.e. 250 micrometers), and its length of threaded portion is 6 millimeters.
The micro nut utilized extra fine wires and the standard nuts of M1.2 are shown in figure 2. The nut utilized extra fine wires is made by brazing an extra fine wire which is coiled on the inside of a small tube. The micro nut has following dimensions; its major diameter is 0.65 millimeters, its pitch is 0.1 millimeters (i.e. 100 micrometers), and its thickness is 4 millimeters. Just for reference, millimeters. The micro nut utilized extra fine wires and the standard nut of M1.2 has following dimensions; its major diameter is 1.2 millimeters, its pitch is 0.25 millimeters (i.e. 250 micrometers), and its thickness is 1.2 millimeters.

3. Micro mechanical system composed by the micro-screw and the micro-nut

3-1. Micro stage
A micro-stage composed by the micro-screw and the micro nut is developed as shown in figure 3. and figure 4. The micro screw with pitch of 100 micrometers acts as a lead screw of the stage, and the micro nut with pitch of 100 micrometers acts as a driving nut of the stage. An angle plate is attached to the micro nut for restraining rotations of the nut. The driving nut travels 100 micrometers by one turn of the micro screw. Position accuracy of the stage was followings: the mean travel of strides in which the micro screw rotated one turn was 103.3 micrometers, standard deviation of the strides (i.e. $3\sigma$) was 1.9 micrometers.

3-2. Screw-worm mechanism
A screw-worm mechanism composed by the micro-screw, the screw-worm gear is developed as shown in figure 5 and figure 6. The screw-worm gear consists of the standard screw of M2 and a flexible screw in which the extra fine wire is brazed around a flexible wire made by same manufacturing method for the micro screw. The flexible screw is coiled and is brazed along a groove of the standard screw. The screw-worm gear is moved to its axial direction with spiral motion guided to the standard nut of M2 by the rotation of the micro screw. Each pitch of the micro screw and the flexible micro screw is 400 micrometers, and reduction ratio between the micro screw and the screw-worm gear is 1/34.5. Therefore, travel distance becomes 11.6 micrometers in one turn of the micro screw because the pitch of the
standard screw of M2 is 400 micrometers and travel distance is 400/34.5 micrometers.

4. The external micro gear and the internal micro gear utilized extra fine wires

The external micro gear and the internal micro gear utilized extra fine wires are shown in figure 7. Pitch of these gears is 400 micrometers. Module of the gears is 127.3 micrometers.

The external micro gear utilized extra fine wires are made through following processes as shown in figure 8. Firstly, a needle pin to be hardly soldered is prepared. We used a hypodermic needle as the needle pin. The pin is made of stainless steel and is hardly soldered. Its diameter is 800 micrometers. Secondly, an extra fine wire to be firmly soldered is closely coiled around the needle pin. We used a tinning copper wire as the extra fine wire to be firmly soldered and its diameter is 200 micrometers.

Thirdly, the extra fine wires to be firmly soldered and the extra fine wires to be hardly soldered are arranged around the coiled needle pin. We used the tinning copper wire as the wire to be firmly soldered and used a tungsten wire as the wire to be hardly soldered. Both diameters of the wires are 200 micrometers. Fourthly, these wires are bound by the extra fine wire to be hardly soldered. Fifthly, the bound and coiled needle pin is soaked in melted solder, and the wire to be firmly soldered is brazed around the coiled needle pin, yet the wire to be hardly soldered is not brazed. Finally, the wire to be hardly soldered is removed, and the wire to be firmly soldered is remained as teeth of the micro gear. The needle pin is removed from the coiled and brazed wire. The coiled and brazed wire forms a hub of the gear.

We coiled and removed the wires by hand. The solder consists of 50 percent tin (Sn) and 50 percent lead (Pb).

The internal gear utilized extra fine wires are made through almost same processes as shown in figure 8. We use a little thick pin as the substitute of the needle pin. On coiling process as shown in figure 8-(2), the extra fine wire to be hardly soldered is closely coiled around the needle pin. After the binding process as shown in figure 8-(4), a the bound and coiled thick pin is inserted in a ring and is soaked in melted solder. Finally, the wires to be

Figure 7. The external micro gear and the internal micro gear utilized extra fine wires.

(1) Preparing the needle pin
(2) Coiling the extra fine wire
(3) Arranging the extra fine wires
(4) Binding the extra fine wires
(5) Brazing the extra fine wires
(6-1) Removing the coiled wire
(6-2) Removing the extra fine wire

Figure 8. Making processes for the micro gear.
hardly soldered and the a little thick pin are removed. The internal micro gear is manufactured.

5. Rotational test for the gear trains

A gear train engaged two external gears was rotated in the experiments as shown in figure 9-(1). Drive gear having nine teeth rotated with the angular velocity of 1000 rpm, and the other gear having eleven teeth had been rotated over 10 minutes. Other gear train engaged the external gear and the internal gear was also rotated over 10 minutes as shown in figure 9-(2). These gears have not broken yet.

The external micro gear and the internal gear have a same module of 127 micrometers (i.e. their pitches are same length of 400 micrometers).

6. An external micro gear constructed around a tube mesh.

The external micro gear constructed around the tube mesh is shown in figure 10. We used a tube mesh as the substitute of the coiling wire in figure (8)-2, so the melted solder permeated enough between the extra fine wire and the tube mesh. The extra fine wire that composes gear teeth was strongly brazed to the tube mesh that becomes the gear hub.

7. Prompt results of other trial micro parts utilized the extra fine wires

A micro stage supported by six linkages is shown in figure 11-(1). The linkages were made by coiling and knotting of the extra fine wire. A slider crank mechanism is shown in figure 11-(2) as an application of the linkage.

9. Conclusions

The micro mechanical systems composed by the micro-screw and the micro-nut are developed, and the external micro gear and the internal micro gear utilized extra fine wires are developed, also rotations of the gear trains were confirmed by experiments.