Hybrid ultrasonic actuator for force-feedback interface

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1. Introduction

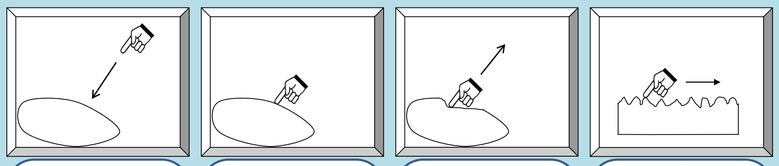
An ordinal force-feedback device by electromagnetic motor (EMM)
- Reproduction of the feeling of softness is good.
- Reproduction of the realistic feeling of hardness or roughness is not easy.

On the other hand,

Ultrasonic motor (USM)
- Rapid response and operation by the frictional force.

Effective

A force-feedback device by USM
- Reproduction of the realistic feeling of hardness or roughness will be good.



Free
A user doesn't touch a virtual object and can move freely.

Holding
A user touch a virtual object and is held.

Reaction
A user feels elastic force of a virtual object.

Roughness (Application)
A user feels roughness of a virtual object.

Table. Operating status of EMM, USM and hybrid ultrasonic actuator under electrical driving conditions.

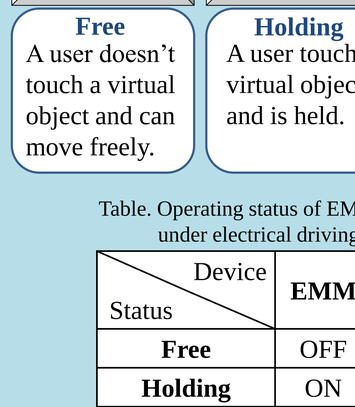
Device / Status	EMM	USM	Hybrid ultrasonic actuator
Free	OFF	Unable	Clutch OFF
Holding	ON	OFF	OFF
Reaction	ON	ON	ON

Problem: An ordinal USM cannot control the state of free, because a stator vibrator is always preloaded to a rotor or slider.

Solution: An USM with a clutch function.

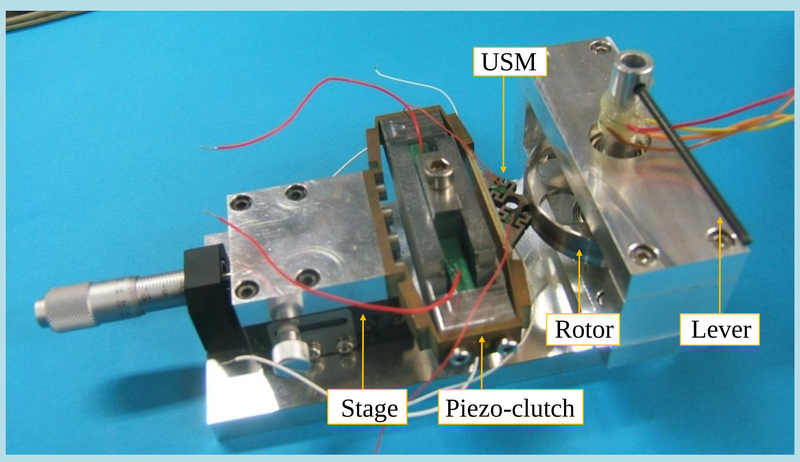
Objective: Development of a hybrid ultrasonic actuator which can electrically control a preload and generate a thrust.

2. Construction



USM part : Generate a thrust.
Piezo-clutch part : Control a preload.

A user can simply confirm the feeling of a virtual object on one axial revolution by a handling lever.



3. Operating principle

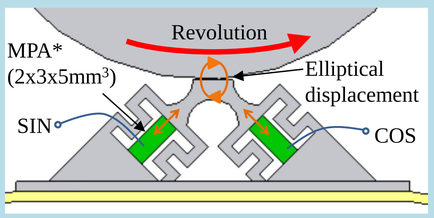
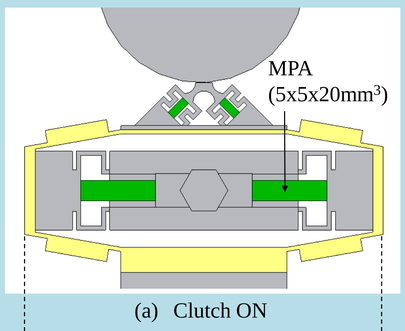


Fig. Operating principle of the USM.
*MPA (Multilayer piezoelectric actuator)

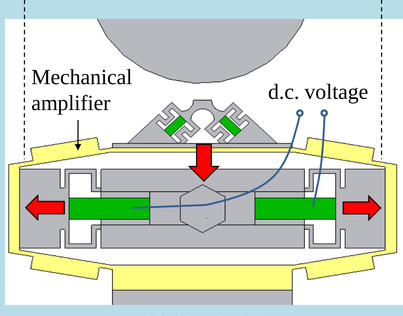
Two MPAs are arranged perpendicular to each other.

Problem: Only MPA doesn't have displacement enough for the clutch operation.

Solution: The piezo-clutch have a mechanical amplifier.



(a) Clutch ON



(b) Clutch OFF

Fig. Operating principle of the Piezo-clutch.

4. Measurement results

4.1 Response time of displacement of piezo-clutch

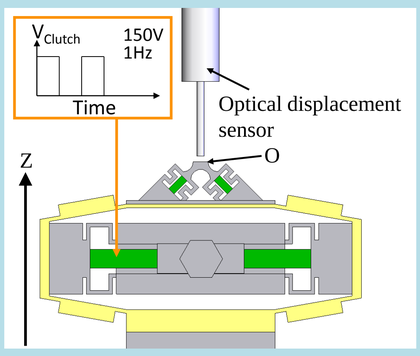
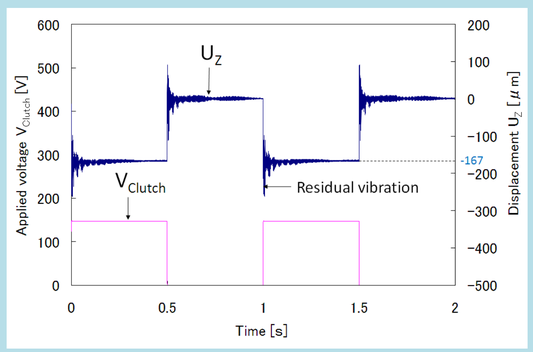


Fig. Measured displacement at the point O.



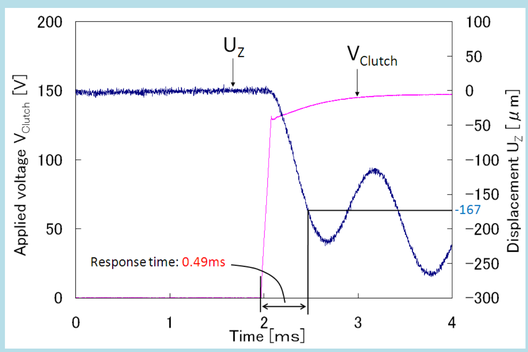


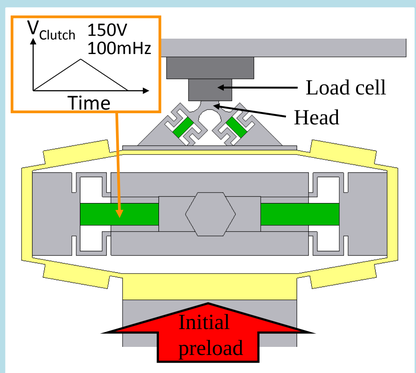
Fig. Measured response time of displacement at the point O immediately after input pulse.

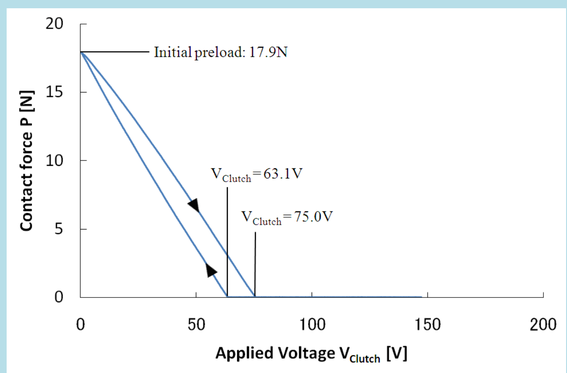
Measured displacement was not steady immediately after input pulse because of the residual vibration of the mechanical amplifier.

Target displacement: -167μm
Response time : 0.49ms

The piezo-clutch had a rapid response.

4.2 Preload control by piezo-clutch

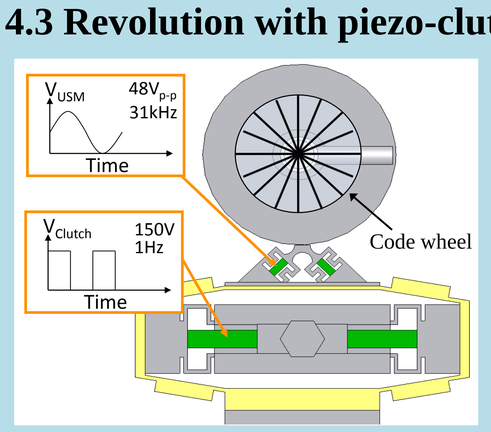


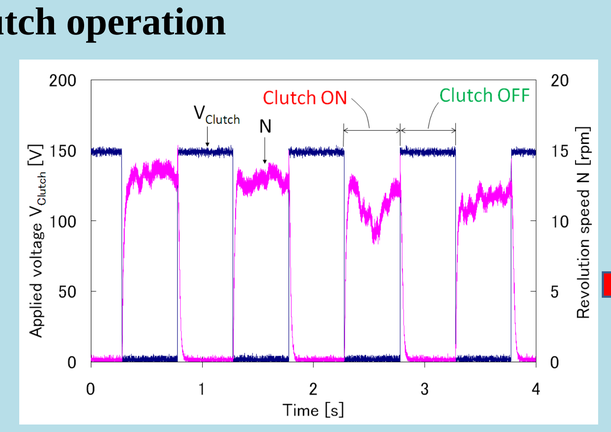


V_{clutch} = 75.0V: The head of the USM was separated from the load cell.
V_{clutch} = 63.1V: The head of the USM was contacted again to the load cell.

The piezo-clutch was possible to control preload and operate clutch function by changing input voltage.

4.3 Revolution with piezo-clutch operation

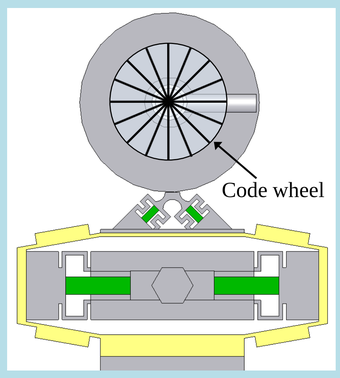




Clutch ON : Rotation
Clutch OFF: Free

This actuator was able to operate as hybrid ultrasonic actuator with USM and piezo-clutch function.

4.4 Revolution speed characteristics



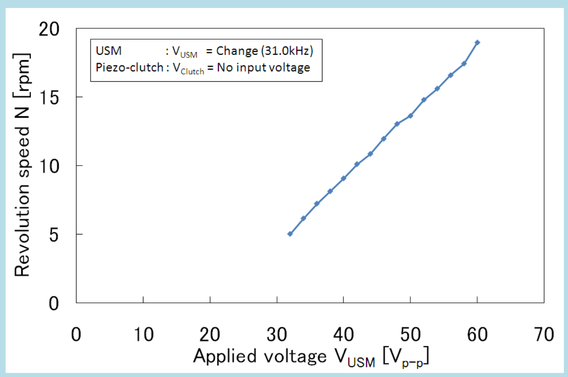


Fig. Revolution speed vs. input voltage to MPAs of USM.

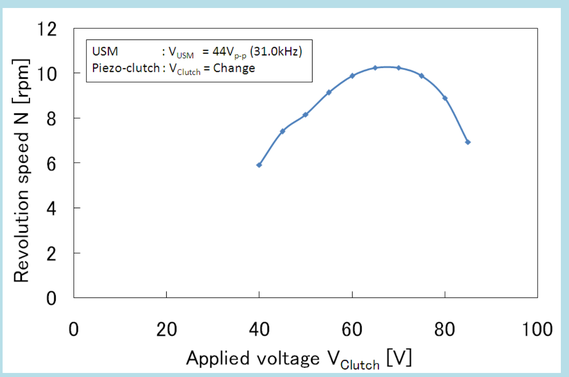
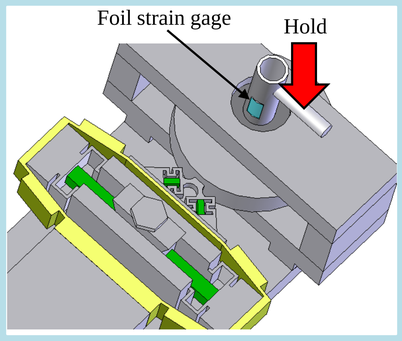


Fig. Revolution speed vs. input voltage to MPAs of piezo-clutch.

The USM or the piezo-clutch were possible to control revolution speed by changing input voltage.

4.5 Torque characteristics



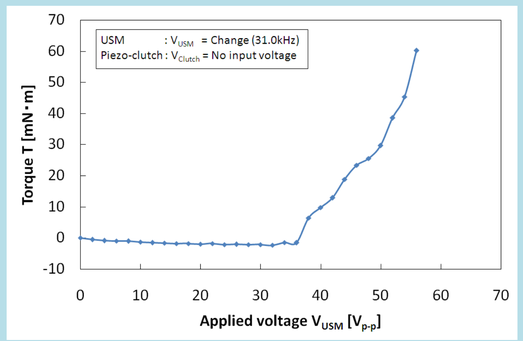


Fig. Revolution speed vs. input voltage to MPAs of USM.

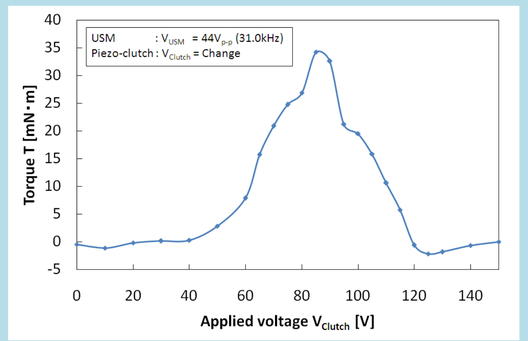


Fig. Revolution speed vs. input voltage to MPAs of piezo-clutch.

The USM or the piezo-clutch were possible to control torque by changing input voltage.

Hybrid ultrasonic actuator will be possible to reproduce the state of reaction of a virtual object.

5. Conclusions

- A hybrid ultrasonic actuator which has USM function and piezo-clutch one with a rapid response was successfully developed as a first trial.
- The USM and the piezo-clutch were possible to control revolution speed and torque by changing input voltage.
- When pulse was applied to MPAs of the piezo-clutch, it is necessary to control the residual vibration of mechanical amplifier.