An ultrasonic actuator with electrical preload control function for force-feedback interface

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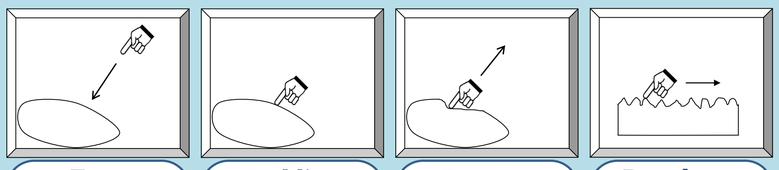
1. Introduction



Free	Holding	Reaction	Roughness (Application)
A user doesn't touch a virtual object and can freely move.	A user is just touching a virtual object and being held.	A user is feeling the elastic force of a virtual object.	A user feels the roughness of a virtual object.

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

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

Table. Operating statuses of EMM, USM and ultrasonic actuator with clutch under electrical driving conditions.

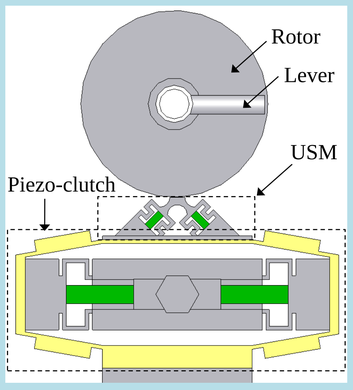
Device / Status	EMM	USM	Ultrasonic actuator with clutch
Free	OFF	Unable	Clutch OFF
Holding	ON	OFF	OFF
Reaction	ON	ON	ON

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

Solution: USM with a clutch function.

Objective: Development of an ultrasonic actuator with clutch which can electrically control a preload.

2. Construction



USM part : A thrust generation.
Piezo-clutch part : A preload control.

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

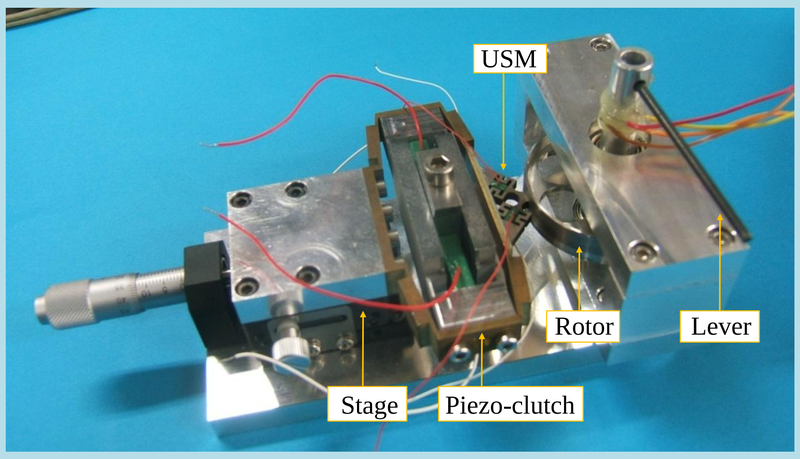


Fig. Experimental setup.

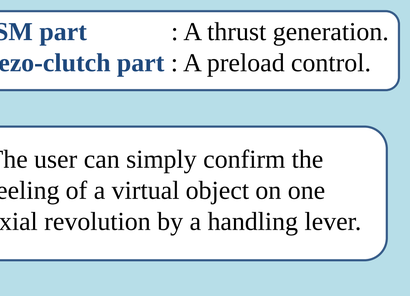
3. Operating principle

Fig. Operating principle of 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 has a mechanical amplifier.



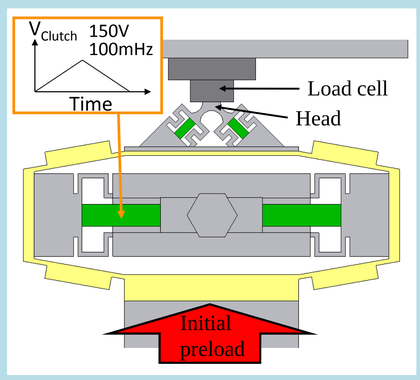
(a) Clutch ON

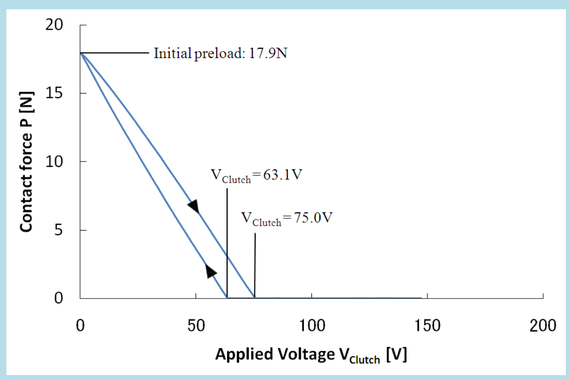
(b) Clutch OFF

Fig. Operating principle of Piezo-clutch.

4. Measurement results

4.1 Preload control by piezo-clutch

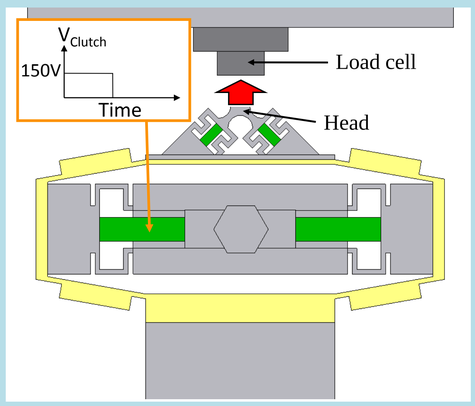


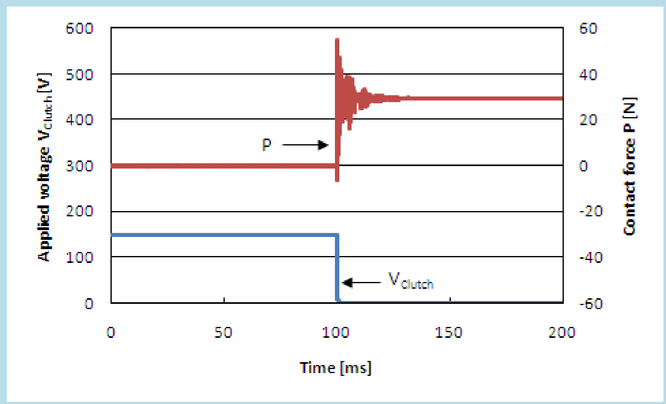


V_{clutch} = 75.0V: The head of the USM was separated from the load cell.
V_{clutch} = 63.1V: The head of the USM was in contact again with the load cell.

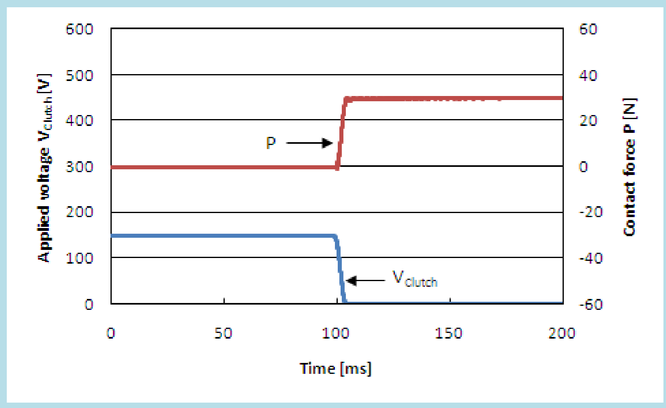
The piezo-clutch was possible to control preload and operate a clutch function by changing the applied voltage.

4.2 Piezo-clutch operation characteristics





(a) In the case of step input voltage. (Indicial response)



(b) Applied voltage of fall time of 3ms.

Fig. Contact force measured in the case of input voltages.

Trailing edge of input voltage: **Step**

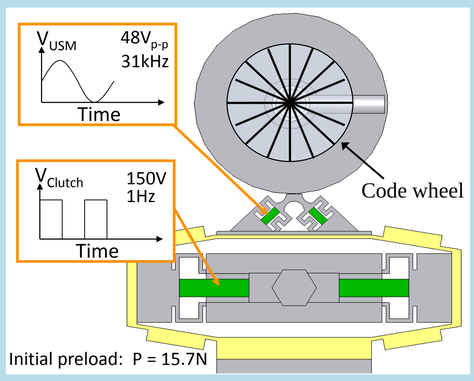
The residual vibration occurs on the mechanical amplifier.

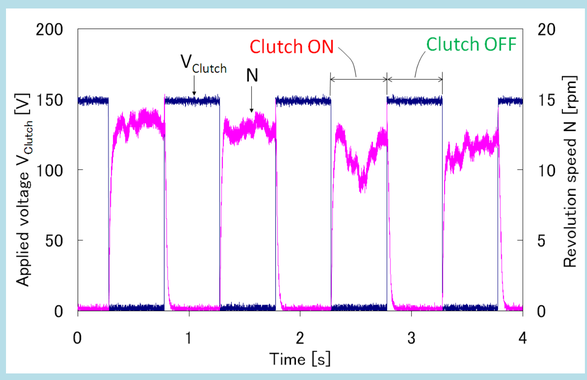
Problem
A user feels the residual vibration as an excess feeling.

Solution
Fall time of applied voltage: **3ms**

The residual vibration on the mechanical amplifier was suppressed.

4.3 Revolution with piezo-clutch operation



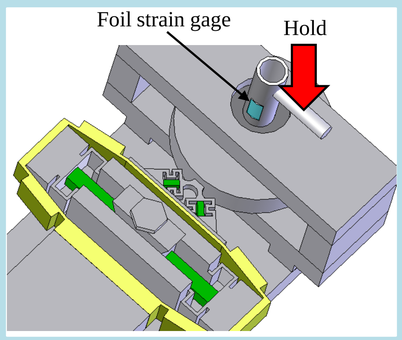


Clutch ON : Rotation
Clutch OFF: Free

The states of torque free and drive were rapidly switched over.

This actuator can be both USM and piezo-clutch.

4.4 Torque characteristics



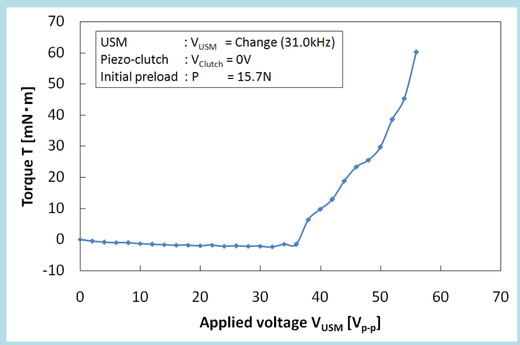


Fig. Torque vs voltage applied to MPAs of USM.

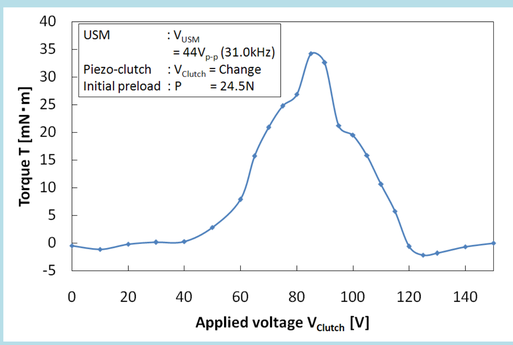


Fig. Torque vs voltage applied to MPAs of piezo-clutch.

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

The Ultrasonic actuator with clutch will be possible to reproduce the state of reaction of a virtual object.

5. Conclusions

An ultrasonic actuator with clutch which has USM function and piezo-clutch one with a rapid response was successfully developed as a first trial.

This device can reproduce the state of free.

When applied voltage of fall time of 3ms was applied to MPAs of the piezo-clutch, the residual vibration on the mechanical amplifier was suppressed.

A user does not feel the residual vibration.

The USM and the piezo-clutch were possible to control torque by changing the applied voltage.

This device can reproduce the elastic force of a virtual object.

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