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Development of 2-D Force Display System Using MR Actuators

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Abstract

A force display system is a kind of these robot systems, which share pepole with the space while they are working, and which directly touch and display force-sences to their users. For such a robot system, it is desirable to estimate safety quantitatively and to ensure mechanically safety. By using MR actuators, the safety can be ensured. Moreover, characteristics of MR actuators which are low inertia, high torque/inetia ratio and high resposibility make the force display system present high rigidity and high fidelity. In this study, we were started developping MR actuators and a 2-D force display system with them. As a result, MR actuators whose torque/inertia ratio are much higher than conventional servo actuators and the 2-D force display system which can present high rigidity are developed. Moreover, this system can ensure safety mechanically and quantitatively.

Key Words: force display, virtual reality, MR fluid, actuator, Safety

1. Introduction

Force display systemes are a kind of robot systems and expected to have much effects and advantages as means of human interface. On the other hand, they are inherently involved a potential hazard in that they may uncontrollably move and hurt operators when something really goes wrong. Thus, for these robot systems, it is most important problem how they are designed to ensure safety. Some robot systems are insisted to ensure safety, but this argument of safety is abstractly. It is desirable that safety of robot systems is ensured quantitatively.

We have insisted that safety of robot systems can be improved by using a clutch-type actuator. Based on this insistence to safety, we have developed ER actuators, MR actuators and human interface as their application[1]∼[4].

In this study, we aim to develop MR actuator with low inertia and high torque/inertia ratio for force display system, and to develop 2-D force display system as its application. Since using MR actuator, this force display system can accomplish the following features:

(i) Mechanically and quantitatively ensurance of safety to the users.
(ii) Presenting free feeling in free space.
(iii) The force presentation with high rigidity.
(iv) The force presentation with high fidelity.

In this paper, merits of clutch-type actuators, especially MR actuators in application to human interface such as force display systems are firstly described. Secondly, the development of MR actuators with low inertia, high torque/inertia ratio and high responsibility is reported. The torque/inertia ratio of the developed actuator is much higher than conventional actuators. Then some basic characteristics of the MR actuators are shown. Lastly, the development of a closed-link-type force display system equipped new MR actuators is described. This system can present force-senses with high rigidity and high fidelity.

2. MR Actuator

2·1 MR Fluid

An MR Fluid (MRF)[5]∼[10] is a non-colloidal solution containing polar particles that are several micrometers in diameter. It is a substance that changes its apparent viscosity (rheological characteristic) according to the strength of the magnetic field applied.

2·2 MR actuator

Figure.1 shows the mechanism of MR clutch. The input part of the MR clutch is rotated in low speed. The strength of magnetic field is changed by the current supplied to the coil, and the torque transmitted from the input part to the output part is controlled by the magnetic field. In short, torque of MR clutch is controlled by the current supplied to the coil. MR clutch has higher responsibility, higher torque/inertia ratio and lower inertia than other conventional clutches, for example, a powder clutch and electromagnetic clutch. This actuator system includes MR clutch and drive-system consisting of a motor and a reduction gear is called MR actuator.

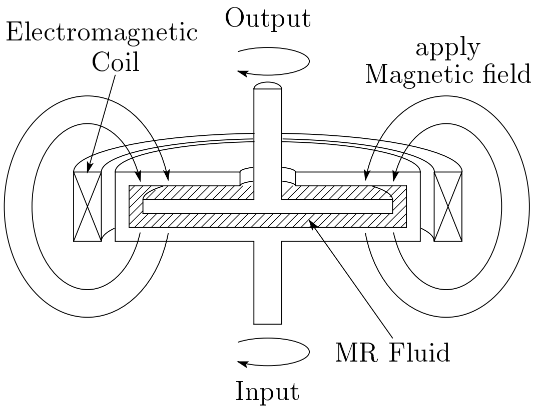

Fig.1 Mechanism of MR clutch

2·3 Merits of clutch-type actuators in safety

In the case of human interface such as a force display system, the robot may come in contact with the user accidentally. Therefore, it is desirable to estimate quantitatively and to ensure mechanically safety[11]∼[12]. The collision energy and the collision force are influenced by the kinetic energy, the kinetic momentum, the speed and the output of the robot system which are proportion to the square of the speed or the speed. Thus, it is possible to discuss quantitatively safety of a robot equipped with an actuator whose maximum angular velocity can be arbitrarily set.

The maximum output speed of the clutch is restricted to the one of input of the clutch. If the input part is driven by using the fixed voltage power supply etc., the maximum speed of the actuator can be set mechanically and arbitrarily. Therefore, it can be said that safety can be ensured mechanically and quantitatively by using the clutch type actuator.

2·4 Merits of clutch type actuators in force display system

When presenting free feeling in free space, a force display system must not disturb the user's motion. If the driving system of a force display system consists of a motor and gear unit, it is difficult to present free feeling because the inertia of the motor influences the user's sense in no small way. On the other hand, in the case of using a clutch type actuator, the inertia of the actuator hardly influence the user's sense.

2·5 Superiority of MR actuator in clutch-type actuators

Generally, the electromagnetic clutches and the powder clutches have been used as a clutch mechanism which can control the transmission torque. However, they are difficult to be used as a servo clutch or a servo actuator because their time constant are from tens of milliseconds to one handred and tens of milliseconds. On the other hand, an ER actuator and a MR actuator have so fast time constant (several milliseconds) that they can be used as a servo actuaor.

In addition, it is easier for the MR actuator to be designed high torque than for the ER actuator because the maximum generation shearing stress of MR fluid is from 50 ∼ 100[kPa] while the one of ER fluid is from 2 ∼ 5[kPa]. Thus, it can be said that a MR actuator has 1)high responsibility and 2)is made to have high torque easily.

2·6 Merits of MR actuators in force display system

According to the above facts, we may say a MR actuator as used for a force display system has the following merits:

(i) As the MR actuator requires no reduction unit and its inertia is quite low, the actuator has good backdrivability.
(ii) Because the MR actuator features large torque/inertia ratio and quick response, it can reproduce high-frequency torque. It can, therefore, provide users with such a feeling as they will have when they hit a hard object.
(iii) Since the MR actuator is one of the clutch systems, the maximum rotating speed of the output shaft is governed by the driving speed of the input part. That is, the maximum speed of the output shaft is limited mechanically.
(iv) A force display system that has a lower inertia can be developed with the MR actuator. A lower-inertia sysytem means a smaller shock when users are accidentally hit by the system.
(v) In emergency, by turning the applied magnetic field off, user can shut off the output of the MR actuator quickly.

3. Development of MR Actuator

The new MR actuator is developed for a force display system. The basic mechanical and magnetic structure is same as the MR actuator which has developed by Rin, et al[4]. Moreover, the following mechanically devices are given to the new MR actuator.

(i) The thickness of the output disk is designed 1)to keep the strength of its part installed on the output shaft and 2)to reduce the inertia of it.
(ii) The tendency that the metal particles of MR fluid sink in the bottom is strong because specific gravity of the metal particles is quite different from one of oily continuous medium. Then the shape of the bottom of the part filled with MR fluid is made so flat that decentralization of

the metal particles was caused easily.

(iii) The output shaft is designed in consideration of rigidity to realize high fidelity in high-frequency band.

Figure.2 and Figure.3 are a picture and a cross section of the clutch part of the new MR actuator respectively. Table 2 is characteristics of the MR clutch developed.

Fig.2 A Picture of MR clutch

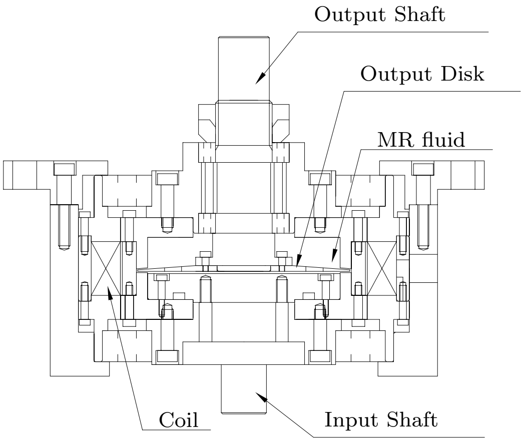

Fig.3 Cross Section of MR clutch

Table 1 The characteristics of MR clutch developed

Diameter of Casing	170 [mm]
Height	120 [mm]
Diameter of Output Disc	75 [mm]
Inertia of Outout Parts	2.6×10^{-5}[kg $\cdot$ m^2]
Mass	4 [kg]

4. Characteristics of MR Actuator

Some basic experiments on the new MR actuator are carried out. Figure.4 and Figure.5 show dynamic and static characteristics of MR actuator respectively. In these experiments, the input rotating speed is 5[rad/sec]. Time constant of the MR actuator is several milliseconds and the maximum torque of it is 10[N·m]. Torque saturation is originated when coil current given the MR actuator is more than 1[A] because MR fluid itself is saturated magnetically. Table 2 is the summary of the characteristics of the MR actuator. Base torque in this table means the torque generated when coil current is 0[A].

Table 3 is comparison between the MR actuator and conventional actuators. As shown in this table, torque/inertia ratio of the MR actuator is much higher than one of conventional actuators. Thus, it can be said that the new MR actuator has enough high output torque for the force presentation, high resposibility and less mechanical delay than conventional actuators.

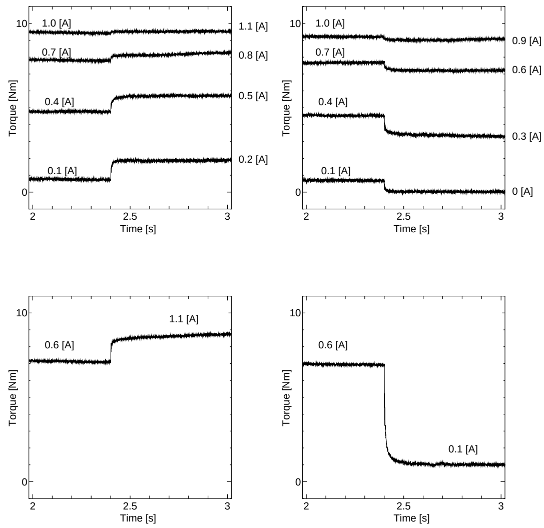

Fig.4 Dynamic characteristics of MR actuator

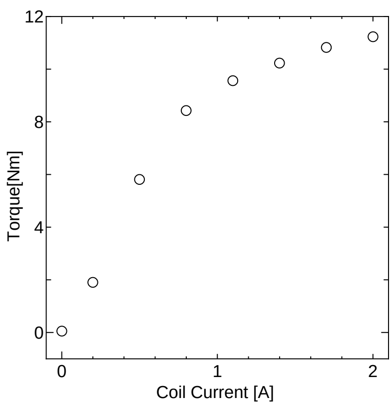

Fig.5 Static characteristics of MR actuator

5. Development of Force Display System

By using the MR actuator, the following advantages in a force display system are obtained.

Table 3 Comparison between MR actuator and conventional actuators

		MR Actuator	AC Servo	DD Motor
Maximum continuous Torque	[N · m]	10	9.5	8
Inertia of Outout Parts	[kg · m^2]	2.6×10^{-5}	12.1×10^{-4}	1.5×10^{-2}
Torque/Inertia Ratio	[1/s^2]	3.8×10^5	7.9×10^3	5.3×10^2

AC Servo Sanyo Denki Co.,Ltd P20B13300DXS:3.0[kW]
DD Motor Yokogawa Electronics Manufacturing Corporation DR1008B

Table 2 The characteristics of MR clutch developed

Torque	Max10 [N · m]
Base Torque	1.65×10^{-2}[N · m]
Time Constant	2.4 ∼ 6.9[ms]
Torque/Inertia Ratio	3.8×10^5[1/s^2]

(i) The system can present high rigidity because the MR actuator has high torque/inertia ratio property.
(ii) High responsibility of the MR actuator can make the force presentation with high fidelity possible.
(iii) Low inertia and low base torque of the MR actuator can improve free feeling in free space.

Moreover, the following mechanical devices are done to enlarge mechanical regidity, to reduce friction of the output transmission system and minimize the size of a force display system.

(i) The output transmission system is composed of a belt and pulleys not to generate the backlash.
(ii) The rigidity of the system is designed enough high to be used in high frequency band.
(iii) The belt tensioner in the output transmission system is constructed without any idlers because the friction genarated by an idler ruins free feeling in free space.
(iv) To reduce the construction area, one DC servomotor and a set of reversing gears drive four input parts of MR clutches.

5·1 2-DOF Force Display System

Figure.6 is a schema of output transmission system. As shown in this figure, this force display system has four MR clutches. And they control the upper link and the lower link governing the position of the handle. The input parts of MR clutch1 (MRC1) and MRC2 are driven clockwise by the DC sevomotor, and the input parts of MRC3 and MRC4 are driven counterclockwise by the DC sevomotor via a set of reversing gears. The upper link is controlled by MRC1 and MRC3. That is, MR actuator1(MRA1) controlling the upper link consists of MRC1, MRC3 and the DC servomotor. Similarly, MRA2 consists of MRC2, MRC4 and the DC servomotor. Since rotational direction of two MR clutches are different, MR actuators are driven by push-pull operation. The output torque of the system generated by MR actuators is transferred through a belt-pulley mechanism to a parallel link mechanism. The reduction ratio of the belt-pulley mechanism is 1:4. The tension of the belt in each output transmission system is controlled by sliding the position of MRC2 and MRC3.

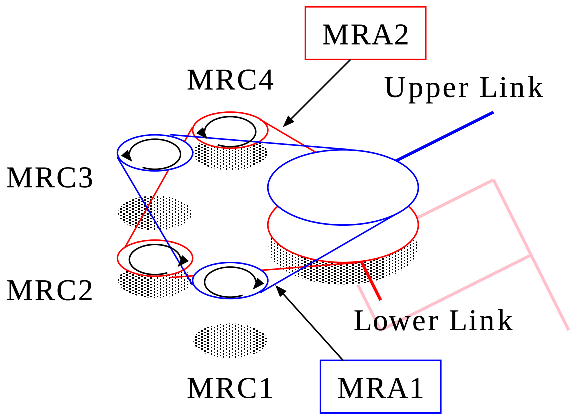

Fig.6 Schema of output transmission system

Table 4 is the summary of the characteristics of the new force display system. Attached to the driven-pulley shaft is a rotary encoder which measures the rotational position of the MR actuator with a resolution of 1,296,000[pulse/rev]. Then, a resolution of the handle position is approximately 4.9×10^{-4}[mm].

Table 4 The characteristics of Force Display System

Size of the system	$W630 \times D540 \times H970$[mm]
Operation Region	$W660 \times D240$[mm]
Force displayed	Max190 [N]
Num. of MR clutch	4
Input Part Actuator	DC Motor:78[W]
Sensor	Laser Rotary Encoder(Canon) K-1:1296000[pulse/rev]

5·2 Comparison with a force display system using the ER actuator

We have developed the force display system "NIOH"[3] using the ER actuator. However, this system had left the room of the following improvements.

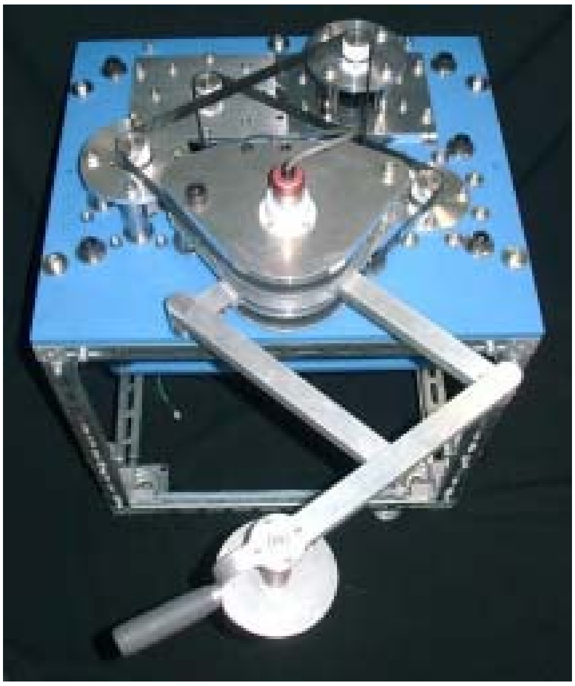

Fig.7 A 2D-Force Display System

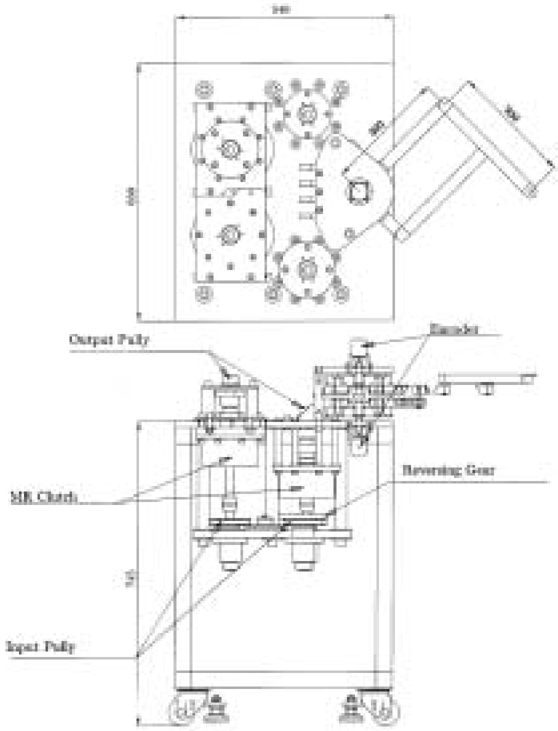

Fig.8 Upper View and Cross Section of 2D-Force Display System

(i) Decrease in resistance by inertia of actuator output part and friction of the driving system by which free feeling in free space is ruined.
(ii) Increase of expressible rigidity.
(iii) Decrease in construction area

Equipped the MR actuator instead of the ER actuator and given some mechanical devices, the new force display system is improved as follows.

(i) Because 1)the inertia of the output part of the MR actuator is about a half of the one of the ER actuator and 2)friction in the driving system is reduced, the new system can present more free feeling in free space. Moreover, danger to the user when the system contacts with the user accidentally is reduced because of reduction of the inertia.
(ii) The new system can higher rigidity since 1)the torque/inertia ratio of the MR actuator is larger than the one of the ER actuator and 2)the mechanically rigidity of the system is improved.
(iii) The maximum force presented is enlarged while the size of the clutch part is reduced.
(iv) The construction area is reduced because 1)one servomotor drives all input part of the clutches and 2)the new system requires no high-pressure power supply.

6. Performance of Force Display System

To investigate the characteristcs of the force display system, basic experiments are carried out. The experimental system is shown in Figure.9

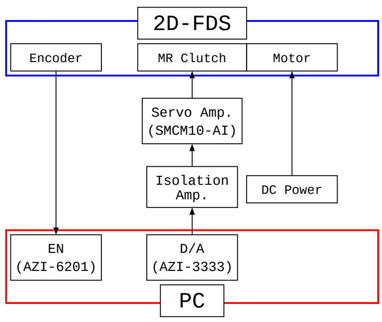

Fig.9 Concept chart of Experimental System

An experiment that is to trace the surface of virtual walls as shown in Fig.10(up) is done. Here, X and Y are shown in Fig.11. As a result, We can feel every sharp corners and very hard walls. And the system success to present more free feeling in free space than one using the ER actuator. As shown in Fig.10(down), the corner is presented so sharp that the user can not trace correctly when he or she moves the handle to some extent fastly.

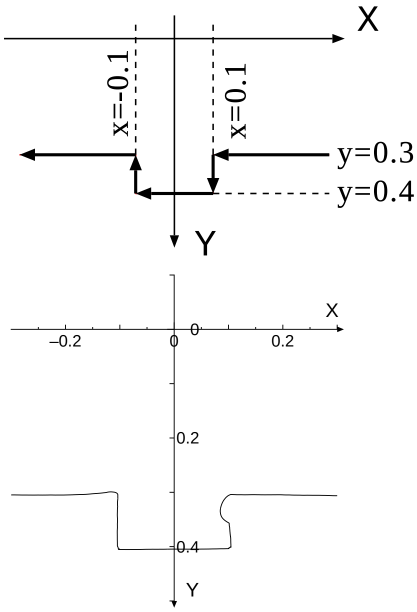

Fig.10 Schema(up) and Result(down) of virtual wall tracing examination

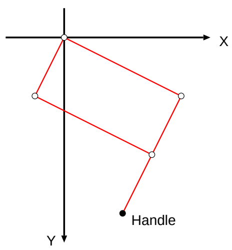

Fig.11 Setting of coordinate system

7. Conclusions

(i) In this paper, merits of the MR actuator in safety and in applocation to the force display system are discussed. Because of the clutch type actuator, safety of the system using the MR actuator is quantitatively estimated and mechanically ensured. The MR actuator has higher torque/inertia ratio than conventional servomotors and low output inertia. These properties contribute to present high rigidity and to improve safety respectively.

(ii) The new MR actuator with low inertia, high torque/inertia ratio and high responsibility is developed. The torque/inertia ratio of the actuator is much higher than conventional actuaotrs. The maximum torque is 10[N·m] and time constant is several milliseconds.

(iii) The force display system using the MR actuators is developed. By using the MR actuator and performing some mechanical devices, the system is improved as follows in comparison with the system using the ER actuator.

(1) Improvement of operativeness and backdrivablility
- Reduction by half of the base torque
- Reduction of the inertia of the output part
- Reduction of the friction which originates in the output transmission system.

(2) Increase of the output force range by a factor of six

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