FORCE-FEEDBACK DEVICE USING MAGNETORHEOLOGICAL FLUID: MR CLUTCH

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Abstract:
As one of power transmission devices, a clutch transmits a power from power source to operating parts. Most of clutches are susceptible to damages by backward power transmission. To cope with this problem, we investigate a new type of clutch which uses magneto-rheological fluid (MRF). This MR clutch has a simple structure, and can control the transmitting power and avoid power source breakdown by excessive backward power transmission. Since the MR clutch can act as semi-active damper as well, we can apply this device to various fields that need clutch and damper at the same time. In order to confirm its performance and investigate its applicability, we designed and manufactured MR clutch, and applied it to build a force-feedback device for virtual bicycle simulator.

Introduction

Most of reaction force systems generate only an active or semi-active reaction force. For the active reaction force, it is hard to use active actuators in a continuous manner. Since active actuators are prone to heat damages for a continuous active reaction force. In addition, fast control action is needed for the generation of the semi-active reaction force with a motor.

We present here the study of the reaction force generation device with a motor and a magneto-rheological fluid based clutch, in which the rheological characteristics are varied according to the strength of the magnetic field.

It is easy to generate active and semi-active reaction force with a simple structure and without motor damage. It can be applied to various application areas which need the reaction force system such as virtual reality systems, construction machinery, game market and so on.

Magneto-rheological fluid

Magneto-rheological fluid (MRF) is one of the controllable fluids, which changes its damping and rheological characteristics from Newtonian fluid, in which the shear yield stress is proportional to the shear strain, as shown in Figure 1.(a), to Bingham fluid, in which the shear yield stress is generated without the shear strain as shown in (1) and Figure 1.(b) when magnetic field is applied.

\[
\tau_y = \tau_y(u) + \eta \dot{\gamma}
\]  

(1)

It has several advantages such as high yield strength, low viscosity, robustness to impurities and wide temperature range of stability. If we design a device by using this material, we can not only design a simple structured device which generates semi-active force but also expect a rapid response.

In order to design a device using MRF, we must select its parameters by making use of magnetic analysis of the magnetic circuit to prevent the magnetic saturation.

MR clutch

Due to the progress of technologies and the broaden application areas, the demands of the reaction force system rise. The reaction force system improves the efficiency of operation or gives the feeling of reality to users in virtual simulators by providing appropriate reaction forces.

There are two kinds of reaction forces as follow; an active reaction force and semi-active reaction force. Most of areas that need the reaction force system require both of the active and semi-active reaction forces. Most of the conventional systems use a motor to provide the reaction force. In the reaction force system with a motor, the motor is prone to heat damages for a continuous active reaction force, since most directions of actions for operator are contrary to rotating direction of the motor, and the motor is rigidly connected to operating parts. Hence all of operating energies of operator are backwardly transmitted to the motor. In addition, fast control action is needed for the generation of the semi-active reaction force with the motor. Because it is hard to use it in a continuous manner, the program for protection of motor is needed.

In this paper, we investigated a device for the reaction force system with a motor and a MRF based
As mentioned above, we called this device the MR clutch. In case the MR clutch is applied to the reaction force system with motor, it can generate not only active reaction force but also semi-active reaction force.

The MR clutch connects the motor and operating part in series as shown Figure 2.

![Fig. 2: connection of MR clutch and motor](image)

In order to generate the active reaction force, the motor is running and the MR clutch transmits the motor power to the operating parts. To generate semi-active reaction force, the motor is electrically or mechanically stopped and the MR clutch acts as a damper. In the both cases, the magnitudes of the reaction forces are regulated by the input current applied to the MR clutch. As presented Figure 2, the motor is not rigidly connected to the operating part in contrary to the conventional systems and the magnitude of the reaction force transferred to the operating part is controlled by the current applied to the MR clutch. Hence, in the case of active reaction force, the motor is not prone to heat damages by backward transmitting power from the operating part.

**Application to handling part of virtual bicycle simulator.**

The virtual bicycle simulator developed by Dept. of Mechanical Engineering and Computer Science in KAIST (Korea Advanced Institute of Science and Technology) provides the similar feelings of riding of the real bicycle to a user on the simulator. (as shown in Figure 3.)

The sources of a rotating force in handle, which is one of the reaction forces from a handle for riding bicycle, are road types, road irregularities, bicycle movements, and so on. The rotating reaction forces have an sensitive effect on bicycle movements and stability. In the virtual bicycle simulator, presentations of steering reaction forces of handle are very important to the stability and movement of bicycle, and provide the feelings of the realities.

The rotating reaction forces are composed of active and semi-active reaction forces. The active reaction force parts are caused by road irregularities and bicycle movements. The semi-active reaction force parts caused by road types are involved in the light and heavy steering feelings of a rider. Hence we utilized the MR clutch to this application to generate active and semi-active reaction forces.

The major design goals were established for the MR clutch in the steering system of virtual bicycle simulator, as follows: 1) maximum dissipated torque is approximately 5Nm. 2) control frequency is up to 2Hz.

The motor used with MR clutch is Brushless DC motor, and is attached on a geared motor. The housing material is SM15C, a kind of compound steel and the MRF is MRF-132LD made by Lord company. To concentrate the flux path to desired parts for improving efficiencies, some components of housing are made by aluminum.

To select parameters of the MR clutch and predict its performance, we performed the magnetic circuit analysis to prevent the magnetic saturation with magnetic characteristics of SM15C and MRF. We requested KRISS (Korea Research Institute of Standard and Science) to investigate the magnetic characteristics of SM15C. The characteristics of MRF is given by manufacturer.

![Fig. 3: The virtual bicycle simulator at KAIST](image)
Designed MR clutch and Experimental setup

The drawing of designed MR clutch is presented in Figure 4.

![Fig. 4: The drawing of MR clutch](image)

The motor and MR clutch is attached to the virtual bicycle simulator as shown in Fig. 5.

![Fig. 5: The Installation to application system](image)

The total length of the system is 44cm. There are no interferences between other devices and the user. To confirm the performance of the MR clutch, we set up the experimental settings as presented in Fig. 6.

![Exp. results](image)

Experimental results and discussions

The experimental results for semi-active case with the experimental setup as presented Figure 6.(a) are shown in Figure 7.

Figure 7.(a) is representative of input current versus dissipated torque. We constructed performance equation of MR device as presented in (2). Figure 7.(a) is also representative of performance of semi-active reaction force.

The response time is shown in Figure 7.(b). We confirmed that the response time of this device is satisfactory for our goals.

\[ T_{\text{dissipated}} = 4.287 \times I + 0.009 \]  

Figure 8 is representative of the experimental results for active case with the experimental setup as presented Figure 6.(b).
(a) The experimental results: transmitted torque vs input current

(b) The experimental results: time response (use step input current with magnitude 0.7A)

Fig. 8: The experimental results for active case

Through experimental results shown in Figures 7 and 8, we confirmed the active and semi-active performance of the MR clutch. The experimental results of the both cases are similar to each other. The transmitted torque in Figure 8.(a) is slightly larger than the results shown in Figure 7.(a). This reason seems to be an uncentered alignments of the torque sensor, MR clutch, and fixed jig at the experiment setup as shown in Figure 6.(b).

Conclusion
The MR clutch with the motor that can act as the clutch and the damper was proposed in this paper. Its performance was experimentally verified. In order to confirm the applicability of the MR clutch, we applied it to the steering reaction system of the virtual bicycle simulator. Based on these experimental results and application, we demonstrated the feasibility of the proposed device as the reaction force system.

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References