Basic research of electro-rheological gel drum for novel linear actuator

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Abstract. In recent years, robots that coexist with human are under active researches. Such robots need high safety, backdriveability, large generative force, high speed response, good controllability, and so on. We have put emphasis on the backdriveability and created a novel prototype linear actuator with an ER (Electro-Rheological) gel, a new functional material. It is an all-purpose actuator satisfying characteristics for human-coexistence welfare robot.

1. Introduction
Nowadays, robots manipulated by human are actively researched and developed for virtual reality, rehabilitation, and other application [1, 2]. Such robots need high safety, backdriveability, large generative force, high speed response, good controllability, and so on. Among them, safety has been sometimes mentioned as important [3]. Additionally, high backdriveability is also important for Human-coexistence robots, because it helps manipulating these robots from their end point without large force. If above requirements are realized with actuators or structures, they will also be realized easily in a whole of a robot system.

This study uses an ER gel which is a new functional material, creates a linear actuator which has novel structures utilizing characteristics of the gel, and aims to develop an all-purpose linear actuator combining features required in human-coexistence welfare robots. In concrete, through design, construction and basic experiments of the actuator, we aim to develop hardware and software reaching to practical use [4]. This paper proposes such an ER Gel Linear Actuator (ERGLA), shows a improved design, and presents results of basic experiments.

2. Basic Characteristics of ER Gel
ER gels are a gel structured ER fluids and make a breakthrough two shortcomings of ERF [5]. These issues are sealing problem for use in mechanical elements and ER particle sedimentation. ER gel is that ER particles about 20 µm in diameter are dispersed in an insulating oil, and then a gelling agent is added to that. When an electric field is applied to electrodes sandwiching the ER gel, dielectric polarized particles and the gel component increase the shear stress of the surface of the ER gel several tenfold by the mechanism as shown in figure 1. The history of ER gels’ studies is not so long [6] and applications with ER gels have scarcely been developed in
mechatronics. Recently, Kakinuma etc. proposed a new theory on the mechanism of effects of ER gels and reported samples of ER gels which have large ER effects [7, 8].

For example, an ER gel can be applied to a clutch surface as shown in figure 2. While the ER gel is de-energized, the clutch input force is not transferred because of minimal shear stress. When the ER gel is energized by an electric field, increased shear stress contributes force transfer, that is, the clutch is engaged. The magnitude of the transferred force can be controlled since its shear stress can be controlled by the magnitude of the electric field.

3. The ER Gel Linear Actuator

The designed structures of the ERGLA are shown in figure 3. The ERGLA unit is attached and moves on a fixed bar. The ERGLA unit is connected to loads. Main parts of the ERGLA unit are two ER gel drums (ERGDs), a timing belt, and guide rollers. The fixed bar is pinched by the belt and guide rollers. Each input part of the ERGDs rotates contrarily in the same rotational speed by one driving motor and reversing gears. The ERGLA moves in different ways according to the way of energizing.

Figure 4 shows a sectional view of the ERGD. The gel was fixed on a disk type clutch structure in the drum. An arbitrary torque can be transmitted to the output part of the ER gel drum by control of the electric field for the ER gel. The advantage of this structure is easy increase of the output torque of the drum by multiple input and output gel disks used in the drum.

The produced ERGLA is shown in figure 5. Specifications of the ERGLA and ERGD are described as table 1.
4. Basic Experiments, Results and Discussions

The basic experiment of ERG drum was evaluated by the simple test schematized in figure 6, which was for gauging the output torque of the ERGD while the motor rotated in a constant speed.

Figure 7 shows the basic characteristic of the ERG on ERGD. The generative torque of ERGD is increased with the magnitude of applied electric field.

Figure 8 and figure 9 show results of basic experiments on step responses of an ERGD. The step inputs of the 2.0 kV/mm electric field energized the ER gel at 3.0 s and de-energized at 7.0 s. The four responses in the figures differ in the pressure on the surface of the ER gel. The pressures were able to adjust with weights on the input disk of the drum’s shaft. Each results was averaged from raw data of ten times experiments of the same condition.

The results show that the response time of the ERGD’s torque was about 20 ∼ 30 ms. Response of the ERG may be enough fast for mechatronics or robotics applications as physical supporting in welfare situations. However, the relation of the pressure on the surface of the ER gel and generative force should be invested and the surface pressure ratio should be improved in future study. It seems that the responses occurred at several milliseconds before 3.0 s, but those might be from torque ripples caused by unbalance of the pressure on the gel. Uniformalizing of the pressure is also future issue.

Table 1. Design Spec of the Prototype

|        | ERGD       | ERGLA      |
|--------|------------|------------|
| Weight | 1.24kg     | 5.32kg     |
| Height | 0.10m      | 0.22m      |
| Diameter | 0.11m    | 0.26m      |
| Width  | 0.26m      | 0.26m      |
| Depth  | 0.17m      |            |
| Max.force | 10N       |            |

Figure 5. Prototype ERGLA

Figure 6. Schematic diagram of ERGD test

Figure 7. Basic Character of the ERG
5. Conclusions
This paper showed a novel linear actuator with ER gels, and results of its basic experiments. The generative torque of ERGD was increased with rising ER gel surface pressure. However, the pressure will be needed to set small to keep the backdriveability of ERGLA. In future work, we will improve the surface pressure ratio on the ERG, and then will apply it to robotics applications of welfare situation.

References
[1] G.S. Guthart and K.J. Salisbury Jr. 2000 Intuitive telesurgery system: overview and application Proc. of the IEEE 2000 Int. Conf. on Robotics and Automation 1 618-621
[2] Proc. of the IEEE 9th Int. Conf. on Rehabilitation Robotics(2005). IEEE
[3] D. Engel, J. Raczkowsky, and H. Wörn 2001 A safe robot system for craniofacial surgery Proceedings of the 2001 IEEE International Conference on Robotics and Automation 2 2020-2024
[4] K. Koyanagi, Y. Kakinuma, H. Anzai, K. Sakurai, T. Yamaguchi, T. Oshima, N. Momose and T. Matsuno 2007 Basic Structure and Prototype of Novel Linear Actuator with Electro-Rheological Gel Mechatronics and Automation, 2007. ICMA 2007. International Conference 3266-3271
[5] M. Nakano and T. Nagata 2002 ER Properties and Flow-induced Microstructures of an ER Fluid between Two Parallel Disk Electrodes in Squeeze Flow Mode Int. J. of Modern Physics B 16 17,18 2555-2561
[6] K. Matsuura, T. Yakoh, T. Aoyama, H. Anzai, K. Sakurai and K. Isebe 2002 Smooth Tactile Display in Mouse using Electro-rheological Gel Proceedings of the 2002 International Symposium on Industrial Electronics(IEEE-ISIE 2002) L’Aquila Italy July 8-11 459-462
[7] Y. Kakinuma, T. Aoyama, H. Anzai, H. Sa-kurai, K. Isebe, and K. Tanaka 2005 Basic proper-ties of gel-structured electro-rheological fluids Int. J. of Modern Physics B 19 7-9 1339-1345
[8] Y. Kakinuma, T Aoyama, H. Anzai, H. Sa-kurai, K. Isebe, and K. Tanaka 2006 Application of ER gel with variable friction surface to the clamp system of aerostatic slider Precision Engineering 30 280-287