Development of Universal Robot Gripper Using MRα Fluid

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***Abstract*—We developed a smart magnetic fluid called MRα fluid. The specific gravity of the developed fluid is half and its solidification hardness is twice that of MR fluid. In this paper, the characteristics of the MRα fluid and an application that can control solidification under a magnetic field are described. Further, we developed a novel robot gripper using MRα fluid, and several experimental results investigating the features and capabilities of the gripper are presented.**

I. Introduction

Various types of end effectors of industrial robots have been developed to adapt the robots to various tasks. End effectors used to grip objects are called grippers. The general industry practice is for grippers to employ automatic exchange equipment in accordance with the position and shape of the target in the working process. However, these equipments require several procedures such as the selection of the appropriate gripper and the design of a grip plan according to the estimated position of the target that have become a bottleneck for their employment in a high-speed automatic factory.

Many studies on the mechanism and shape of end effectors and target grip planning have been carried out [1], [2]. A novel gripper to improve the work efficiency was developed to curtail the position estimation of the grip target and the exchange of the gripper [3]. This gripper is called the universal jamming gripper, and it can grip various-shaped objects using the jamming phenomenon[1], which occurs in ground coffee that fills an elastic membrane. On the other hand, because the grip force is dependent on the balance between the environment inside the elastic membrane and the external environment, it is difficult to use the gripper in an environment where the surrounding pressure is high and the surrounding temperature is easily changed.

Therefore, in order to remove these constraints on the operation of the jamming gripper, we focus on MR (magnetorheological) fluid. MR fluid is a smart magnetic fluid, and it can be controlled instantly between fluidization and solidification states at any shape by applying a magnetic force under the above-mentioned constraints. First, we reviewed the properties of the MR fluid, and then, we developed a novel fluid called MRα fluid by adding nonmagnetic material to improve the hardness of solidification of the MR fluid. The improvement is confirmed by survey results, the details of which are described in this paper. In addition, we conducted some experiments on the MRα fluid to investigate the grip force and its characteristics. Furthermore, we installed the gripper in an industrial robot, and verified the effectiveness of the gripper with some experiments using the robot system.

[1]This phenomenon is characterized by the loss of mobility and solid-like behavior if the density of the granular material becomes high.

The remainder of this paper is organized as follows: Section 2 presents the related studies. In Section 3, the preparation of the proposed MRα fluid and the construction of its gripper described. In Section 4, the performance of the proposed gripper is verified via experiments. In Section 5, the performance and characteristics of the MRα fluid are investigated. Finally, Section 6 provides a summary of the paper.

II. Related Studies

This section reviews the structural characteristics of the jamming gripper. We developed the gripper as shown in Fig. 1 on the basis of the literature [3]. An elastic membrane is filled with ground coffee, and an air compressor is used to relieve air pressure in the elastic membrane. The procedure used by this gripper to grip a target is as follows: 1) the gripper is pressed against the target, and the elastic membrane part copies the shape of the target; 2) the elastic membrane part is sucked by the air compressor, and it hardens with the jamming phenomenon; and 3) the target is lifted and manipulated. Because the gripper can hold even targets of arbitrary shapes and positions, the exchange of the gripper is not required in the working process it is utilized in. Moreover, complicated calculations of the target hold plan, posture estimation of the target object from a hold start to completion, and so on, are also unnecessary. The jamming phenomenon occurs even if sand is used as a filling of the elastic membrane. However, ground coffee is the best from viewpoint of the weight and gripping force [3]. On the other hand, with several preliminary experiments we confirmed that the grip force of the universal jamming gripper fluctuates according to the adjustment of the amount of filling. This fact suggests that there is a possibility that changes in the volume of the air in the elastic membrane affect the grip force. That is, the changes in atmospheric pressure and temperature have a strong influence on the grip force. Moreover, it is clear that underwater use is difficult.

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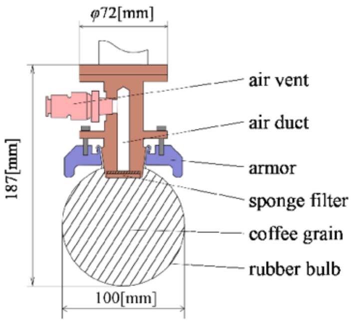


(a) Schematic diagram


(b) Overview


(c) Overview of the operation

Fig. 1. Developed universal jumming gripper (a conventional gripper).

III. MR Fluid for Jamming Gripper

A. Smart fluids with controllable solidification

The solidifications of ER (electrorheological) and MR fluids can be controlled by the application of electric and magnetic fields, respectively. Recently, these fluids have often been used as components of robotic peripherals, and the associated control methods and characteristics are widely known. The viscosity of the ER fluid changes according to the electric field, and it has a homogeneous and dispersed system type [4]. ER fluid has a Newtonian fluid property, whereas MR fluid has a Bingham fluid property. The shear stress of a Newtonian fluid is proportional to its shear rate, and its shear stress is 0 [kPa] when its shear rate is 0 [s^{-1}]. That is, its viscosity can be changed, but it does not behave like a solid. On the other hand, because the Bingham fluid has a shear stress when its shear rate is 0 [s^{-1}], it behaves like a solid. That is, the dispersed system MR fluid behaves like a solid in an electric field.

Next, the viscosity of the MR fluid increases 10^6 times in several milliseconds under an applied magnetic field, and the MR fluid has a Bingham fluid property. In the absence of a magnetic field, MR fluid has a much higher liquidity than other magnetic fluids. However, when a magnetic field is applied, a large shear stress of several kilopascals occurs in the fluid, which changes the fluid to a solid condition [5].

As mentioned above, the dispersal system ER fluid and MR fluid are candidate fluids that can achieve an effect similar to the jamming phenomenon. These two types of fluids have the advantage of a high-speed response to magnetic field changes. On the other hand, in general, MR fluid can produce a larger shear stress than the dispersed system ER fluid with the same electric power. Therefore, we constructed a novel universal gripper using the MR fluid.

B. Problems with MR fluid

The shear stress of the conventional MR fluid becomes saturated at 90 [kPa] by a magnetic flux of 0.3 [T] [5]. In order to confirm whether the elastic membrane involving MR fluid can be solidified sufficiently using a neodymium magnet, which is the most powerful magnet, we conducted a preliminary experiment. In this experiment, a latex balloon filled with 100 [mL] of MR fluid was contacted with a neodymium magnet under a magnetic flux density of 0.3 [T], and it was investigated if a lightweight cable can be gripped by the solidified balloon. The results of this experiment are as follows:

- The MR fluid in a remote location from the neodymium magnet was almost not solidified, because the magnetic flux density decreases rapidly with the distance from the neodymium magnet. That is, a sufficient solidification of all the MR fluid for object grip was not generated.
- Because the MR fluid had a comparatively large specific gravity, it was found that the balloon hangs down in the direction of gravity.
- A strong force was required to pull apart the neodymium magnet and the balloon. That is, this suggests that the use of an electromagnet is desirable for quick control of the MR fluid.
- The latex balloon composed of natural rubber was dissolved with the passage of time. It was determined that the oil contained in the MR fluid dissolved the natural rubber.

IV. MRα Fluid Gripper

In general, because the magnetic flux density of electromagnets per unit weight is lower than that of neodymium magnets, and we must prepare a large, heavy electromagnet to generate sufficient magnetic flux density for the solidification of the MR fluid. Furthermore, the specific gravity of the MR fluid is comparatively high. Therefore, installing a gripper that includes many MR fluids in a general industrial robot whose payloads are on the order of 10 [kg] may be difficult.

We developed a novel MR fluid called MRα fluid in order to solve these problems. In the following, we describe the solidification principle of the MRα fluid and the details of its experimental study.

A. The solidification principle of the MRα fluid

The principle underlying the solidification of the MR fluid under a magnetic field is shown in Fig. 2. Conventional MR fluid consists of iron particles with diameters of a few micrometers, oil, and additives that prevent the precipitation of the iron particles. When a magnetic field is applied, the iron particles align themselves along the lines of magnetic flux and form a columnar structure, and the elastic membrane

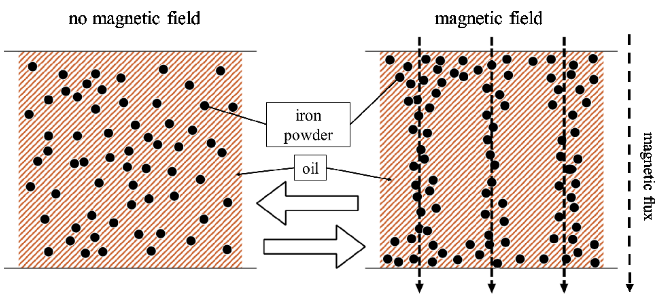


Fig. 2. Solidification principle of the MR fluid.

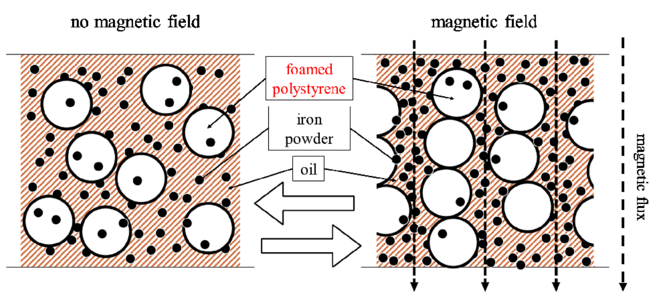


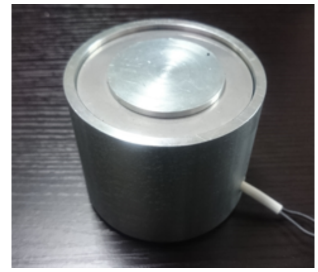
Fig. 3. The solidification principle of MRα fluid.

involving the MR fluid is solidified. When a force greater than the shear stress of the MR fluid is externally applied, the columnar structure is destroyed and deformed. Then, when the magnetic field is removed, the iron particles revert to the random distribution state. Although the solidification hardness of the MR fluid can be improved by changing the mixing ratio of iron powder and oil to a value that can generate a sufficiently large shear stress to increase the amount of iron powder, its fluidity falls remarkably and the weight increases.

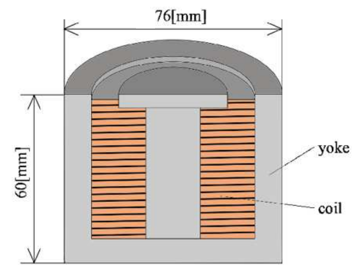
The principle of the solidification of the MRα fluid with a magnetic field is shown in Fig. 3. This fluid is prepared by mixing the MR fluid and the nonmagnetic particles, and it has the following features: the solidification force with a fixed magnetic flux density is more than twice as strong as that of the MR fluid, and the specific gravity is approximately half that of the MR fluid. When a magnetic field is applied, the iron particles align themselves along the lines of magnetic flux and form a column structure, and the nonmagnetic particles enter the crevice between the iron column structures. When an external force is applied, the nonmagnetic particles act as an aggregate of the columnar structure of the iron particles. With such a mechanism, the shear stress of the MRα fluid becomes strong against an external force.

B. Construction of the MRα fluid gripper

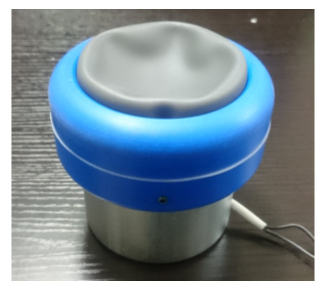
We developed a universal gripper using the MRα fluid called the MRα fluid gripper, which is shown in Fig. 4. The prototype was constructed using an electromagnet as shown in Fig. 4(a) and (b), and its overview and structural diagram are shown in Fig. 4(c) and (d), respectively. Because it was found that the oil in the MR fluid dissolves the natural rubber, we used silicone rubber as the elastic membrane of the gripper. The silicone rubber is filled with a fixed quantity of the MRα fluid. Moreover, an external collar was made to pinch the silicone rubber and connect the rubber and the electromagnet.



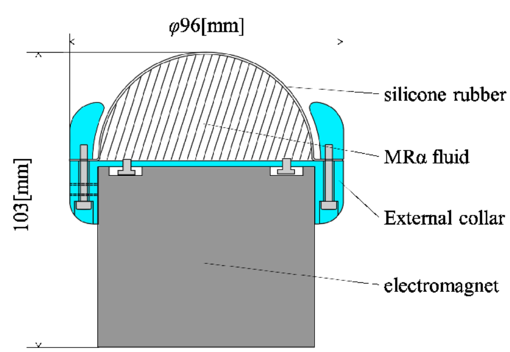
(a) Overview of electromagnet.



(b) Structural diagram of electromagnet.



(c) Overview of MRα fluid gripper.



(d) Structural diagram of MRα fluid gripper.

Fig. 4. Prototype of MRα gripper.

C. Characteristics of MRα fluid

The following experiment was conducted to investigate how the properties of MRα fluid are influenced by the size of nonmagnetic particles. The prototype of the MRα fluid gripper shown in Fig. 4 was used for the experiment. The experiment was conducted as follows: 1) the mixed volume ratio in MRα fluid of MR fluid and nonmagnetic particles was 50%; 2) the elastic membrane was filled with MRα fluid;

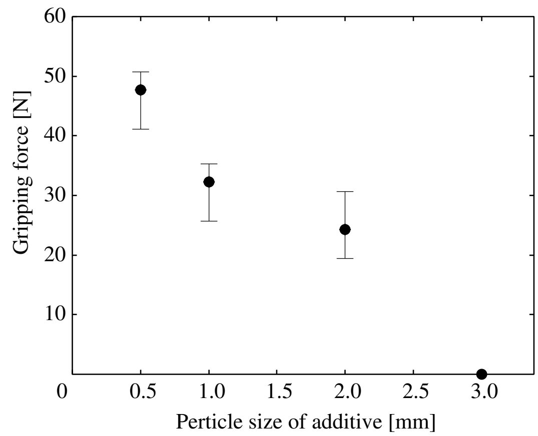


Fig. 5. Grip force versus the sizes of nonmagnetic particles.

3) the perpendicular upper part of the gripper was pressed to a target object connected to a force gage, a power supply was connected to the electromagnet, and the target object was gripped by the gripper; and 4) the gripper was pulled up, and the maximum force on the target object was measured. Nonmagnetic particles of various sizes were mixed with MR fluid, and the maximum grip forces of the gripper for the various particle sizes were measured by the above procedure. We used four types of nonmagnetic particle size 0.5 [mm], 1.0 [mm], 2.0 [mm], and 3.0 [mm]. The experimental results are shown in Fig. 5. The results show that the grip force of the gripper is maximized when the nonmagnetic particle diameter is 0.5 [mm]. However, the experiment for particle sizes smaller than 0.5 [mm] was not conducted, and the character of MRα fluid when still smaller particles are used is unknown.

D. Mixed volume ratio of nonmagnetic particles

It was found from the above experiment that a nonmagnetic particle diameter of 0.5 [mm] is suitable for preparing MRα fluid. Therefore, next, we investigated the properties of the mixed volume ratio of nonmagnetic particles. The experiment was conducted by measuring the grip force when the mixed ratio is changed as follows: 1) several samples of MRα fluid with the same volume were prepared by changing the mixing volume ratio of MR fluid and the nonmagnetic particles; 2) the elastic membrane was filled with the MRα fluids in order; 3) the perpendicular upper part of the gripper was pressed to a target object connected to a force gage, a power supply was connected to the electromagnet, and the target object was gripped by the gripper; and 4) the gripper was pulled up, and the maximum force on the target object was measured. The results of the experiment are shown in Fig. 6. The results show that the grip force of the MRα fluid gripper is maximized at the 50% ratio of the MR fluid and nonmagnetic particles.

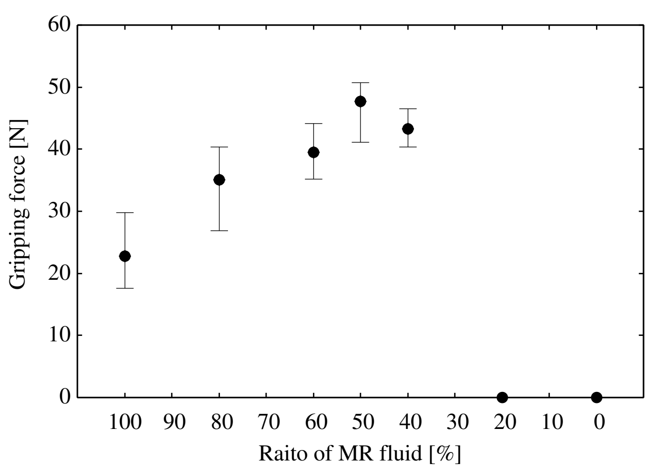


Fig. 6. Grip force versus the mixed volume ratio of nonmagnetic particles.

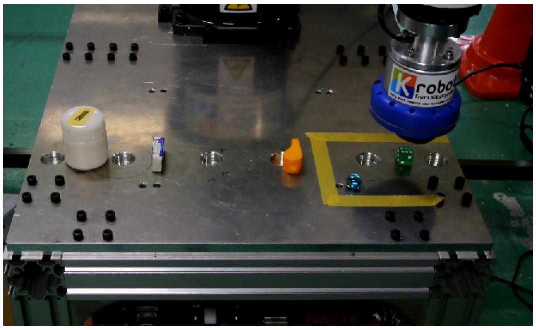
Fig. 7. Six-axis industrial robot equipped with the developed novel gripper using the MRα fluid.

V. Installation an Industrial Robot

We attached the MRα gripper in a six-axis industrial robot, and conducted several grip experiments. First, we installed the MRα fluid gripper in the robot, and programmed the robot so that it could manipulate the target object by teaching playback. Next, we conducted several experiments to confirm the gripping ability with various nonmagnetic objects as shown in Fig. 8(a). It was confirmed from these experiments that nonmagnetic objects of various shapes can be gripped by the developed gripper as shown in Fig. 8(b). Moreover, a 2 [L] bottle filled with water could be lifted satisfactorily. The ability to generate a maximum payload of 50.67 [N] was confirmed. The payload of 70 [N] of this industrial robot could be handled.

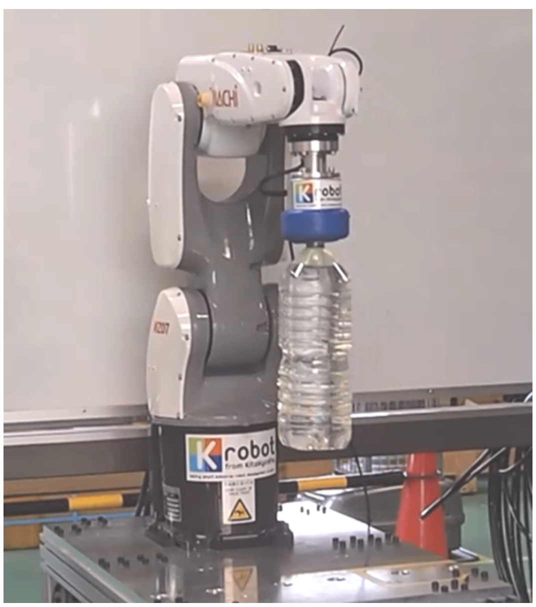
VI. Conclusion

First, the advantages and disadvantages of the universal jamming gripper developed in recent years were reviewed, and the characteristics of the ER fluid and MR fluid were described. Next, the solidification principle of MR fluid was described, and the solidification principle of the MRα fluid, which compensates for the disadvantages of the fluid, was described. Then, the experiment to investigate the influence



(a) Gripping several targets:
dice, marble, whistle, eraser, and small container.

(b) Gripping a whistle.



(c) Gripping a water bottle.

Fig. 8. Operation of the developed gripper using the MRα fluid.

of the size of the mixed nonmagnetic particles, and it was found that the suitable diameter for maximizing the grip force of the gripper is under 0.5 [mm]. Moreover, an experiment to investigate the influence of the mixing volume ratio was conducted, and it was found that the grip force of the MRα fluid gripper is maximized at a 50% ratio of the MR fluid and nonmagnetic particles. Finally, we developed a novel gripper using the MRα fluid and checked its performance by installing it in an industrial robot. It was confirmed from the experiments that nonmagnetic objects of various shapes can be gripped by the developed gripper, and a maximum gripping force of 50.67 [N] could be generated.

In future studies, the components, i.e., the silicone rubber, electromagnet, and external collar of the gripper will be improved.

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