Application of Magneto-rheological device in Knee Prosthetic

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Abstract

Recovering the biomechanical function, comfort and quality of every-day life is a prime consideration when designing prosthetic devices for human body/ robots. The magneto-rheological (MR) prosthetic knee is an example of such a device.
The paper presents a comprehensive and a combined MR device design and MR fluid design approach, aiming to advance the MR prosthetic knee.

Keyword:-Magneto-rheological, prosthetic knee.

Introduction

MR fluids are a class of smart materials whose rheological properties can be controlled with a magnetic field. Conventional MR fluids consist of a base fluid, immersed with ferromagnetic micron-sized particles. With the application of a magnetic field, the iron particles are drawn together in electromagnetic chains. Hence, the stronger the magnetic flux in the fluid, the stronger the particle chains. MR fluids have many industrial applications. They are, for example, increasingly being considered in a variety of devices, such as, dampers, valves, brakes and clutches [1-4]. Examples of MR prosthetic devices are a variable stiffness knee joint [5-6] and a variable stiffness, below knee, leg [1,8]. An example of an MR orthotic device is a variable stiffness brace [7].

An MR prosthetic knee, manufactured by the company Ossur Inc. [6], is called the Rheo knee. It was originally developed by a group of scientists at the Massachusetts Institute of Technology and patented under US patent specification 6,764,520 [9]. The knee is a synergy of artificial intelligence, advanced sensors and MR actuator technology. The knee uses a magnetic field to vary the viscosity of the MR fluid, and thereby its flexion resistance. Unlike existing hydraulic systems, the resistance offered by the MR fluid is activated only when the individual needs it, and it is activated instantly. Hence, the stiffness of the knee can vary in real time as the amputee walks. This results in a natural and effortless motion. The knee is equipped with an MR rotary brake that utilized the MR fluid in direct-shear mode. The brake consists of a magnetic coil which is fed with electrical current to generate a controlled magnetic field in the fluid. The core and the core sides are made of a cobalt-iron alloy. This alloy has the highest magnetic saturation of all known soft magnetic materials. The outer and the inner houses are made of aluminium and titanium, respectively, which are nonmagnetic materials. The steel blades are arranged tightly, side by side in the chamber to enlarge the area that is affected by the shear force. The blades are connected alternately to the outer house (stator) and to the inner house (rotor). The stator is connected to the amputee’s residual limb while the rotor is connected to the amputee’s lower part of the leg (below the knee), producing the relative motion between the stator and the rotor. The gap between the blades, where the fluid resides is small compared to the thickness of the blades. As the knee rotates into flexion or extension, the thin rotary blades shear the particle chains to create resistance. The result is a varied fluid shear force within the knee, restoring more natural pelvic position during pre-swing and reducing fatigue levels. The research presented here aims to advance this device allowing amputees to tackle more demanding situations, like hill-climbing for example. The aim is to improve the quality of life for above-knee amputees using the MR prosthetic knee.

Literature Review

Magnetorheological (MR) fluids are currently used in a variety of applications due to their property of varying viscosity under the influence of a magnetic field [4, 10, 11] . A sector in which MR fluids have been successfully introduced is prosthetic devices [1]. For example, MR fluids are used in prosthetic dampers [8] and in prosthetic rotary disk brakes, utilizing the fluid in direct shear mode [5,9].An MR prosthetic knee is an example of a direct shear mode device [12, 13] and this device is the motivation for the research. In this device, the field-induced characteristics and the off-state characteristics of the MR fluid are of equal importance. The field-induced shear yield stress determines how rigid the knee joint is, under the influence of a magnetic field, and the off-state viscosity determines how flexible it is, in the absence of a magnetic field.

MR Fluid Design

Motivated by the use of MR technology in an actuator for a prosthetic knee [6, 9, 12], this work investigates MR fluids with a potential application in small devices. In the aforementioned prosthetic knee actuator, the MR fluid is contained between a numbers of thin steel blades that move relative to one another. As the knee rotates into flexion or extension, the blades shear the particle chains to create resistance; the result is a varied fluid shear force within the knee. The MR fluid gap in the knee actuator is micron-sized and hence, in order for the fluid to be active in the gap, it cannot be loaded with particles bigger than a few microns. Due to this size limitation, the research looks towards small micron-sized particles and nano-sized particles as a feasible option for the MR fluid compositions to be used in the actuator. Low solid loadings are preferred due to problems injecting fluids with high solid loading into the small actuator.

In general, magnetorheological (MR) fluid compositions can vary widely. However, the majority of existing MR fluids are composed of micron-sized iron particles suspended in a carrier fluid [14]. Common carrier fluids are silicone-based, hydro carbon based and water-based [10]. An example of MR fluid structure can be seen in Figure 1.

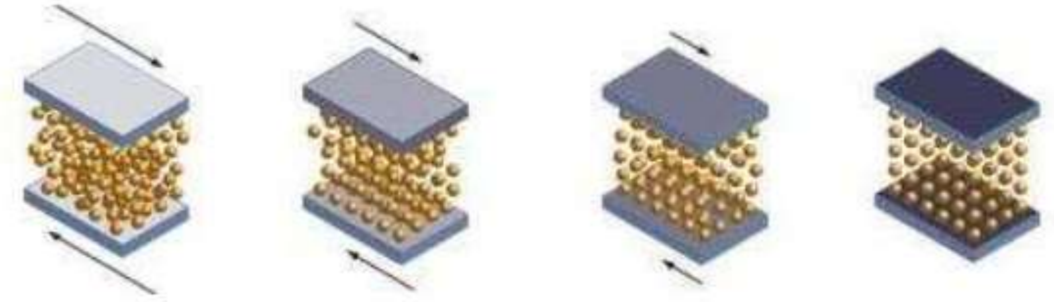

Fig.no.1 MR fluid on-state and off-state structure.

The on- and off-state rheological behavior of bimodal MR fluids has been studied experimentally [15]. They reported the off-state viscosity to decrease with an increasing ratio between coarse particles (6.7 μm) and the fine particles (1.8 μm). They also reported a bimodal MR fluid (33 % coarse particles / 67% fine particles) to have higher field-induced shear stresses when compared to the corresponding unimodal fluids. They have also used bimodal size distributions to increase the yield-stress while simultaneously reducing the off-state viscosity of MR fluids.

The rheological properties of conventional MR fluids have been researched extensively. It is well established that the shear yield stress can be increased by simply increasing the volume fraction of iron particles .A clear drawback, however, is that an increase in particle loading, increases the field-independent plastic viscosity of the fluid .It has been demonstrated that the yield stress is related to particle sizes and particle size distributions. For example, bigger particles exhibit higher yield stresses than smaller particles because they have a higher magnetic saturation value. Furthermore, bidisperse suspensions have demonstrated higher yield stresses than unimodal fluids

Conclusion

The investigation has quantified the effect of solid loading for the proposed application. As expected, with an increasing solid loading, the on-state shear-yield stress and the off-state viscosity tend to increase. A fluid with a solid loading of 0.25 by volume has been shown to have the highest ratio between the on-state shear-yield stress and the off-state viscosity for all the fluids in this paper.

The effect of particle size on the on-state performance of the MR fluids has shown the shear yield stress to increase when going from fine powder to coarse powder. The increase is significant when comparing the fluid employing the coarse powder to the fluid employing the fine powder. The effect of particle size on the off-state viscosity is shown not to be directly proportional to the particle size. The fluid employing the smallest particles exhibits the highest off state-viscosity to a large extent while the fluid employing HS powder exhibits the lowest off-state viscosity. The measurements show an increase in off-state viscosity when replacing the HS powder with larger particles.

A combined MR fluid design approach and an MR device design approach has been presented, motivated by improving the quality of life of amputees using an MR prosthetic knee.The MR device approach has shown that the on-state braking torque of the device can be increased from 40-45 Nm to 60 Nm without increasing the off-state rotary torque from that of the reference design. A key design parameter to achieve this is the gap size between the rotating steel blades in the fluid chamber. A gap size of 24 μm and a blade number of 67 has been implemented in newly available prosthetic knee product, with good results. However, the analysis suggests that these values should be increased further to improve the qualities of the prosthetic knee.

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