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BRAKES AND CLUTCHES WITH SMART FLUIDS

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Abstract
The aim of the paper is to present some constructive aspects concerning the brakes and clutches, as controllable devices, realized with rheological fluids. There were taken into consideration suck kinds of devices, using both magneto-rheological (MRF) and electro-rheological (ERF) fluids. The presented theoretical study can stay at the base of an optimal design of the MRF and ERF brakes and clutches.

Keywords: brake, clutch, smart fluid

1. Introduction

The main directions of actual studies in the field of MRF and ERF devices are: methods of optimization of electronic control of MRF and ERF devices, taking into account the strongly non-linear behavior of these fluids; mathematical modeling and numerical simulation of MRF and ERF devices; finding new applications.

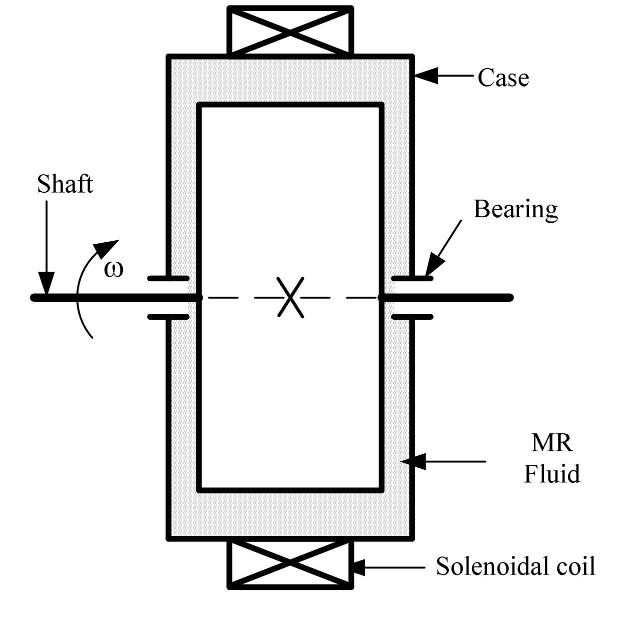
2. Magnetorheological fluid brake

2.1. Construction and Work of MRF Brake

The MRF brake is a device that transfers the braking torque with the help of shearing stress of the fluid. The MRF brake has the property that the generated braking torque can be rapidly modified, as a response of applying of an external magnetic field. The MRF brake has a relatively simple construction, in comparison with conventional brakes, this thing being one of its big advantages, which assures a very high reliability.

Essentially (figure 1), the cylindrical MRF brake consists in a cylinder (rotor) placed on the shaft of the wheel that must be braked; the rotor turns in a perfectly insulated cylindrical case, forming one piece with the vehicle chassis, and the space between the rotor and the case walls is completely filled with MRF; in the exterior of the case, coaxially with this one, it is placed the control electromagnet, which usually has a toroidal shape. The rotor turns with the angular velocity ω of the braked shaft.

In the absence of the magnetic field generated by the electromagnet, the magnetic particles, suspended in the mass of MRF, influence in an insignificant measure the relative motion between the rotor and the external case. In the moment when the vehicle driver gives the braking command, the coil of electromagnet is passed trough by the electric current,



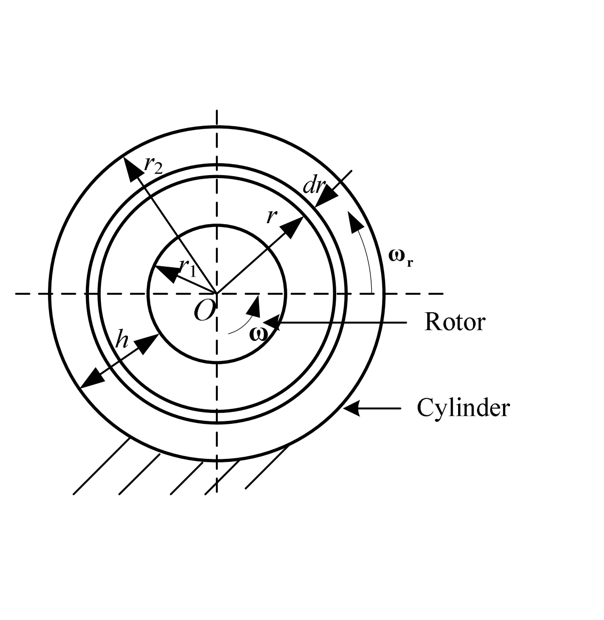


Fig. 1 *Principle schema of the cylindrical MRF brake*	**Fig. 2** *Schematic transversal section in the MRF brake*

generating a magnetic field whose flux passes by the MRF. As a result, it appears the polarization of magnetic particles in suspension, they forming structures of particles chains, disposed along of magnetic field lines. These structures, under the form of particle chains, make sensibly heavier the motion of MRF, the consequence being the increasing of the shearing stress of fluid. Thus, using the shearing effort of MRF, it is obtained the braking effect. The value of braking torque can be continuously modified, by controlling the intensity of the command magnetic field.

2.2. Calculus of Braking Torque

When the magnetic field is absent, the magnetic particles are randomly dispersed in the mass of the carrier fluid and the MRF is freely flowing in the space between the rotor and the fixed cylindrical case. The MRF presents a behavior of Newtonian type [3], so that the shearing stress of MRF can be expressed under the form $\tau = \eta\dot{\gamma}$, where: τ - shearing stress; η - viscosity of MRF, in the absence of magnetic field; $\dot{\gamma}$ - velocity of shearing.

In the moment of magnetic field appliance, the behavior of MRF is rapidly changing from the Newtonian type to the Bingham fluid type, presenting variable flowing resistance. In accordance to the Bingham fluid properties, the shearing stress has the extrusion $\tau = \eta\dot{\gamma} + \tau_B$, where τ_B is the supplementary yield stress, that appears as an effect of applying the external magnetic field; its value, is evidently, a function of induction B of the magnetic field.

On experimental way, [3], it was studied the dependence of the shearing stress on the shearing velocity, in correlation with the intensity of the applied magnetic field. So, it was remarked the fact that the MRF presents a variable flow resistance, the shearing stress increasing with the intensity of the applied magnetic field. All these remarks confirm the theoretical hypothesis concerning the behavior of MRF as a fluid of Bingham type.

The essential problem in the design of a MRF brake is the calculus of the generated braking torque.

In the moment when the magnetic field is applied, the MRF develops a braking torque whose moment M has the form $M = 2\pi r^2 w\tau$, where: w - thickness (radially measured) of the fluid zone where the magnetorheological effect appears; r - polar radius of the geometrical element of fluid, of elementary thickness dr.

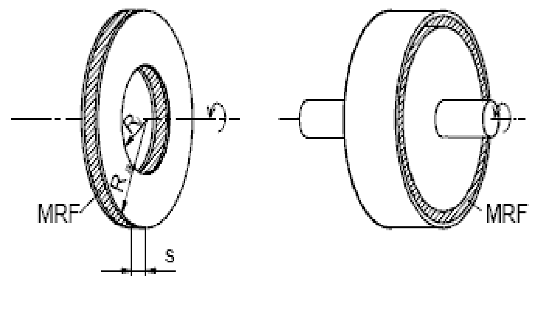
As it results from the second equation, the shearing stress τ is proportional to the shearing velocity $\dot{\gamma}$. This one [3], has the form $\dot{\gamma} = r\dfrac{d\omega_r}{dr}$, where ω_r is the angular velocity in the MRF, corresponding to the position r of the element of fluid. From the equations below, it is obtained the elementary variation of the angular velocity ω_r, along of the polar radius, $d\omega_r = \dfrac{1}{\eta}\left(\dfrac{M}{2\pi w r^3} - \dfrac{\tau_B}{r}\right)dr$.

By integrating this differential equation, taking into account the boundary conditions of the MRF brake, figure 2, $\omega_r = \omega$ for $r = r_1$ and $\omega_r = 0$ for $r = r_2$, it is obtained the braking torque developed by the brake, $M = \dfrac{4\pi w\tau_B r_1^2 r_2^2 \ln\dfrac{r_2}{r_1}}{r_2^2 - r_1^2} + \dfrac{4\pi\eta w r_1^2 r_2^2 \omega}{r_2^2 - r_1^2}$, where r_1 and r_2 are the radius of rotor and cylindrical case, respectively.

From the figure 2, it results the thickness of the MRF layer, between the rotor and the cylindrical case, $h = r_2 - r_1$. If it is taking into account the fact that at the real constructions of brakes, the thickness of MRF layer is much smaller than the radius of rotor, i.e. $\frac{h}{r} << 1$, from the last two equations, for the moment of braking torque it results the expression $M = 2\pi w \tau_B r_1^2 + \frac{2\pi\eta w r_1^3 \omega}{h}$.

3. Magnetorheological Fluid Clutch

The problems concerning the construction, working and calculus of MRF clutches present very similar aspects with the same problems treated to the MRF brakes. Anyway, it is necessary to present the main constructive solutions used to the MRF clutches, figure 3, a and b. So, in figure 3a, it is presented the schema of a MRF clutch realized with two disks, the space between them being completely filled with MRF; in figure 3b, the two components of the clutch consist in coaxial cylinders, the space between them being also completely filled with MRF. Naturally, the two composing disks or cylinders form one piece with the driving and driven shafts, respectively.



(a) (b)

Fig. 3 *Constructive solutions for MRF clutches [4]*

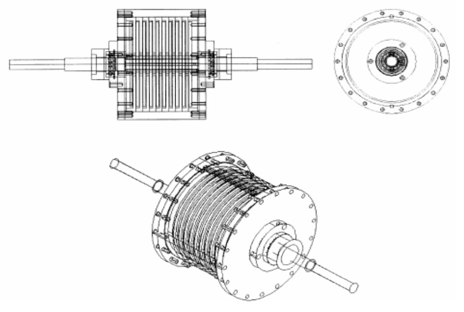


Fig. 4 *Typical schema for a multi-disk ERF device [5]*

4. Electrorheological Brake and Clutch

4.1. Construction and Work of ERF Devices

An ERF device has as main components three parts: the input element, the output one and the ERF. Each element forms one piece with the corresponding shaft. The mechanical power is transmitted by the kinetic energy of the input element to the ERF. If the energy is absorbed, the device operates as a brake, and if the energy is transmitted from the input element to the output one, the device works as a clutch.

A representative schema of an ERF device [5] is presented in figure 4. In the schema, it can remark one input shaft with a number n of equally spaced disks and an output tubular shaft with $n-1$ also equally spaced disks. The disks are alternatively connected, one to the input shaft and one to the output shaft.

The gap between two disks is very thin (about 1 mm). Naturally, the two shafts are perfectly isolated.

Another very often used constructive solution consists in two coaxial cylindrical elements, connected each one to the input and output shafts, respectively. The input cylinder is a massive one, and the output cylinder represents a cylindrical case, the space between two elements being perfectly sealed and filled with ERF. The two composing elements are very strong electrically isolated and they are connected to a tunable DC source, of high voltage.

4.2. Calculus of ERF Rotary Devices

In order to evaluate the moment of torsional torque (braking torque, transferred torque respectively), it is adopted the Bingham model, where the shearing stress is described by the formula $\tau = \tau_0 + \mu \frac{dv}{dh} = \tau_0 + \mu \frac{\omega r}{s}$, where: τ_0 - supplementary yield stress, that appear as an

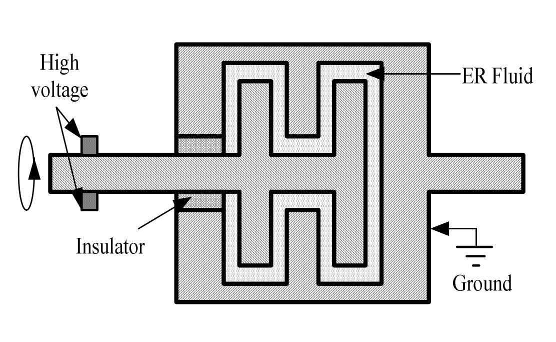


Fig. 5 *ER clutch with two plates*

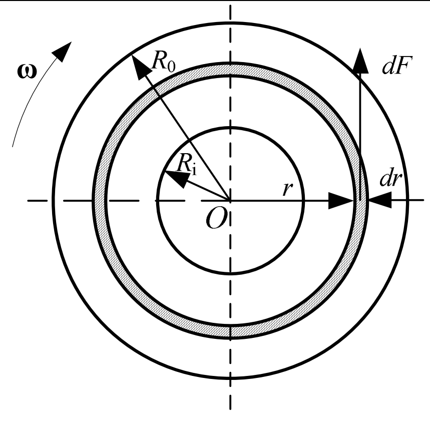


Fig. 6 *Elementary area on the ring disk [5]*

effect of the electric field; μ - viscosity of ERF, in the absence of electric field; s - distance between two disks.

The global torsional moment due to the set of parallel rotating disks can be expressed as the sum of two components: the viscous one (M_μ) and the electrorheological one (M_e). The expression can be obtained by integrating the elementary torques between the internal radius R_i and the external one R_0 of a disk (figure 6), $dM = nrdF = nr(\tau \times 2\pi r dr) = 2\pi n r^2 \left(\tau_0 + \mu \frac{\omega r}{s} \right) dr$, where dF is the hydraulic elementary force.

From the equation (10), by integrating, it results $M = 2\pi n \tau_0 \int_{R_i}^{R_0} r^2 dr + 2\pi n \mu \omega \frac{1}{s} \int_{R_i}^{R_0} r^3 dr$ or $M = M_e + M_\mu$, where $M_e = \frac{2}{3} \pi n \tau_0 \left(R_0^3 - R_i^3 \right)$, $M_\mu = \frac{1}{2s} \pi n \mu \omega \left(R_0^4 - R_i^4 \right)$.

5. Conclusions

These devices, realized with MRF and ERF, can be used with real success in automations, robotics, military technology, in the field of medical engineering, respectively in prosthetics and devices for medical gymnastics recuperation

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