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Conception of the electronic controlled magnetorheological clutch

***Abstract**. This paper's goal is to show conception of the electronic controlled clutch witch magnetorheological fluid (MR Fluid). The proposal of coupling construction, structure of control system is presented and results of calculations of the magnetic field distribution and clutching torque value as well calculation of the clutch shaft are shown. In the paper properties of magnetic fluids and fundamentals of magnetorheological devices operation are described.*

***Streszczenie** W artykule przedstawiono koncepcję elektronicznie sterowanego sprzęgła z cieczą magnetoreologiczną. Zaprezentowano propozycję konstrukcji sprzęgła, strukturę jego systemu sterowania oraz rezultaty obliczeń rozkładu pola magnetycznego, momentu sprzęgła oraz obliczenia konstrukcyjne wału sprzęgła. Opisano również podstawowe właściwości cieczy magnetycznych i przykłady zastosowania w urządzeniach elektromechanicznych. (**Koncepcja sprzęgła magnetoreologicznego ze sterowaniem elektronicznym**)*

Keywords: clutch, magnetorheological fluid, magnetic field distribution, control system.
Słowa kluczowe: sprzęgło, ciecz magnetoreologiczna, rozkład pola magnetycznego, układ sterowania.

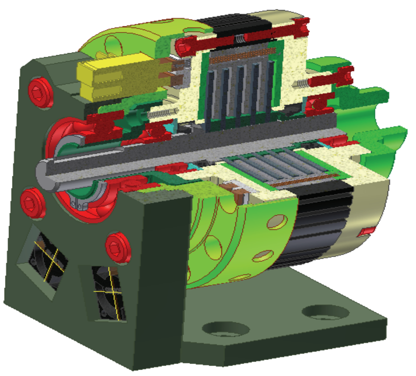
Introduction

The magnetorheological fluid (MR Fluid) belongs to groups of smart materials for which specific properties appear on influence of the external magnetic field. In the external magnetic field viscosity of the fluid increases. Thanks to this feature MR fluid is applied in brakes, dampers and clutches [1]. In these devices MR fluid is introduced between moving parts. Magnetic field which changes viscosity of MR fluid is generated by the coil carrying the current. I and the permanent magnet. Thanks two sources of magnetic field (coil and permanent magnet) the clutch generated clutching torque $T_C(I=0)$ without necessity supplying the coil. The current I flowing the coil can decrease clutching torque $T_C(I_-)$ or increase $T_C(I_+)$.

Proposal of coupling construction

The figure 1a shows design of multidisc clutch and shaft with discs (Fig. 1b). Quantity discs was determined on the basis of electromagnetic calculations.

a)



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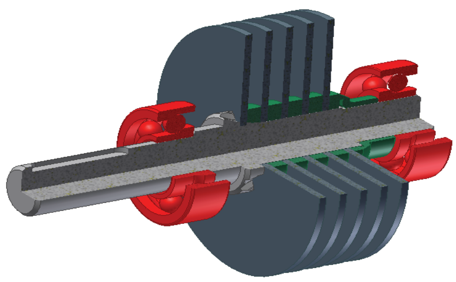


Fig.1. Design of multidiscs magnetorheological clutch and its schaft

The possible functions which multidiscs magnetorheological clutch can fulfil: dynamometrical function (for example in the screwdriver), safeties clutch, for half-active elimination of rotary vibrations, and for the system of the soft start-up.

For the accomplishment of these tasks designing up to the specific application is necessary. Example: for safeties clutch not necessary is applying the magnetic tubule and the permanent magnet. In this construction are also unnecessary all sensors (position sensor, temperature sensor). For a change for half-active elimination of rotary vibrations clutch must use all signals for correct work. Authors made an attempt to design the clutch for all functions. It is a universal solution which enables the realization of every of exchanged functions. The project process is presented for schematic figure in picture 2.

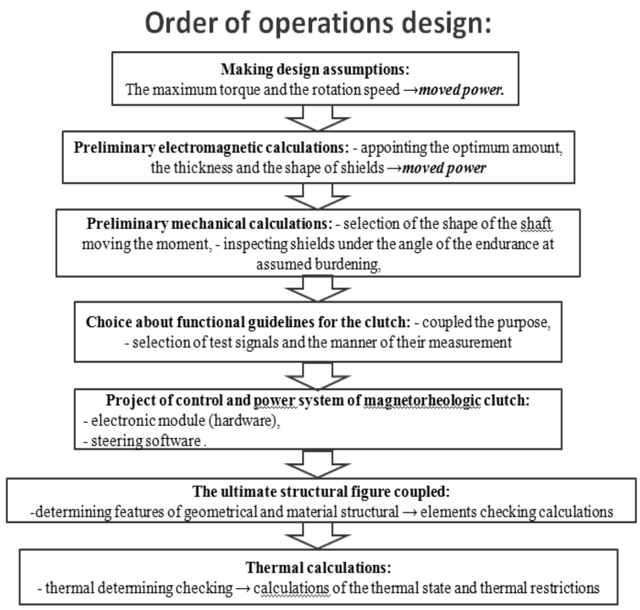


Fig.2. The project process for multidiscs magnetorheological clutch

Design assumptions:

They assumed that the scope of the produced coupling T_S moment would be located in a scope from 0 to about 22 Nm (T_{Smax} = 22 Nm) for the MRF-122EG (fig. 8). Simultaneously they assumed that the maximum n_{Smax} rotation speed would take out 1000 obr/min. And so the maximum power moved by the clutch at assumed parameters will take out equation (1):

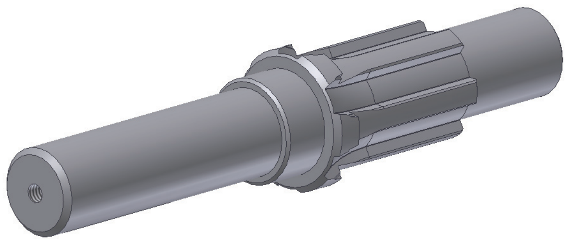
$$P = \frac{T_{s\,max} n_{s\,max}}{9549.3} = \frac{22 \cdot 1000}{9549.3} = 2.303kW \quad (1)$$

For more distant calculations they accepted *P=2,3kW*.

Calculation of the clutch shaft

For the clutch shaft calculations checking, associated with transferred charges were conducted. The loads for the shaft are: a torque T_{Smax}=22Nm and crosswise force F=50N. The project and calculations were conducted in the Inventor 2010 program. The figure 3a presents the model of the shaft and loads of the shaft – figure 3b.

a)



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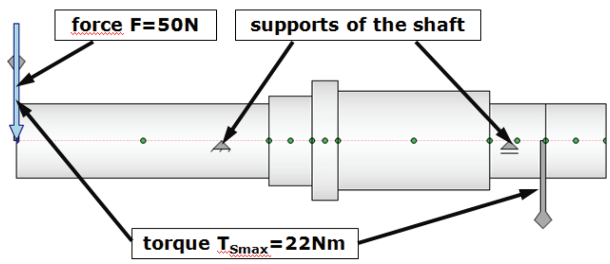


Fig.3. The shaft for magnetorheological clutch

In picture 4 results of calculations were presented for the shaft under the influence of assumed loads [4].

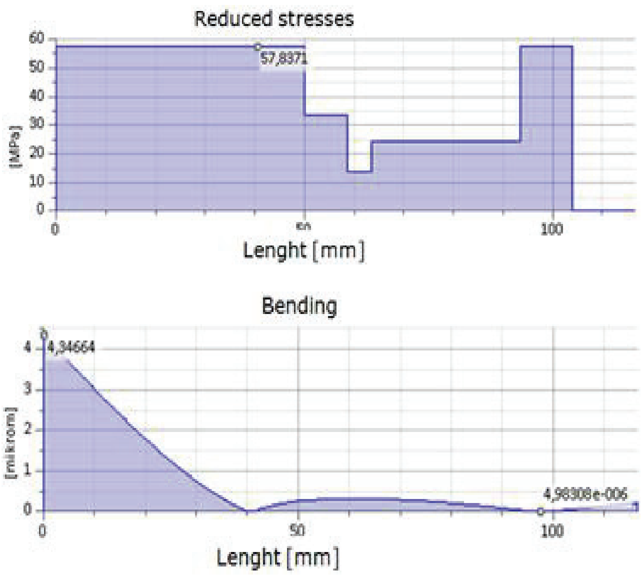


Fig. 4. Results of calculations

Results of calculations show that the shaft about accepted dimensions will move assumed loads

Calculations of the magnetic field distribution and clutching torque value

For the proposed structure of the magnetorheological clutch magnetic field models were made [2]. The models were different for the sake of number, thickness and diameter of discs.

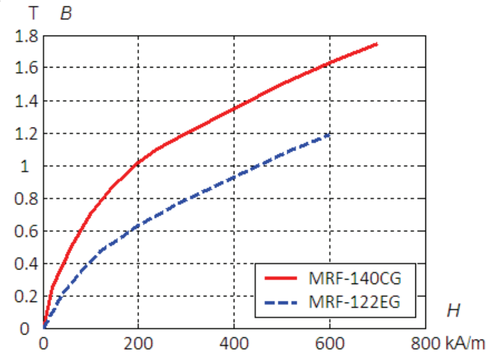


Fig.5. Magnetization curves of different magnetorheological fluid types.

The models take into account magnetization curves of steel and magnetorheological fluid. The field calculations were made for two cases, for applying in the clutch magnetorheological fluid MRF-122EG and MRF-140CG [3]. For both cases magnetization curves of particular magnetorheological fluid (Fig.5) were taken into account. The magnetic field distributions (Fig.6) were calculated with taking advantage of magnetic field models.

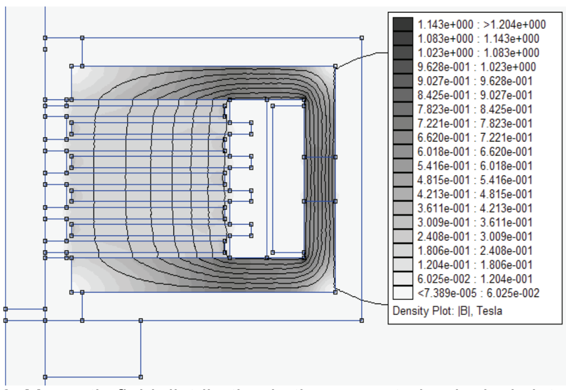


Fig.6. Magnetic field distribution in the magnetorheological clutch

On the base of the magnetic field distributions and catalogue values of yield share stress in magnetorheological fluids (Fig.7) clutching torque values were determined. The results of the calculations are shown in Fig.8 as clutching torque versus coil current characteristics $T_C(I)$. Fig.8 shows two characteristics for two types of magnetorheological fluids – MRF-122EG and MRF-140CG.

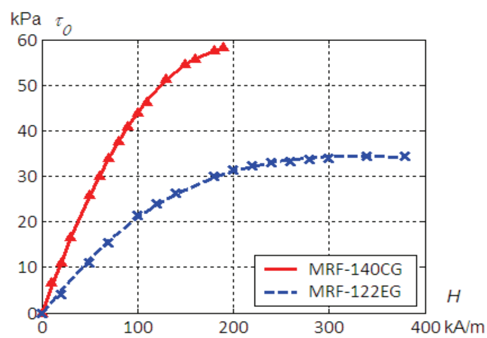


Fig.7. Yield share stress versus magnetic field intensity $\tau_0(H)$ for different magnetorheological [3]

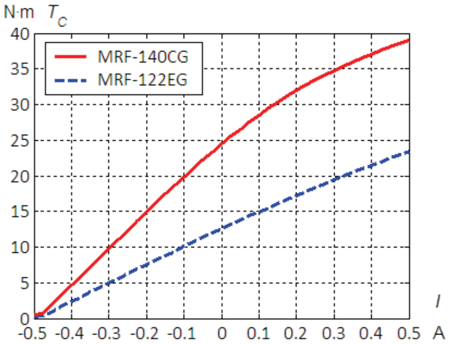


Fig.8. Clutching torque $T_C(I)$ versus coil current for different magnetorheological fluid types [2]

For the MRF-122EG the characteristic $T_C(I)$ is almost linear whereas for MRF-140CG is nonlinear but the T_C values are bigger for the same values of *I*. The $T_C(I)$ characteristic determines control system of the clutch.

Structure of control system

On the base a result of field calculations a solution of magnetorheological clutch control system is proposed. The diagram of the control system is shown is Fig. 9. The best parameters of the investigation are got when current no exceed than 0,7A and voltage no exceed than 24V.

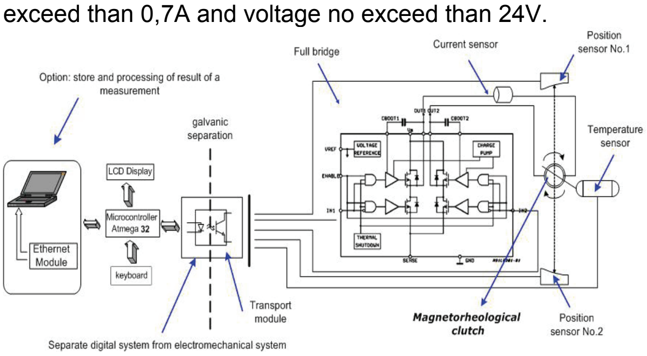


Fig.9. Block diagram of control system of magnetorheological clutch with storage options and working result of a measurements basic parameters

Thanks such solution it is possible to fluently control of torque transmitted by the clutch. Appearance slip will be controlled through two cooperated position sensors, which are placed on moving parts of the clutch. When the slip is detected microcontroller control the full bridge in order to achieve unclutch state. Temperature sensor as well current sensor enable protection for overload.

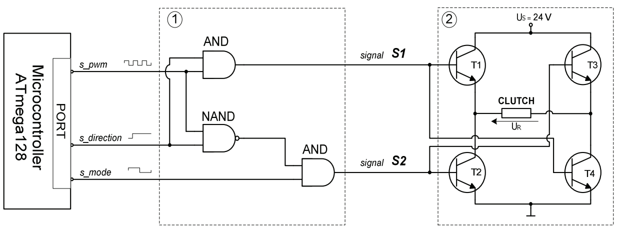


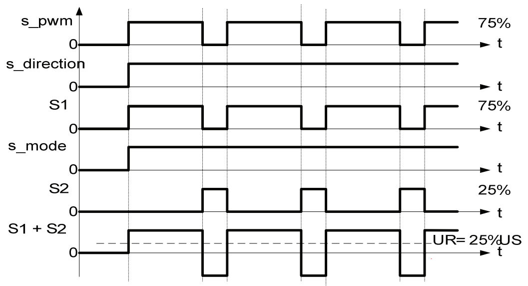
Fig.10. Scheme of system enabling control of magnetorheological clutch in two modes

The adjustment desired value torque of the magnetorheological clutch, is made by change of clutch coil average value of voltage supply. This voltage value is received by the way of proper keying of transistor-bridge by the PWM (Pulse Width Modulations) signal.

In the first prototype version application of two modes of control, which are connected with way of keying of transistors bridge is planned. The change of modes during utilize device, it will be possible thanks designed system enabling control of magneto rheological clutch in two modes (Fig. 10). Three logical gate mediate in transmission of PWM signal, in the way dependent on choice of mode, with help ***s_tryb*** signal. The ***s_direction*** signal is always set in high state independently of the way of control.

The time diagrams of signals for control of average value voltage supply of clutch coil is shown is Fig. 11. The need of research of clutch for two control modes is connected with kind of MR fluid which was used for construction of clutch. The designers predict that, with the control of transistors of only one half bridge (mode II), it will possibly come to the change in working point of permanent magnet (magnetization or demagnetization) in effect one-way the flow variable current.

a)



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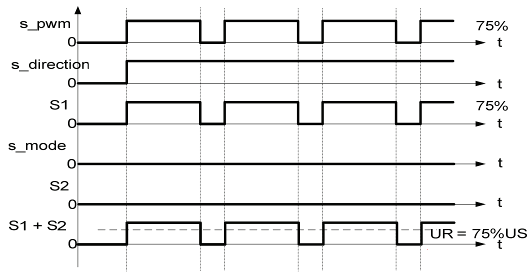

Fig. 11. Time diagrams of signals for control of average value voltage supply of clutch coil**:** a) mode I; b) mode II

Therefore is also planned controlled with used switching pair of transistors of bridge in one cycle of PWM signal (Fig. 11a). It will cause passage of current in two-way by the coil of magnetorheological clutch and contribute to eliminate the change of working point of permanent magnet in order to increase precision of control.

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