Clutch and Brake Related Testing of Magnetorheological Fluids Using the BASF Twin Gap Magnetocell

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Abstract:
A new magnetocell, based on a plate-plate twin gap with housing and integrated online flux density measurement, allows for a reliable rheological characterization of magneto¬rheological fluids (MRF). Various modifications introduced into the commercial magnetocell version MRD180/1T (Physica/Anton Paar), distinctly improve the homogeneity of the magnetic flux density distribution and broaden the range of accessible shear rates in a MCR501 rheometer up to more than 3000 s^{-1}. The new design has been licensed to the manufacturer, to provide a commercial twin gap magnetocell. Fixed volume dosing of MRF yields an improved reproducibility of flow curve measurements, as required for the design of technical devices like MR clutches and MR brakes. The twin gap magnetocell enables the mimicking of MRF response relevant for clutch and brake applications, like shear rate or shear stress step or ramp testing, and drive cycle testing. The dynamic shear stress response to changes of flux density and/or shear rate may be characterized. Testing of MRF is possible for brake applications under constant holding torque conditions in the pre-yield regime. MRF creep and recovery for various imposed shear stresses may be monitored as a function of time. Comparison with a concentric cylinder pilot clutch underlines the validity of the shear stress versus flux density characteristic as determined with the twin-gap magnetocell.

Zusammenfassung:
Eine neue magnetorheologische Messzelle wurde entwickelt, um eine zuverlässige Charakterisierung magnetorheologischer Flüssigkeiten (MRF) zu ermöglichen. Die Messzelle beruht auf einer Platte-Platte Doppelspaltanordnung mit zylindrischer Einhausung des Messspaltes und einer zusätzlichen Online-Flussdichtemessung. Zahlreiche Modifikationen der kommerziell verfügbaren Einfachspalt-Magnetmesszelle von Anton Paar (MRD180/1T) waren nötig, um eine signifikant verbesserte Homogenität der Flussdichteverteilung im Scherspalt zu erreichen. Weiterhin wurde durch Modifikationen an der bestehenden Messzelle eine deutliche Erweiterung des zugänglichen Scherratenbereichs von bis zu mehr als 3000 s^{-1} in einem MCR501 Rheometer erzielt. Das neue Design der Doppelspalt-Magnetmesszelle wurde an Anton Paar lizenziert. Mit einer exakten Volumendosierung der MRF mittels Pipette wurde eine ausgezeichnete Reproduzierbarkeit von Fliesskurvenmessungen erreicht, die für die Entwicklung technischer Geräte wie MRF-basierter Kupplungen und Bremsen unerlässlich ist. Mit der Doppelspalt-Magnetmesszelle kann das rheologische Verhalten von MRF in technischen Kupplungs- und Bremsanwendungen simuliert werden. Beispiele sind Tests von Scherraten- oder Schubspannungs-Rampen bzw. -Stufen und auch praxisnahe Fahrzyklusprüfungen. Darüber hinaus kann das Schubspannungsverhalten von MRF hinsichtlich Änderungen der Flussdichte und/oder der Scherrate charakterisiert werden. Ausserdem kann das Verhalten von MRF für Bremsanwendungen getestet werden, die ein konstantes Haltemoment erfordern. Das Kriech- und Kriecherholungsverhalten von MRF für unterschiedliche aufgeprägte Schubspannungen wird dazu als Funktion der Beanspruchungszeit bestimmt. Der Vergleich mit einer konzentrischen Zylinderkupplung im Pilotmassstab unterstreicht die Relevanz der mit der neuen Doppelspalt-Magnetmesszelle aufgenommenen Schubspannungs-Flussdichte Charakteristik magnetorheologischer Flüssigkeiten für technische Anwendungen.

Résumé:
Une nouvelle cellule de mesure magnétorhéologique permettant une caractérisation fiable de liquides magnétorhéologiques (MRF) a été développée. Cette cellule de mesure est basée sur une disposition à double entrefer plan-plan avec cartérisation cylindrique de l'entrefer de mesure et une mesure en ligne supplémentaire de densité de flux. De nombreuses modifications de la cellule de mesure magnétique à entrefer simple d'Anton Paar (MRD180/1T) disponible dans le commerce ont été nécessaires pour parvenir à une nette amélioration de l'homogénéité de la distribution de la densité du flux dans l'entrefer de cisaillement. De plus, des modifications apportées à la cellule de mesure existante ont permis d'atteindre une nette extension de la zone accessible de taux de cisaillement de plus de 3000 s^{-1} dans un rhéomètre MCR501. La nouvelle conception de la cellule de mesure magnétique à double entrefer à été concédée sous licence à Anton Paar. Un dosage volumétrique précis du MRF au moyen d'une pipette a permis d'obtenir une excellente reproductibilité des mesures de courbes d'écoulement, indispensable au développement d'appareils techniques tels que les embrayages et les freins à base de

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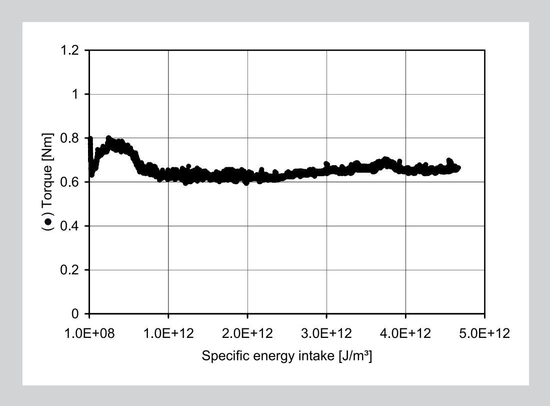

Figure 13: Torque versus specific energy intake for durability tests using the dedicated BASF durability test cell (temperature 35°C, rim shear rate 200 s^{-1}, flux density approximately 0.5 T).

of commercial clutches and brakes. Shear rate ramp testing allows studying the stability of MRF formulations including thixotropy. A combination of shear rate ramp tests with step shear rate and step flux density changes is also possible. Due to the high shear rates and flux densities accessible, realistic drive cycle tests are feasible. Comparison with a concentric cylinder pilot clutch underlines the validity of the flow properties of MRF from the twin gap magnetocell for the design of MR devices. Shear durability tests on MRF are possible up to energy intakes of approximately 10^{10} J/m³. For long-term durability testing up to energy intakes higher than 10^{12} J/m³, a twin gap design with sealings and efficient temperature control is required, however. For brake applications, constant shear stress testing with the twin gap magnetocell allows for the determination of the creep resistance of MRF, and the maximum holding torque of a brake under pre-yield conditions.

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APPENDIX

BASF DURABILITY TEST CELL

As was shown in Figure 7, only short term durability testing is possible with the twin gap magnetocell. Using the same principle, a dedicated magnetocell has been developed for MRF durability testing. With the durability test cell, accelerated testing is performed in order to achieve life time dissipated energy input to MR-formulations within a few days. A schematic of the dedicated durability test cell is shown in Figure 12. A twin gap plate-plate arrangement is used with the magnetic field acting perpendicular to the plane of shear. The magnetic field is generated by two permanent magnets sitting opposite each other on the two sides of the shear gaps. Continuous shear is applied to the MRF and the resulting torque measured on the rotor axle. The energy dissipation in the MRF is calculated by integrating the measured torque M as a function of the torsional angle φ:

$$W = \int_{\varphi_0}^{\varphi_1} M(\varphi) d\varphi \tag{6}$$

The torsional angle φ is related to the number of revolutions n by $\varphi = 2\pi n t$, with t being the time in the durability test. Normalization of the dissipated energy W by the MRF volume V in the test cell results in the specific energy intake W/V (compare Equation 5).

Temperature and pressure measurement in the cell is possible to achieve full data acquisition. The experimental parameter range of the durability test cell is chosen such that conditions typical of commercial clutch and brake applications are simulated: temperature range 25 to 150°C, maximum shear rate 500 s^{-1}, and maximum flux density in the MRF filled shear gaps 0.5 Tesla. The maximum torque is 2 Nm. Key for reliable durability testing is the sealing of the shear gap in order to avoid, e.g. MRF base oil loss and any environmental influences on the MRF. Sealing is achieved by a pair of static gaskets at an outer radius, and a pair of dynamic gaskets at an inner radius (compare Figure 12). Furthermore, an efficient cooling system is required to remove the heat produced in the MRF. In order to achieve this, the whole durability test cell is immersed into an oil bath thermostate. The cell may easily be dismantled, enabling reproducible MRF extraction for further analytics as a function of dissipated energy.

In Figure 13, a durability test on MRF is shown. The MRF is able to withstand energy intakes as high as 5.10^{12} J/m³ without distinct change of the torque (or shear stress) response when measured in the dedicated BASF durability test cell. The reason for the high durability of the MRF is the presence of sealings in the durability test cell. Furthermore, the excellent oil bath temperature control reduces the temperature increase in the shear gaps to a minimum. Typical power intakes of a few Watt cause an adiabatic temperature rise of some Kelvin per second. A

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powerful temperature control of the shear cell as well as efficient sealings are important prerequisites for reliable durability testing. The twin-gap plate-plate arrangement of the BASF durability test cell with sealed sample chamber therefore represents an excellent device for reliable durability testing on brake and clutch type magnetorheological fluids.

REFERENCES

[1] Basonetic® (2009), BASF MR-Fluids: http://www.catamold.de/p02/CAPortal/en_GB/portal/MRF/content/Produktgruppen/MRF/Basonetic5030

[2] Carlson JD, Jolly MR: MR fluid foam and elastomer devices. Mechatronics 10 (2000) 555.

[3] Casson N: A flow equation for pigment-oil suspensions of the printing ink type. Rheology of Disperse Systems, Ed. Mill CC, Pergamon Press, London (1959) 84-104.

[4] Ciocanel C, Molyet K, Yamamoto H, Vieira SL, Naganathan NG: Magnetorheological fluid behaviour under constant shear rates and high magnetic fields over long time periods. J. Eng. Mater. Technology 128 (2006) 173.

[5] Goncalves FD, Koo JH, Ahmadian M: A review of the state of the art in magnetorheological fluid technologies – Part I: MR fluid and MR fluid models. Shock and Vibration Digest 38(3) (2006) 203.

[6] Kieburg C, Oetter G, Lochtman R, Gabriel C, Laun HM, Pfister J, Schober G, Steinwender H: High performance magnetorheological fluids tailored for a 700 Nm automotive 4-wheel-drive clutch. Proceedings of the 10th International Conference on Electrorheological Fluids and Magnetorheological Suspensions, Gordaninejad F, Graeve OA, Fuchs A (Eds.) York in World Scientific, New Jersey (2007) 101.

[7] Kieburg C, Oetter G, Gabriel C, Laun HM, Steinwender H: MR-Coupling: Prototype Car Testing and MRF Durability Requirements. ERMR2008 (2008) Dresden, Germany.

[8] Laeuger J, Wollny K, Stettin H, Huck S: A new device for the full rheological characterization of magneto-rheological fluids. Int. J. Mod. Phys. B. 19 (2004) 1353.

[9] Laun HM, Gabriel C: Measurement modes of the response time of a magneto-rheological fluid (MRF) for changing magnetic flux density. Rheol. Acta 46 (2007) 665.

[10] Laun HM, Gabriel C, Kieburg C: Twin gap magnetorheometer using ferromagnetic steel plates – Performance and validation. J. Rheol. 54 (2010) 327-354.

[11] Laun HM, Schmidt G, Gabriel C, Kieburg C: Reliable plate-plate MRF magnetorheometry based on validated radial magnetic flux density profile simulations. Rheol. Acta 47 (2008) 1049.

[12] Li WH, Du H, Chen G, Yeo SH: Experimental investigation of creep and recovery behaviors of magnetorheological fluids. Materials Science and Engineering A333 (2002) 368.

[13] See H: Mechanisms of magneto-and electro-rheology: Recent progress and unresolved issues, Appl. Rheol. 11 (2001) 70.

[14] Smith AL, Ulicny JC, Kennedy LC: Magnetorheological fluid fan drive for trucks. Journal of Intelligent Material Systems and Structures 18(12) (2007) 1131.

[15] Soskey PR, Winter HH: Large step strain experiments with parallel-disk rotational rheometers. J. Rheol. 28 (1984) 625.

[16] Ulicny JC, Balogh MP, Potter NM, Waldo RA: Magnetorheological fluid durability test—Iron analysis. Materials Science and Engineering A 443 (2007) 16.

[17] Ulicny JC, Hayden CA, Hanley PM, Eckel DF: Magnetorheological fluid durability test—Organics analysis. Materials Science and Engineering A 464 (2007) 269.

[18] Wiehe A, Kern S, Maas J: Rotatory MRF-actuator for an automotive door assistent. Automatisierungstechnik 56 (2008) 155.

[19] Wollny K, Laeuger J, Huck S: Magneto sweep – A new method for characterizing the viscoelastic properties of magneto-rheological fluids. Appl. Rheol 12 (2002) 25.

[20] Laun HM, Gabriel C, Kieburg Ch: Wall material and roughness effects on transmittable shear stresses in plate-plate magnetorheometry of a magnetorheological fluid (MRF). Rheol. Acta (2010) submitted.

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