Magneto Sweep – A New Method for Characterizing the Viscoelastic Properties of Magneto-Rheological Fluids

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Abstract:
The viscoelastic properties of a magneto-rheological fluid can be variably controlled using a magnetic field. A new measuring method is introduced which is based on oscillatory tests. In contrast to flow curves from experiments at steady shear rate, the new method allows an exact determination of a magneto-rheological fluid's viscoelastic properties as a function of the preset magnetic field strength. The "Magneto Sweep" is an oscillatory test method, each with constant amplitude and constant frequency while logarithmically increasing the magnetic field strength (Magneto Sweep). For typical magneto-rheological fluids (MRF) three characteristic regions and two significant transition points can be determined. These transitions mark the corresponding change in material behavior resulting from an increasing magnetic field strength.

Zusammenfassung:
Die viskoelastischen Eigenschaften einer magneto-rheologischen Flüssigkeit können mit Hilfe eines magnetischen Feldes variabel eingestellt werden. Die vorgestellte, neue Messmethode basiert auf Oszillationsmessungen. Im Gegensatz zu Fließkurven, d. h. reinen Rotationsversuchen, erlaubt die neue Messmethode eine exakte Bestimmung der viskoelastischen Eigenschaften als Funktion der magnetischen Feldstärke. Der „Magneto-Sweep" wird als Oszillationsversuch mit konstanter Deformation und Frequenz bei logarithmisch ansteigender magnetischer Feldstärke durchgeführt. Für typische magneto-rheologische Flüssigkeiten (MRF) können drei charakteristische Bereiche und zwei signifikante Übergangspunkte ermittelt werden. Die Übergänge kennzeichnen die jeweilige Änderung des Materialverhaltens bei einer Erhöhung der magnetischen Feldstärke.

Key Words: Magneto sweep, Magneto-rheological fluid, nano-MRF, magneto-rheological effect, magneto-rheological device, particle arrangement, linear range of chain formation

1 INTRODUCTION

Magneto-rheological fluids (MRF) are suspensions of particles which can be magnetized. MRF exhibit fast, strong and reversible changes in their rheological properties when a magnetic field is applied, making them very interesting for a lot of technical applications. MRF are similar to electro-rheological fluids (ERF), but much stronger, more stable and easier to use. Research into using MRF to control mechanical elements has been undertaken since the late 1940s [1]. The first patent for clutches based on MRF was registered by M. Winslow as early as 1953 [2]. Up until recent years, however, industrial application was unsatisfactory due to the poor quality of the available magnetic fluids. The introduction of nano-MRF has solved one of the main problems: Sedimentation is prevented by using very small magnetic particles (with a diameter of *30 nm*). Furthermore the liquid phase should not evaporate and the suspension should not be abrasive. Most of the problems have already been solved. A commercially available damping system that takes full advantage of the controllable rheology of MRF and delivers valveless damping control will first appear on passenger vehicles in the beginning of 2003 [3]. The current I applied to an electro-magnetical coil inside the damper's piston controls the flow of the MRF in the damper [4]. Further commercial systems are e.g. a MRF brake, "steer-by-wire" vehicle control, controllable friction damper that decreases the noise and vibration in washing machines, above-the-knee prosthesis, and seismic mitigation MRF damping systems protecting buildings and bridges from earthquakes and windstorms [5].

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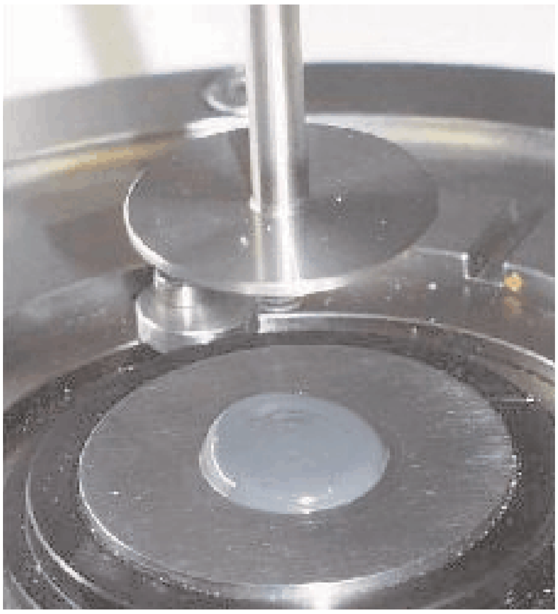

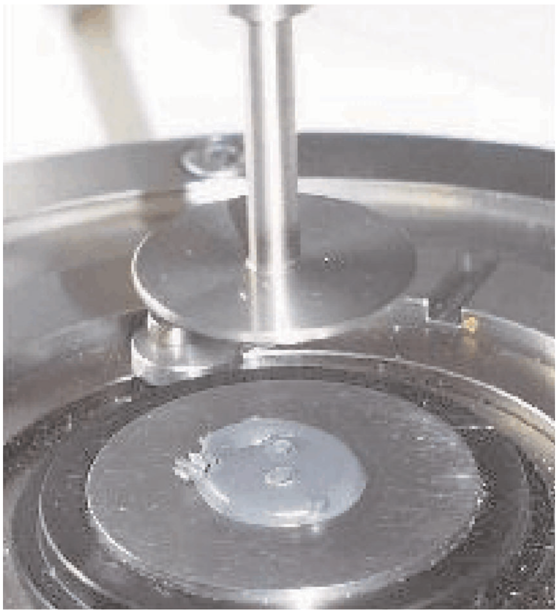

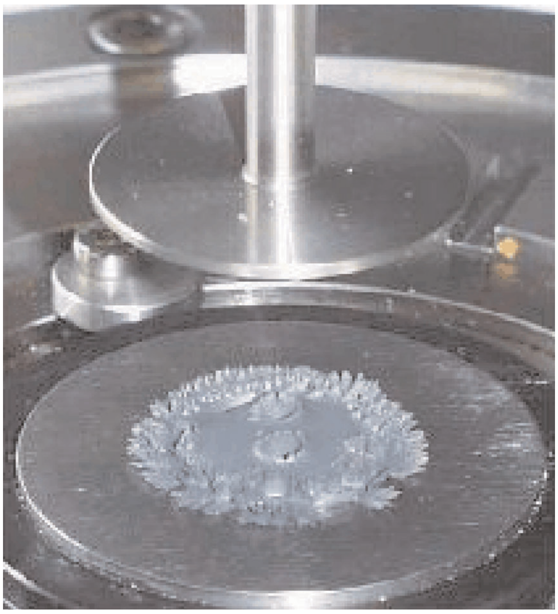

Figure 10 (left above): Parallel-plate sensor with a MRF showing the quasi gel character (Region II.).

Figure 11 (right above): Parallel-plate sensor with a MRF exceeding Region II (from Region II. to Region III.).

Figure 12 (left below): Parallel-plate sensor with a MRF showing consolidation to rigid needles oriented to the outer, disconnected magnetic bridge between cover and highly permeable base ring which is not yet demagnetized (Region III.).

results for the complex viscosity. The chain structure predominates over the base fluid.

The elastic portion increases more than the viscous portion when the magnetic field strength is increased (Fig. 7). This occurs because the carrier fluid is obstructed in its flow direction due to the orientation of the dispersed solid particles along the field lines (Fig. 1). A further increase of the magnetic field strength results in a rigid chain formation along the field lines (Region III.).

Region III. – Particle arrangement preventing flow

Exceeding the linear range of the complex viscosity curve at H = 50,000 A/m, the sample becomes increasingly "immobile" (Fig. 11), the ratio between viscous portion (G'') and elastic portion (G') decreases with increasing magnetic field strength.

Rigid chains of magnetic particles are formed along the field lines preventing flow. At the end of the test at H = 185000 A/m, the sample has a consistency like cold butter, i.e. of a viscoelastic material. When the maximum magnetic field strength is applied, the complex viscosity of the MRF increases more than a factor of 1000 compared to the initial viscosity value.

5 CONCLUSIONS

Using a magneto-rheological measuring cell and the corresponding control unit, oscillatory tests can be performed for precise measurement of the structural strength and flowability of magneto-rheological fluids (MRF) as a function of the magnetic field strength H *(magneto sweep)*. Characteristic points and regions of a magneto sweep, if presented in a log/log scaled diagram, can be determined: The minimum in the complex viscosity function corresponding to a magnetic field strength favoring flow.

The maximum in the loss factor function corresponds to the linearly increasing complex viscosity function. The maximum marks the transition between a particle arrangement which allows flow to a particle arrangement which obstructs flow. For the two investigated MRF which have the same solid concentration the end point of the linear region mark a transition to a state in which flow is prevented by tight particle chain formation along the field lines. The end point of this linear region mark transition to the rheological behavior, in which flow is prevented by tight particle chain formation along the field lines.

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