HOMOGENEOUS ELECTRORHEOLOGICAL FLUIDS APPLIED TO VIBRATION CONTROL

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Abstract. *The purpose Electrorheological (ER) fluids are capable of providing continuously variable damping forces in response to an electrical stimulus. Many prototype ER dampers, described in the literature, have been based upon exploiting the variable shear properties of ER fluids. Recently, an alternative mode of operation, namely squeeze-flow, has been identified and investigated. Furthermore, most of these investigations have been carried out using various particle-dispersion ER fluids. This paper is concerned with an experimental investigation of the performance of a homogeneous electrorheological (ER) fluid in an oscillatory squeeze-flow. The fluid is sandwiched between two parallel plane circular electrodes, the upper one fixed and the lower one oscillating normal to its plane. Of particular interest is the temporal variation in the force transmitted through the fluid in response to changes in the oscillation frequency and the applied voltage. In addition, the effect of temperature changes on the response of this fluid and the relevance of the work in the application to vibration control are discussed.*

Keywords*: Homogeneous electrorheological fluids, squeeze flow, vibration control*

1. Introduction

Electrorheological (ER) fluids, which belong to the general class of smart materials, can exhibit a massive and reversible change in their rheological properties such as yield stress, apparent viscosity and other moduli when subjected to an electric field. These fluids have been known since the late 1940s when Winslow (1949) investigated their first potential engineering application. These fluids involve slurries of solid semi-conducting particulates, typically of micrometers in size, in dielectric liquids. The response of these fluids to an applied field is the familiar chaining of the particulates in the field direction and the resulting “solidification” or increase in the apparent viscosity of the fluids (Block, 1990). Industrial applications of these fluids, during the last two decades, have seen considerable progress involving investigations into prototype and model devices. The majority of these devices have employed ER fluids in simple flow or shear mode of operation. An alternative arrangement, squeeze mode, in which the fluid is subjected to compressive and tensile stresses in a direction parallel to the applied field, has been identified (Stanway, 1992). It was shown that the yield stress in this mode, developed under DC excitation, is greater than that available in shear typically by a factor of ten. This increased fluid strength was systematically investigated by the author and others (see for example a recent investigation by El Wahed, 2003) to exploit the mechanical and electrical properties of ER fluids in squeeze. Furthermore, recent findings of homogeneous (without dispersed particles) ER fluids has prompted further scientific and engineering studies on the ER effect (Inoue, 1995). It was shown that large stresses were measured when this new fluid was subjected to shear loading.

The present investigation addresses the determination of the performance of a homogeneous ER fluid in squeeze under various mechanical and electrical conditions.

2. Experimental Arrangement

The experimental rig, Fig. 1, consists of a Ling Dynamic Systems electromagnetic shaker (Model No. V450) which is capable of providing vertical oscillatory motion with a maximum amplitude of 19 mm (peak-to-peak) over a frequency range from zero to 7.5 kHz.

The shaker head is attached rigidly to a Kistler (Model No. 9311A) piezoelectric force link and an earthed brass electrode having a recessed cylindrical cavity of diameter 95 mm which provides the reservoir for the ER fluid. The high voltage (upper) electrode is a circular brass disc of diameter 56 mm, its circumferential edge and rear face surrounded and supported by a PTFE collar. This is rigidly attached to a second identical force link and positioning assembly to the supporting frame. This arrangement allowed changing the initial inter-electrode gap without compromising the rigidity of the top assembly (electrode).

The instantaneous displacement of the lower electrode is determined using an RDP (type GTX 2500) LVDT, the velocity using an RDP (Type 240A0500) self-induced velocity sensor and the acceleration using an Endevco (Type 7254-100) accelerometer, all three devices attached to the upper surface of the lower electrode. Electrical excitation of the ER fluid is achieved by means of a Trek (Model 664) high voltage amplifier, driven by a Thander (Model TG102) function generator. The Trek device allowed monitoring the applied voltage and the drawn current via 0-10V output monitoring facility. Data acquisition and processing are achieved using a Measurement Group (Type ESAM) analogue to digital converter that is controlled by a Pascal program running on an IBM compatible personal computer. Feedback control was not imposed in these tests but could be achieved, if required, using a Ling Dynamic Systems (Model DSC4) digital sine controller employing as input the signal from the accelerometer. In order that meaningful comparisons could be made between the results of the various tests, the ER fluid temperature was controlled by re-circulating water through a second closed cavity in the lower electrode using a Grant Instruments (Model LTD6) temperature controller.

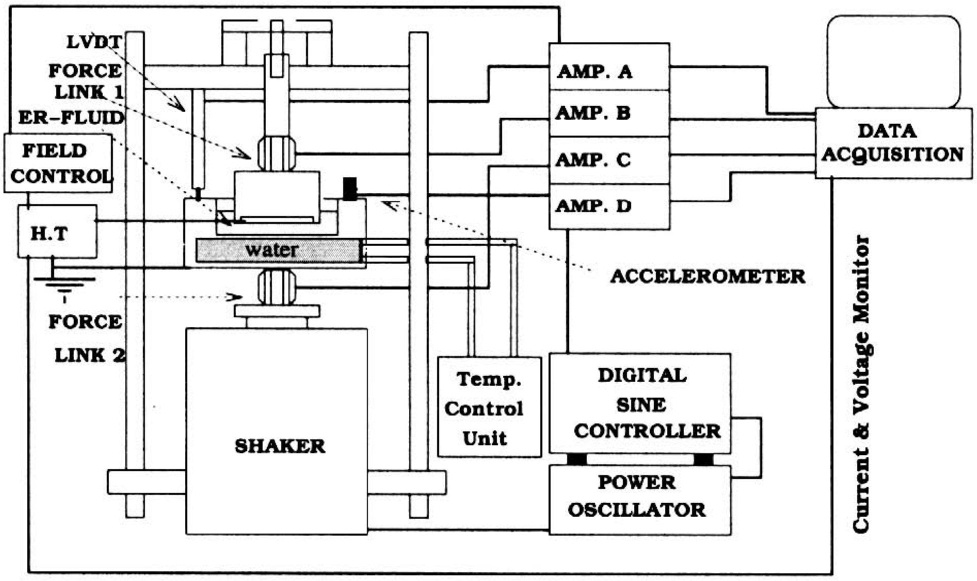

Figure 1**:** Experimental Arrangement.

The two force links were calibrated statically by sequential loading using small weights, while the LVDT was calibrated using a dial gauge. The accelerometer, pre-calibrated by the manufacturer, was found to function as specified to within ± 0.6% when its maximum transverse sensitivity was checked using the digital sine controller. As an additional check, the displacement signal from the LVDT was differentiated twice using central differences and the resulting signal was found to compare well with that from the accelerometer. Finally the data acquisition system was checked against a DC signal supplied by a millivolt calibration unit (Time Electronics Ltd, Model 404S) and was found to be accurate to within ± 0.5%.

The ER fluid used in this investigation was supplied by Asahi Chemical Industry Co. and consisted of a liquid crystalline polysiloxanes diluted with polymethylsiloxane.

3. Results and Discussion

An extensive testing programme has been conducted in order to assess the characteristics of a homogeneous ER fluid, employed in a squeeze cell that simulates a short stroke damper, under a range of electrical and mechanical input conditions. The tests carried out consisted of the simultaneous measurement of the input force delivered by the shaker, the transmitted force across the fluid, the displacement, velocity and acceleration of the lower electrode together with the applied voltage and the current through the fluid. These measurements were collected at a sampling frequency of 5 kHz for a set of mechanical frequencies in the range 2 to 20 Hz. The input displacement amplitude of the lower electrode, for the electrically unstressed fluid, was chosen as 1.25 mm (peak to peak) at the resonant frequency of the system. The mean separation of the electrodes was chosen to be 2.0 mm. DC excitation of the ER fluid under test was in the range 0 to 2 kV. The temperature of the ER fluid was maintained at either 30 °C or 50 °C.

The displacement (Peak to Peak) of the lower electrode and its dependence on the mechanical frequency is shown in Fig. 2 for three applied voltages between 0 and 1.0 kV and a fluid temperature of 30 °C.

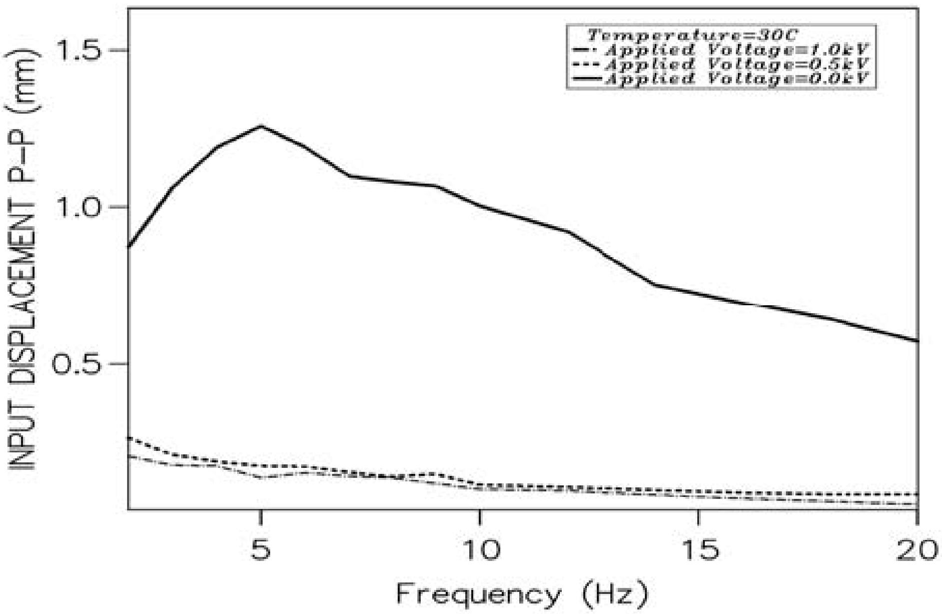

Figure 2: Input Displacement versus Frequency

When the fluid is unstressed, there is a resonant peak at about 5 Hz and little damping of the lower electrode. It is evident that when a voltage of 1.0 kV was applied, the vibration is considerably reduced to small values for all frequencies within the range considered. However, at lower value of 0.5 kV, slightly higher displacement amplitudes were noticed particularly at frequencies lower than 6 Hz. A convenient representation of the performance of the ER cell is shown in Fig. 3 in which the force transmissibility, defined as the ratio of transmitted force to input force, is shown plotted against frequency for the same applied voltages.

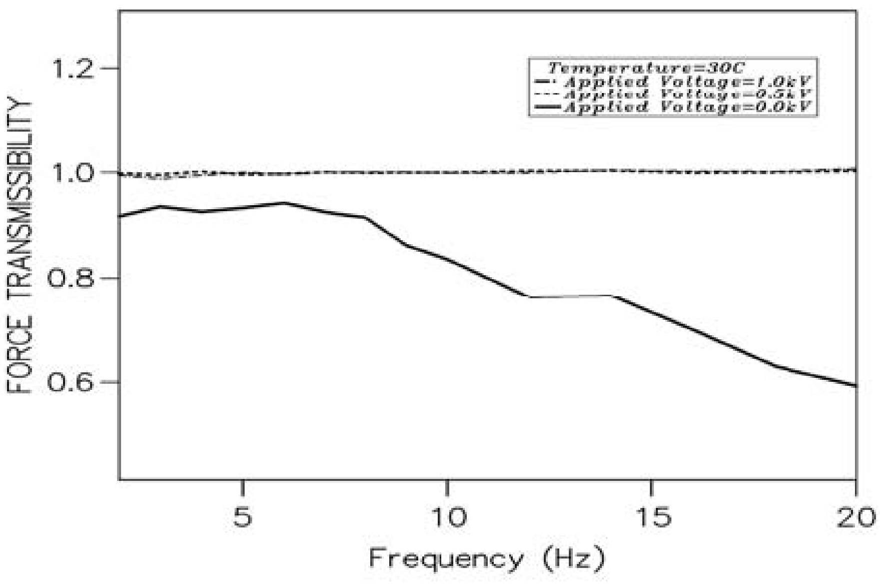

Figure 3: Force Transmissibility v Frequency

For an applied voltage of 0.5 kV, it appears that the ER fluid exhibits “solid body” characteristics as the transmissibility remains close to unity. The performance of this fluid was then assessed under a temperature of 50 °C and the results are summarised in Fig’s. 4 and 5 in terms of input displacement and force transmissibility, respectively.

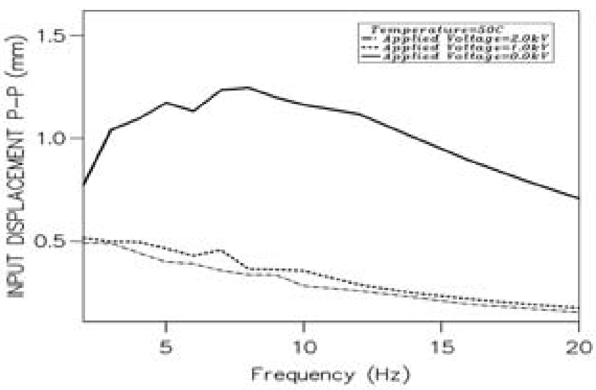

Figure 4: Input Displacement versus Frequency

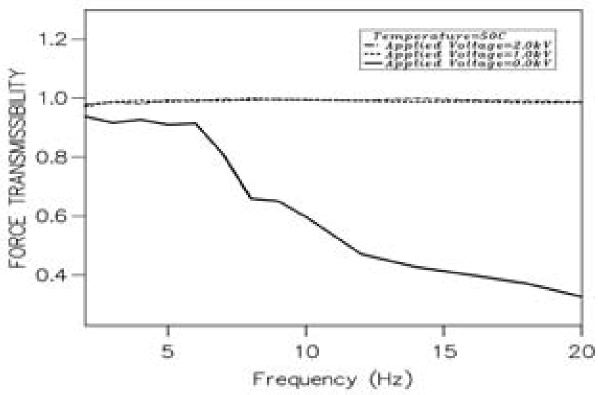

Figure 5: Force Transmissibility v Frequency

It can be seen that this ER fluid showed weaker performance when the temperature increased from 30 °C to 50 °C, as 2.0 kV applied voltages could not reduce the input displacement to levels below 0.4 mm particularly for low frequencies.

The increase in the level of the force transmitted by the fluid when subjected to high voltages could be ascribed to the stretching of the liquid crystalline polysiloxanes droplets, which coalesce to form bridges between the electrodes, increasing the apparent viscosity of the fluid. This may be similar to the formation of chains between the electrodes when a dispersed ER fluid is subjected to high electric fields.

It is worth mentioning that although the input displacement of the lower electrode was considerably reduced, for the two fluid temperatures, when voltages of about 1.0 kV were applied, higher voltages could not suppress the vibration completely. This is contrary to the case of a dispersed ER fluid that was tested under similar conditions but was seen to be capable of completely arresting the shaker (El Wahed, 1998).

In the second part of this investigation, the ER fluid was subjected to a step change in the applied voltage when the oscillation frequency was 5 Hz.

Figure 6 shows the results of this test when the ER fluid temperature was maintained at 30 °C. It can be seen that the input displacement undergoes an abrupt change on the application of 0.5 kV and this is accompanied by a rapid change in the level of the transmitted force. However, this ER fluid seems to require about 5 seconds to reduce the input displacement from 1.25 mm (peak to peak), measured just before the application of the step voltage, to 0.4 mm.

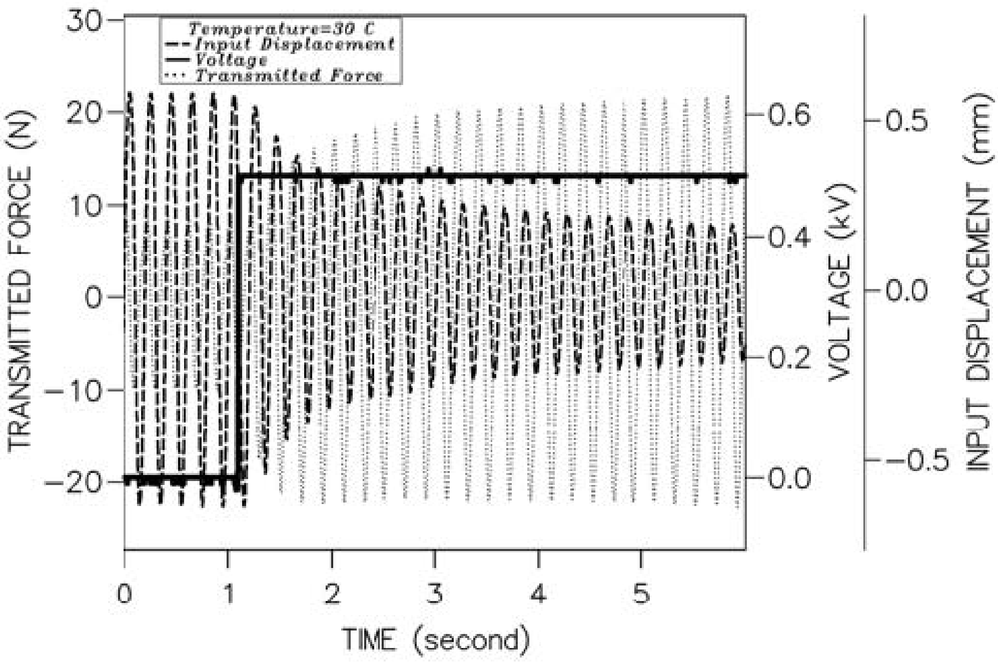

Figure 6: Responses to Step Change in Voltage

Figure 7 shows further decrease in the level of the input displacement and further increase in the level of the transmitted force. This growing strength of the fluid was seen to continue for about 40 seconds, which was the period that was allowed to elapse before the data presented in Figures 2 and 3 were collected. The first large decrease in the level of the input displacement, shown in Fig. 6, may be ascribed to the elongation of the liquid crystalline polysiloxanes droplets whilst the further decrease, shown in Fig. 7, may be attributed to the formation of cylinders consisting of viscous polymer.

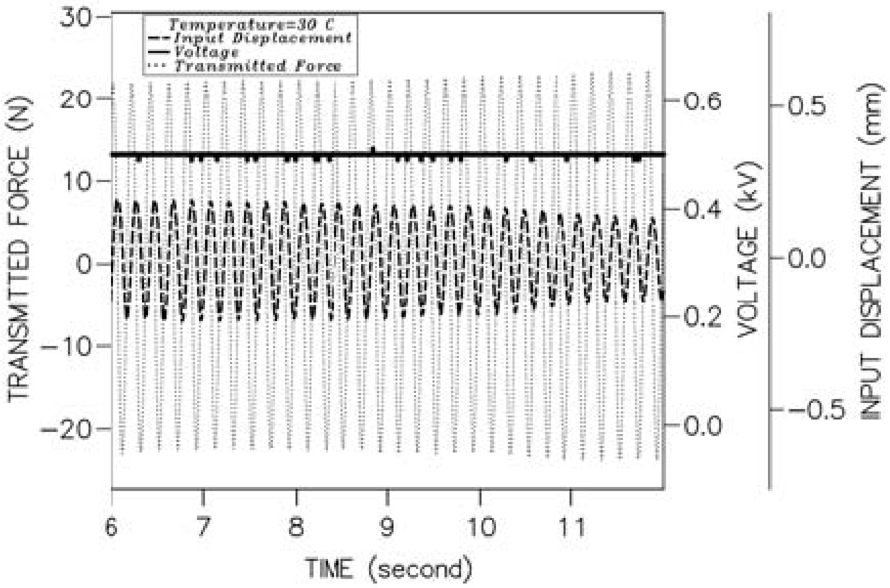

Figure 7: Responses to Step Change in Voltage

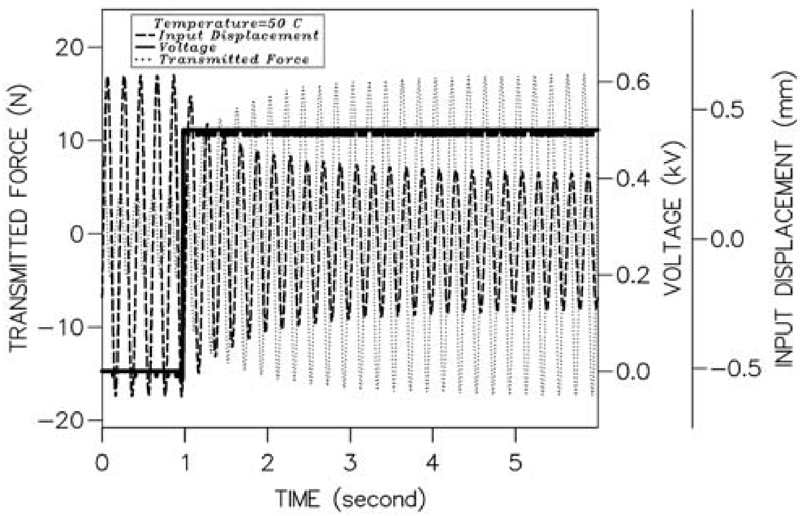

Figure 8: Responses to Step Change in Voltage

Figure 8 shows the behaviour of this ER fluid when the fluid temperature was raised to 50 °C and for a step change in the level of the applied voltage. The fluid, at this temperature, showed similar response although further reduction in the level of the input displacement was not noticed after the initial 5 seconds period, Fig. 9.

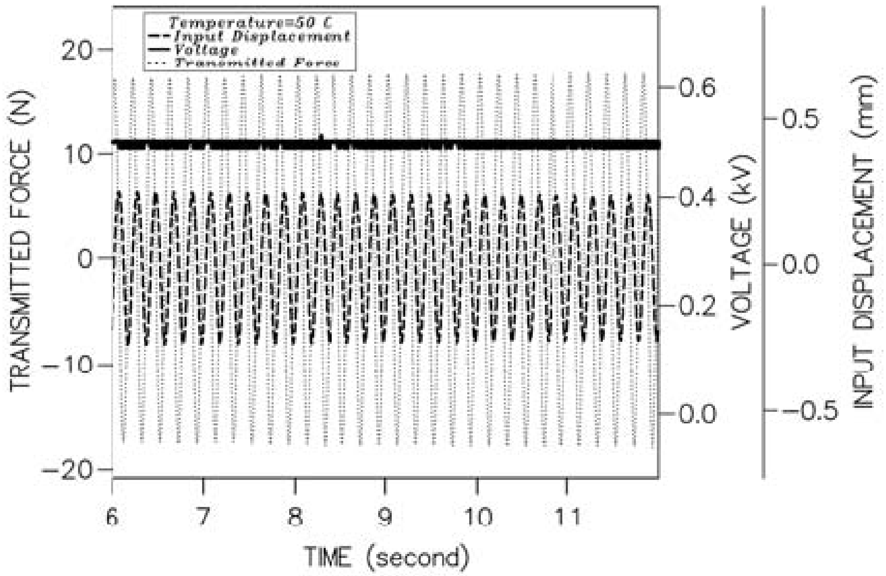

Figure 9: Responses to Step Change in Voltage

The response of this fluid seems to be slow in comparison with that of the dispersed ER fluid that showed much faster response (El Wahed, 1996). The temperature dependence of the time response indicated the existence of a significant intermolecular interaction.

4. Conclusions

In this paper, the characteristics of a homogeneous ER fluid, which consists of a liquid crystalline polysiloxanes diluted with polymethylsiloxane, was investigated under compressive and tensile stresses. This was necessary in order to explore ways by which the output of an ER cell, which is designed as a short stroke damper, may be maximised. The performance of this fluid was seen to be different in comparison with that of a dispersed ER fluid. This was evident in both the strength of the fluid represented by vibration amplitude suppression and force transmissibility, and the response time during which a strong ER effect was developed.

5. References

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6. Responsibility notice

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