A Magnetic Bearing Rheometer With Unprecedented Low Torque Performance

Bernard Costello, Nigel Doe, Peter Foster and Raoul Smith

TA Instruments Ltd., Fleming Way, Crawley, West Sussex, RH10 9NB, U.K.

ABSTRACT

TA Instruments recently launched a new rotational rheometer, the AR-G2 with a magnetic bearing, that gives better low torque performance than any previously available commercial rheometer. In this presentation we will describe how this leads to better quality data, for a range of standard and commercial materials.

INTRODUCTION

The quality of data that can be obtained on a controlled stress rotational rheometer is partly controlled by the torque resolution of the instrument. This depends not just on the quality of the motor, but also on the quality of the components of the coupling between the motor and the sample. This coupling contains one or more bearings, which until now have either been of the mechanical or air type on commercial rheometers. Of these, the air bearing type is superior, in that it gives lower friction and smoother operation, but it seems that the limits of this type of technology are close to being reached, and any further improvements would be prohibitively expensive.

For the AR-G2 rheometer TA Instruments decided to develop a magnetic bearing, as it had been shown by other workers[1] that these performed better than air bearings. However, it was also a requirement that the improvements made did not compromise other aspects of the instrument's performance or its mechanical integrity.

A magnetic version of the instrument thrust bearing, which supports the rotating shaft in the horizontal plane, was developed, but, although a solution to the magnetic radial bearings, which prevent lateral movement, was found, this was too complex to be economically justifiable. However, it is known that most of the friction and run out on an air-bearing rheometer are produced by the thrust bearing, rather than the radial bearings.

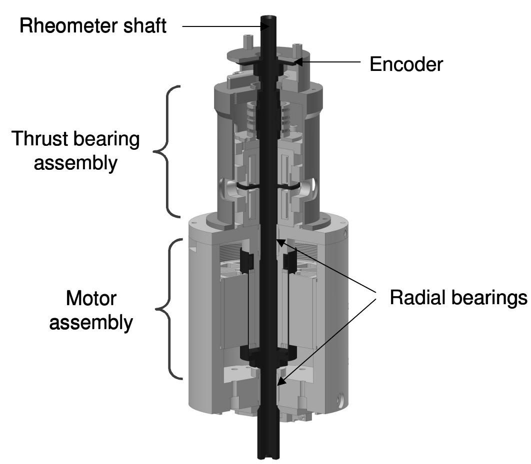

Figure 1: exploded view of the rheometer drive and bearing system. The rotating components are shown as darker.

An additional source of friction in a controlled stress rheometer is the motor itself. On earlier instruments, the gap between the motor and the stator was optimised to remove the effect of motor heating on the torque. To reduce the motor friction, the gap was widened, but it tthen became necessary to measure the temperature of the rotor *in situ*; the method developed to allow this is the subject of U.S. patent 6,798,099. An exploded view of the instrument drive and bearing system is shown in Fig. 1; the rotating components are shown as dark, the stationary components as light grey.

These changes reduced the instrument friction from about 1 μN.m for an air-bearing instrument, to about 0.3 μN.m for the AR-G2. They also produced a smoother operation, and improved the instrument's transient response.

PERFORMANCE

An informative method for assessing the basic performance of a controlled stress rheometer, i.e. in the absence of sample, is to rotate at a fixed, low, angular velocity for an increment number of revolutions. The torque required to hold at this velocity is monitored and reported as a function of time or angular displacement. This method will show imperfections in the bearing assembly, that tend to produce a residual torque acting in either sense (clockwise or anti-clockwise).

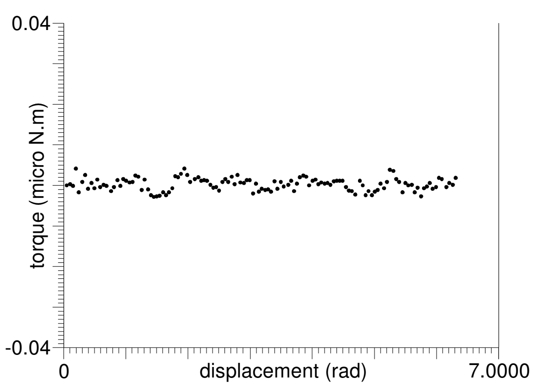

Figure 2: residual torque without sample at angular velocity 0.05 rad s^{-1}.

Results for such a test are given in Fig. 2, which shows torque plotted against displacement for one revolution at an angular velocity of 0.05 rad s^{-1}. The torque range was less than 7 nN.m.

The low residual torque results in the instrument's ability to obtain high quality data for low viscosity materials in steady shear to as low as 10^{-2} μN.m (Fig. 3). At the temperature used, 20°C, decane has a viscosity of 0.92 mPa.s. Decane is used as a low viscosity fluid, rather than water, because it shows less intrusion from surface effects.

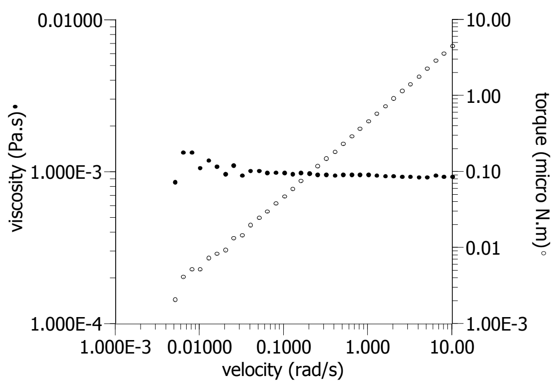

Figure 3: viscosity of decane at 20°C. The accepted value is 0.92 mPa.s

The unprecedented low torque performance of the AR-G2 is also shown in dynamic mode. Results for a Newtonian oil with a viscosity of 5.54 Pa.s are presented in Fig. 4, with the magnitude of the complex viscosity and Two sets of data are shown, in which viscosity the displacement amplitude plotted against the torque amplitude. In one case the experiment was conducted in controlled torque mode, in the other in direct controlled displacement mode. In both cases reliable data has been obtained at torques as low as 3 nN.m. Note, however, that maximum possible error in the torque amplitude at low torques is actually significantly lower than 3 nN.m.

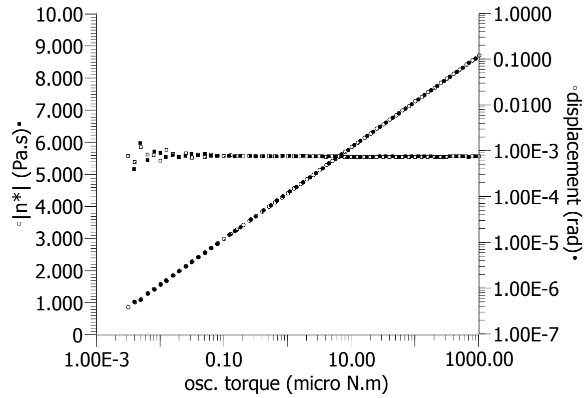

Figure 4: magnitude of the complex viscosity and displacement for of a 5.54 Pa.s oil: open symbols controlled torque, filled symbols controlled displacement

The transient response of the instrument is shown in Fig. 5, in which angular velocity is plotted against time for four step changes in velocity. The set velocities were 0.01, 0.1, 1.0 and 10 rad s^{-1} respectively: in all cases the starting velocity was zero. The sample was a 1 Pa.s oil, the measuring system a 60 mm diameter × 1° cone.

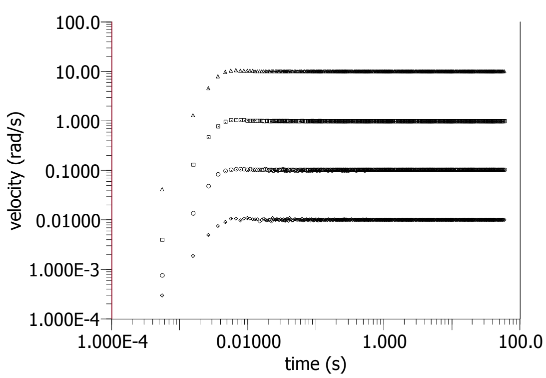

Figure 5 showing time required to reach velocities of 0.01, 0.1, 1.0 and 10 rad s^{-1} from zero, for a 1 Pa.s oil using a 60 mm diameter × 1° cone.

PRACTICAL CONSIDERATIONS

At torques of the order of nanonewton metres, some care and attention is required on the part of the operator. For example, the instrument must be on a firm mount, level, away from draughts, etc. The smallest dust particle or bubble can affect the measurement, and it is essential that all surfaces are thoroughly clean and dry: an air duster may be used to sweep out the geometry gap. Of course, if all that is required is the performance of a comparable air-bearing rheometer, then only the usual precautions need be taken.

ACKNOWLEDGEMENTS

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REFERENCES

1. Plazek, D.J. (1968) “Magnetic Bearing Torsional Creep Apparatus” *J. Polym. Sci. A-2*, 6, 621-638.