FRT transducer

A.J. Franck, TA Instruments

Keywords: ARES, FRT technology, non-compliant transducer

INTRODUCTION[1]

Conventional transducers measure the strain in a compliant member and based on their stiffness, determine the torque resp. normal force (Fig. 1a). This method has several inherent disadvantages. Since the compliant member is strained, the strain has to be accounted for in determining actual sample strain. In dynamic the inertia of the moving mass of the transducer, affects the measured results at high frequences. Further, viscoelastic materials which develop normal forces, drive the cone and plate apart. This effect generates secondary flow fields and the result is an inaccurate transient normal force measurement. To overcome these problems of conventional transducer, all developments have been made towards stiffer transducers. The stiffness however is directly related to the resolution of the strain measurement of the compliant member i.e. the torque resp. force measurement. This implies that the stress resolution decreases with increasing stiffness.

The force/torque rebalance transducer is unique in that it does not use any compliant members to measure force, but rather uses two position control servos which drive the plate back to its original or null position (Fig. 1b). This transducer uses specially designed Low Mass, quick response servos, with an extremely wide dynamic range.

OPERATION

Fig. 2 shows a schematic of the torque/force rebalance transducer. The capacitive position sensor allows a very accurate measurement of the angular position. A torque applied to the upper tool by the sample will force the sensor out of the null position.

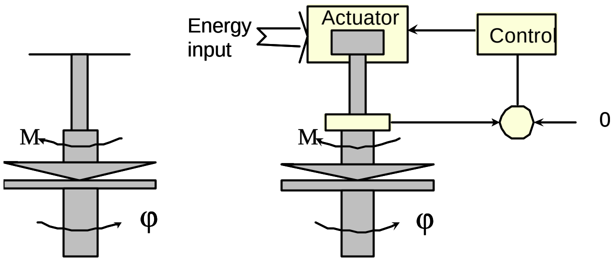

Figure1a &b: Design concept of f a force/ torque transducers

The actuator generates a reaction torque to drive the tool back to the original position. The absolute value of the torque generated by the motor is equal to the torque applied by the sample if friction is negligible. The stiffness of the transducer is now a function of the resolution of the position sensor and the response time of the control loop. The normal force is measured similar to the torque. The block-diagram of the servo control loop is schematically represented in Fig.3. T_A is the torque applied by the sample to the tool. T_R represents the torque generated by the actuator to hold the upper tool in

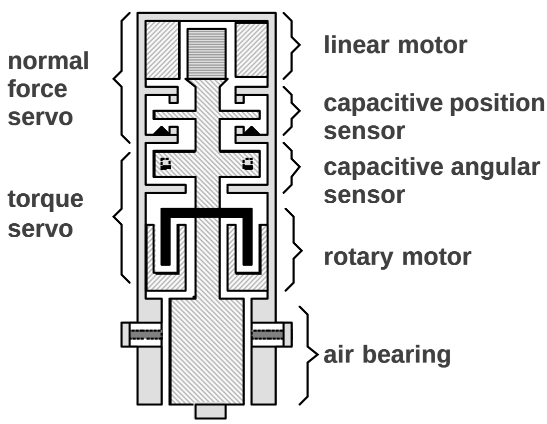

Figure 2: Schematics drawing of the FRT

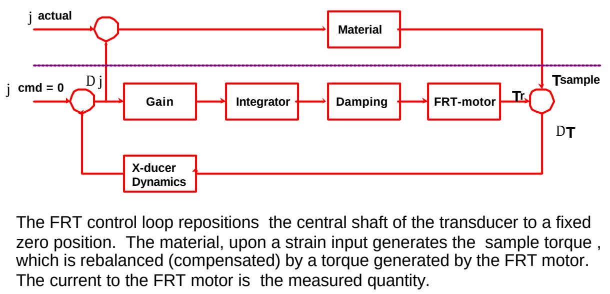

Figure 3: Block diagram of the FRT control loop

the null position. An integrator is necessary to guarantee the quasi-zero compliance. Gain and damping are set to optimize the control loop. Fig. 4 shows the optimized loop transfer function for the melt-transducer (2KFRTN1). The transfer function of the transducer is governed by the inertia of the tool at frequencies above 100rad/s. The transducer behaves linear (phase shift and gain =1) up to 200 rad/s.

FRT AND NORMAL FORCE MEASUREMENT

The measured transient normal force is strongly dependent on the axial compliance of the instrument. Fig. 5 show the transient normal force for a PDMS at shear rates of 5 and 0.5rad/s using cone angles from 0.04 to 0.2 rad. The steady state values of the resultant normal force coincide very well. The transient behavior however is retarded for the tests performed with cones below 0.1 rad. This retardation is a result of the instrument compliance. If the normal force pushes the cone and plate apart, material has to flow towards the center of the cone. This flow affects directly the transient normal stress growth. The smaller the cone angle, the longer the material takes to flow towards the center, the more the normal stress growth is retarded[2]. A theoretical model to estimate the time constant of this retardation process has been proposed by Hansen and Nazem[3] (Fig.6). This model assumes that the separation of cone and plate is infinitesimal, inertia forces can be neglected and the fluid behaves Newtonian. The model provides a time constant (the time required for the normal force transducer to reach 63.2 % of its total travel when a step normal force is applied) which is proportional to the inverse of the system stiffness and to the inverse of the cube of the cone angle. This retardation time constant can be determined experimentally as the difference of the time constants obtained from test performed at two different cone angles. One of the tests has to be perfomed with a cone angle large enough not to cause retardation effects. Results in Fig.5. show no noticable retardation of the normal stress growth with cone angles larger than 0.1 rad. The estimated axial stiffness derived using equation in Fig. 6, is $= 1.5*10^6$ N/m =>Compliance of 0.8 m/kg-force).

FRT TRANSDUCER OPERATION IN DYNAMIC

The torque and force measurement in the FRT (TRT) transducer is not based on the transducer stiffness, but on a direct measurement of the energy (current) input of the servo loop actuator. Thus the sensitivity of the torque and force measurement is related to the actuator performance and not to the transducer stiffness. The direct consequence of this fact is:

- Very low zero drifts with temperature, because expansion, due to heating up of the transducer does not directly affect the force/torque.

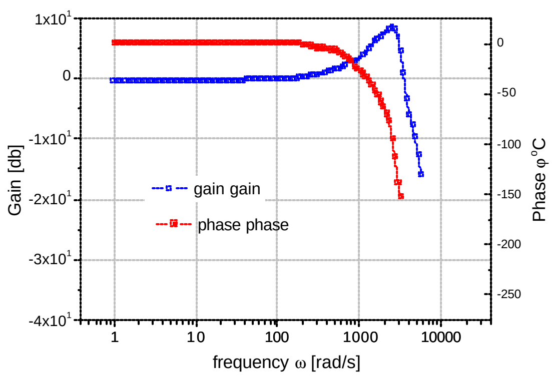

Figure 4: The transfer function of the FRT transducer. The transducer is linear up to 200rad/s

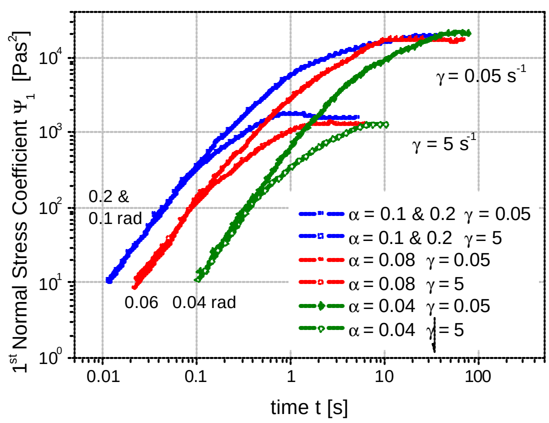

Figure 5: N1 of PDMS measured with different cone angles

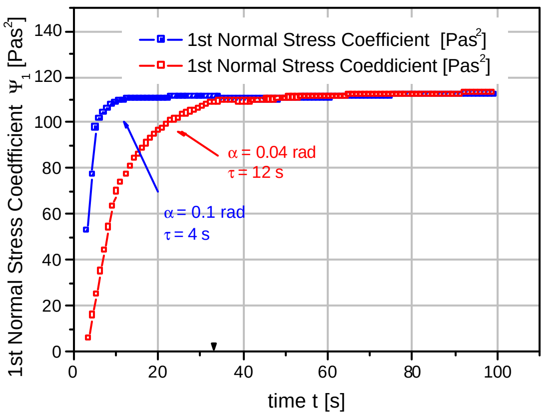

Figure 6: System reponse measured with two different cone angles

· Good dynamic response (up to the maximum frequency of the servo loop) independent of the fore/ torque sensitivity range.

Fig. 7 shows the dynamic response of the FRT, plotted as complex viscosity h*(w) up to the maximum frequency of 100 rad/s for a 100 P silicone oil. No deviation from the Newtonian behavior due to transducer inertia can be detected for this low viscous fluid. This allows the measurement of weak structures in low viscous systems (fruit juices, beverages, etc..), otherwise nearly impossible to determine quantitatively.

CONCLUSION

The force/torque rebalance transducer has some major advantages over conventional transducers.

· Due to the very small compliance of the system no correction for the strain is necessary.

· The FRT operation is based on the compensation of forces and - thus has an extremely wide dynamic range (0.002mNm to 0.2Nm for the 2KFRTN1). This wide dynamic range allows the measurement of viscosity and modulus over a much wider range without changing transducers or the geometry.

· Due to the fact, that the force/torque measurement is not tied to the transducer stiffness, temperature drifts of the zero in torque and normal are virtually non existent. However temperature fluctuations in the sample, as a result of insufficient T-stability, cause density fluctuations which are measured as normal force. This effect increases instrument stiffness. Infinite stiffness of the rheometer in axial direction would make normal force measurements impossible, as small T-fluctuations would cause the normal transducer to overload[1].

The FRT transducer is quasi infinitive stiff with a minimum compliance to allow accurate normal force measurements on polymer melts with a temperature control of better than 0.1 °C in the sample. The FRT is a compromise in terms of stiffness with better sensitivity, lower temperature drift and superior dynamic response than conventional transducers.

REFERENCES

1. Franck, A. presented at the Conference „New techniques in experimental rheology" Reading, UK, September 1985
2. Meissner,J. *J.Appl.Polym.Sci.* 16, 2877, (1972)
3. Nazem, Hansen, *J.Appl.Polym.Sci.*:20, 1355 (1976)

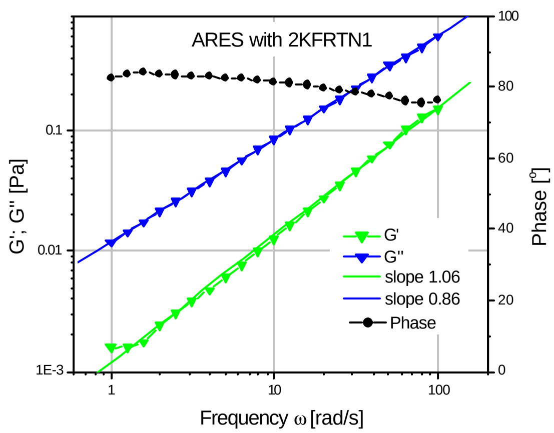

Figure 7: Frequency scan on a 10 cP silicone oil