

MEASUREMENT OF TORQUE IN MICROMOTORS

Jaime I. Hernández-Navarro, Gabriel Ascanio, Leopoldo Ruiz-Huerta, Alberto Caballero-Ruiz

Center of Applied Research and Technological Department, Universidad Nacional Autónoma de México, DF, Mexico,
ascanio@aleph.cinstrum.unam.mx

Abstract: This paper describes a dynamometer developed for the measurement of torque of micromotors as a function of the rotational speed. The operating principle of the device is based on that of a typical viscometer. The shaft of the micromotor to be tested is coupled to a small cylinder, which is placed concentrically into a larger cylinder. The motor torque is transmitted from the inner cylinder to the outer one by means of a well-known viscosity fluid. A pneumatic cylinder supports the outer cylinder, so that the test is performed under free-friction conditions and the torque is determined by a lever arm in contact with a load cell.

Keywords: torque, micromotors, pneumatic bearing.

1. INTRODUCTION

Nowadays, many areas of industry have strong tendencies towards miniaturization of products due to the significant safe of energy, increased efficiency, and the reduction of working spaces and the materials that can be produced. One of the main limitations for miniaturization of mechanic and electromechanic systems is the manufacture of actuators, because these must provide an exceptional power-dimensions ratio. Micromachines tools are examples of the use of microactuators such as micromotors, which are usually built in sizes of about 5 mm. A precise method for measuring torque of micromotors is an essential aspect for characterizing these micromachines.

Both, step and continuous motors, are usually characterized in terms of the holding torque by using different methods available for such purposes. In some applications the use of ammeters and voltmeters are accepted, but this methods do not allow to make a direct and accurate measurement of mechanical power. Other devices are torsion dynamometers fitted to the shaft, which provide useful information of the torque as a function of the rotational speed. In other application, such as viscometers and rheometers, strain gages are usually installed on a torsional bar, which is supported by a pneumatic journal bearing. Such systems are capable of measuring torque of the order of $\mu\text{N}\cdot\text{m}$. However, they are designed for this specific application.

The main drawback of the commercial systems is that they are usually employed for determining the holding

torque. On the other hand, they can provide torque values of the order of $\text{mN}\cdot\text{m}$, which is out of the specifications of micromotors.

In view of the importance of measuring the power of a micromotor, this works deals with the development and the first results of an equipment for the accurate measurement of torque as function of the rotational speed (power). In order to make it very stable, trouble free, of easy alignment and without oscillations, a conical pneumatic bearing was designed.

2. METHODS

A way of characterizing micromotors and conventional motors in general, is by means of a variable load or restriction torque and then measuring its magnitude and the rotational speed. There are some devices for characterizing high power motors, that employ dry friction between 2 surfaces in order to generate the restriction torque but, in this case we need a more stable and precise method due to the relative low torque generated by the micromotor ($\mu\text{N}\cdot\text{m}$). That is the reason why we decide to use calibration oils of well-known viscosity for applying loads, which allows the motor to operate under variable load levels, depending on the fluid viscosity. In that way, we can adjust the test oil viscosity depending on the micromotor power.

The method consists of immersing a low inertia cylinder into the fluid. This cylinder is attached to the micromotor shaft by means of a rigid coupling, so that when the micromotor is operating, it exerts a restriction torque. The latter depends on the rotational speed, the fluid viscosity and geometrical parameters.

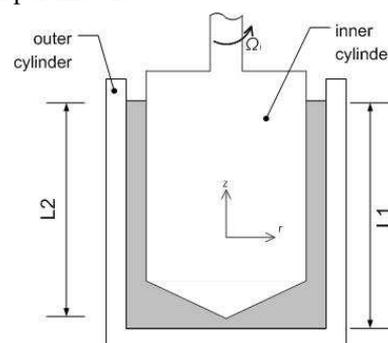


Fig. 1. Frontal view of concentric cylinder array.

This cylinder is placed concentrically into a larger cylindrical cup containing the fluid, which leaves an annular region between both of them. This arrangement, shown in figure 2, is similar to that of coaxial cylinders viscometers. In those instruments, when the outer cylinder rotates with a constant angular velocity, the torque is transmitted by momentum transfer to a fixed inner cylinder. The torque could be determined by measuring the deflection of a shaft coupled to the inner cylinder and thus, fluid viscosity can be calculated.

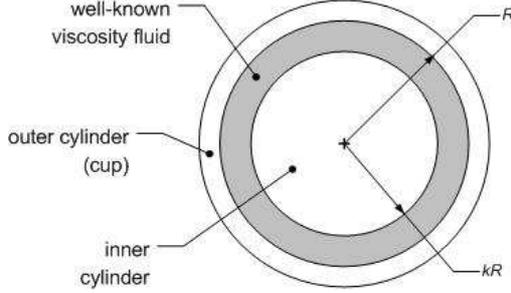


Fig. 2. Upper view of the cylinders arrangement

In our case, this method allows testing the micromotor by increasing or decreasing the load by means of a variation of viscosity (or by changing cylinder dimensions), allowing at the same time to operate the micromotor in a wide range of angular speed and not only at blocked rotor.

Once the micromotor is operating, the power input is transmitted to the fluid through the inner cylinder. Based on mass and momentum conservation laws, we can establish the momentum and mass balance equations in the fluid between the cylinders, and thus, the torque of the inner cylinder (the same as the micromotor) as a function of the torque measured in the outer cylinder can be calculated.

For the momentum transport analysis we should consider that measurements will take place once the fluid had reached a steady state. We can also assume that flow will have a laminar regime because neither rotational speed nor viscosity will make the system reach a critical Reynolds number. On the other hand, the sort of oil employed does not have a relevant variation of neither its density nor its viscosity influenced by the pressure, temperature or humidity changes, so we may consider them as constant parameters.

As the analysis shown in [1] for a Couette viscometer, the following vectorial expression that represent 3 equations of motion, derives from a momentum balance over a flow.

$$\frac{\partial}{\partial t} \rho v = -[\nabla \cdot \phi] + \rho g \quad (1)$$

where ρ represents density, v is a velocity vector, ρg the effect of external forces and ϕ is the combined momentum-flux tensor (the sum of convective, viscous and molecular momentum).

Applying equation (1) to the tangential flow in the annular region between the cylinders and with the

considerations mentioned above, the θ -component of the equations of motion in cylindrical coordinates (is the only one we need for this analysis) simplifies to:

$$0 = \frac{d}{dr} \left(\frac{1}{r} \frac{d}{dr} (r v_\theta) \right) \quad (2)$$

For the boundary conditions of (4), we assume a non-slip condition at the two cylindrical surfaces, and after solving it, we get the velocity distribution in terms of Ω_2 and R and k as shown:

$$v_\theta = \Omega_2 k \left(\frac{\frac{R^2}{r} - r}{\frac{1}{k} - k} \right) \quad (3)$$

The general form of Newton's law of viscosity is:

$$\left[\tau = -\mu (\nabla v + (\nabla v)^T) + \left(\frac{2}{3} \mu - \kappa \right) (\nabla \cdot v) \delta \right] \quad (4)$$

We just need the component of the viscous stress tensor that comes out from (4) that gives us information about torque acting over the cylindrical surfaces:

$$\tau_{r\theta} = -\mu \left[r \frac{\partial}{\partial r} \left(\frac{v_\theta}{r} \right) + \frac{1}{r} \frac{\partial v_r}{\partial \theta} \right] \quad (5)$$

The torque is the product of the moment flux, the surface of the cylinder and the lever arm. To calculate the torque over both cylinders, (equation 5) should be evaluated as follows:

$$T_{inner} = -\tau_{r\theta} \Big|_{r=kR} \cdot 2\pi k R L_2 \cdot kR \quad (6)$$

$$T_{outer} = \tau_{r\theta} \Big|_{r=R} \cdot 2\pi R L_1 \cdot R \quad (7)$$

As we mentioned, we must determine the torque of the micromotor in terms of the measured torque of the outer cylinder. That is:

$$T_{inner} = \frac{L_1}{L_2} T_{outer} \quad (8)$$

As the torque measurement of the outer cylinder must be done under free-friction conditions for an accurate measurement, this cylindrical cup is placed over a pneumatic bearing that considerably reduces the friction losses that could be involved. Such a pneumatic bearing consists of two elements: one static and the other floating. The static element is a hollow structure with a conical cavity, whose function is to provide an axial and radial thrust components to the journal bearing. On the axis of the static element there is a cylindrical cavity which provides a radial thrust as well and guarantees a steady operation of the bearing.

The floating element has a conical surface and a central shaft that complements the static element. This dynamic part fits the static component like a journal bearing. The static element of the pneumatic bearing consists of ten zones for

supplying pressurized air, generating a layer that avoid contact with the other component, even allowing a slight tilt of the floating element.

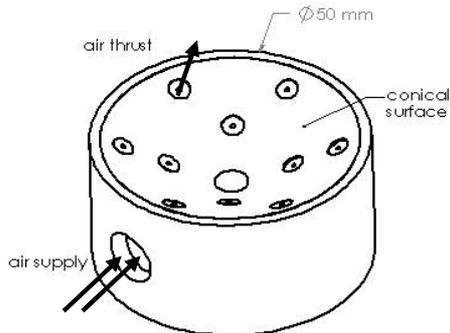


Fig. 3. Pneumatic bearing base.

To accomplish the torque measurement of the outer cylinder, which is transmitted to the floating part of the bearing, the latter is connected to a lever arm through its axial shaft. Such arm turns as the floating part rotates and pushes against a load cell tip transducer of a commercial balance (OHAUS, model SP 202) having a weight range from 0 to 200 g with accuracy of 0.01 g.

With the force measurement provided by the load cell and the lever arm length, we can easily calculate the outer cylinder torque, and thus the micromotor torque.

3. RESULTS

The pneumatic bearing characteristics, such as stability, optimal pressure operation and supported loads were evaluated and the results were the following.

It was found that for a free rotation of the dynamic part of the bearing, a pressure of 2.5×10^4 Pa is required, what generates a clearance of 7×10^{-4} m between both elements. For supporting the load generated by the cup and the fluid it contains (around 45 g), it is necessary to increase the air pressure up to 3×10^4 Pa. The lever arm attached to the dynamic element's shaft generates a moment with respect to the bearing axis of maximum 2×10^{-3} N·m, which generates a slight tilt of the floating element, but it does not produce contact with the static element.

The limitations of the equipment's measuring ranges is not mainly determined by the transducer employed (load cell), whose specifications may allow a range from 1×10^{-6} N·m to 15 N·m and provide resolution of 1×10^{-6} N·m. The minimum torque measured with this dynamometer is 2×10^{-3} N·m, and it is limited by friction losses caused by 2 ball bearings that give to the inner cylinder axial and radial support. Losses caused by the static friction of the pneumatic bearing are neglected. A better measurement range would be achieved as the shaft of the inner cylinder is reduced.

The maximum torque that has been measured with the instrument is 8×10^{-3} N·m, and no adverse effects were observed. However, higher torques are out of the purpose of this work.

The angular speed limit at which the dynamometer can operate is determined by the fluid viscosity. When this limit is exceeded, centrifugal forces cause a displacement of the fluid below the inner cylinder and contact area between the cylinders and the fluid can not easily be determined. We have tested micromotors at a maximum rotational velocity of 3.6×10^2 rad/s, and this effect is far from happening.

As the actual micromotor coupling to the cylinder has no exceptional vibration absorption qualities, slight micromotor vibrations are transmitted to the fluid and to the bearing as well. Thus, instrument's resolution varies depending on vibrational characteristics of micromotors, which introduces oscillations in the load cell, affecting the instrument's precision. The actual precision goes from 2×10^{-5} N·m to 50×10^{-6} N·m, but as far as these vibrations could be isolated, precision would improve its stability.

4. CONCLUSION

A dynamometer for measuring the torque of micromotors up to 2×10^{-3} N·m with a resolution of 2×10^{-5} N·m has been described. The operating principle of such a device is based on the use of two concentric cylinders separated by a fluid of well-known viscosity. Because the outer cylinder is supported on a pneumatic bearing, friction losses are considerably reduced. The torque is determined by measuring the force applied to a load cell times the length of a lever arm.

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