TEST DEVICES FOR MINI- AND MICROMOTORS

W. Brenner, G. Haddad and A. Vujanic

Institute of Precision Engineering
Vienna University of Technology, A-1040 Vienna, Austria

Abstract: Two miniaturised torque sensors, based on the cable brake principle and the so-called measurement cross principle, have been developed. The design principles and production process are described. Experimental results show a fair amount of conformity with technical data for minimotors.

Keywords: Torque measurement, Rotational speed measurement, rotating Microactuators

1   INTRODUCTION

When mini- and micromotors are designed, special methods for miniaturisation are used, for instance, the similarity-method or by the use of various simulation and modelling software [1]. Using such an approach the mechanical behaviour of the motors is calculated based on the macroscopic domain and on the experience with motors, which have already been produced and tested. Testing will show whether the actual behaviour of micromotors corresponds to the calculated characteristics. The two main parameters to be measured are angular velocity and torque.

Torque measurement of a rotary or stationary shaft is an important motor characteristic [2]. By measuring torque and angular velocity, the motor's power input and output can be determined. Torque measurement of an operating system is important for monitoring and estimating the proper functioning of subsequently added machines and overloading of these systems is thus avoided. Like many measured variables, torque must also be sensed indirectly. Here, the main problem is that in many cases torque has to be measured on a rotating machine element. There are many methods for torque measurement but most of them are based on measuring torsion on the axis. For this purpose strain gauges or piezoelements (like in force measurement) are used. The main disadvantage of this method is the complicated signal processing involved. Therefore, contact-less systems such as inductive (non-contact torque measurement based on the phase difference method) or telemetric method (torque sensors based on the magnetoelasitc effect) are preferred.

Rotational motion can be analysed using analogue or digital methods. In the first case, a change in electrical resistance, capacitance or inductance is used as a measure of change of the rotational angle. The digital method, on the other hand, uses an optical arrangement in which a light barrier is used to detect and count marked points. The main advantage of this method is that it can be easily controlled and regulated by microprocessors. Incremental optic encoder can be used as rotational angle sensor. These encoders are then attached to the rotating shaft that is to be monitored. The output frequency is a function of the shaft speed and the number of transparent sectors in the disc. Other types of sensor work on a magnetic or electric basis.

In most of the rotating mini- and microactuators, the available torque is typically around 10 µNm or less. Thus, it is quite obvious that there is a need to invent, design and develop high precision torque measurement systems.

2   CONCEPT AND DESIGN

In accordance with the mentioned main methods, we have decided to realise the following concepts for determining the characteristic of mini- and micromotors.

2.1   The cable brake method for Torque measurement

The cable brake is a closed force system, consisting of the cable (or string) and the cable disc. The force along the string is determined using leaf springs and strain gauges [3]. The steel leaf springs are rectangular. The dimension of the leaf spring is governed by its material, the measured range of force and the range of deformation. The spring retainer clamps the leaf spring and one of the holders are movable in the X-direction with a micrometer. Thus, the string force can be adjusted very precisely.

The string was chosen according to its thermal expansion, diameter and slip. The most suitable string for this purpose is as thin and smooth as possible, which will improve slide friction between

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string and disc. Considering this, we obtained the best results with polyamide string and silk thread. The string is wound around the aluminium disc, which has a chamfer to guide the string, in a single loop. Experiments with discs of different diameters (4, 7 and 10 mm) were executed. Comparisons of the results of measurements with various discs show that discs with a smaller radius lead to more exact results. This can be explained as follows: in a disc with a smaller diameter, a smaller increase in torque per force difference produced ($F_{diff} = F_2 - F_1$) occurs (fig. 1). Thus, the resolution and accuracy will be improved, and it is suitable for measuring small amounts of torque, especially in mini- and micromotors.
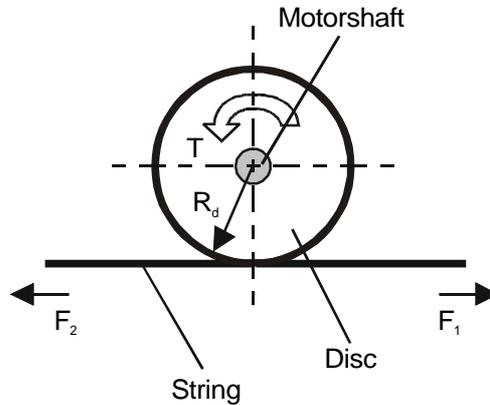
Figure 1. Torque measurement based on the cable brake principle

Because the maximum stress occurs at the clamped end of the leaf spring, the strain gauges have been located as closely as possible to the fixed end. The circuit of strain gauges is arranged as a Wheatstone bridge so that the thermal expansion and overlaying of normal strain will be compensated.

When the disc is not moving, the force in the string is constant, and no force is applied to the disc. When the disc is rotating and the string is stretched, the string causes friction and brakes the disc. Two different forces can be measured at the two ends of the string (F_1 and F_2). The force difference is applied to the disc because of the friction between string and disc. This friction force acts upon the disc's circumference, creating a friction torque with respect to the middle point of the disc. The force difference can be measured and it is possible to calculate the friction torque applied to the disc (and to the motor) with the known disc radius (fig. 2).
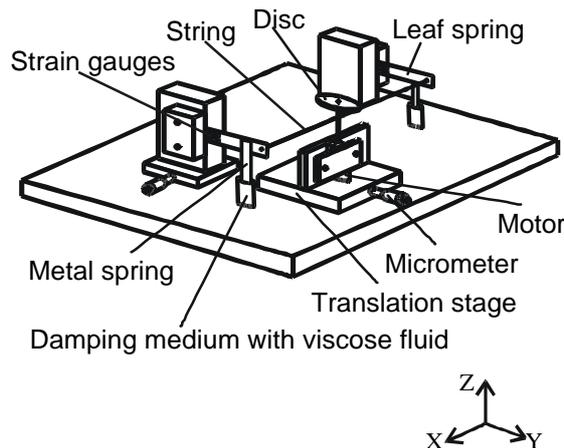
Figure 2. Torque measurement with the aid of leaf springs and strain gauges

The torque T can be deduced by a simple equation (eq. 1).

$$T = (F_2 - F_1).(R_d + R_s) \tag{1}$$

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Here R_d and R_s are the disc radius and string radius respectively. The cable brake system is not free of vibrations. To overcome this problem, a mechanical vibration damping system is used. Thus, each leaf spring has been equipped with a metal strip, which is dipped in a highly viscous fluid (fig. 2).

Moreover, because of the resulting force difference and friction between motor shaft and shaft bearing, a friction torque (T_f) is produced. This friction torque is less than 1 percent of the total torque and has been taken into account by means of a correction factor (eq. 2).

$$T_{motor} = T_f + T_{measured} \tag{2}$$

The rotational speed of the motor is monitored with an optical counter.

2.2   Torque measurement with the aid of the so-called measurement cross element

A second method of torque measurement permits uninterrupted measurement of the rotational speed, torque and characteristics of mini- and micromotors [4]. The motor to be tested is mechanically clamped in a prism-shaped motor mount. The motor mount and motor can be slid in the motor's axial direction by means of a shifting device. A step motor and spindle are used to make the shift in 2 µm steps. The motor shaft is braked by submerging aninterconnected braking device in a brake fluid of known viscosity. Figure 3 is a schematic diagram of a conical brake design.
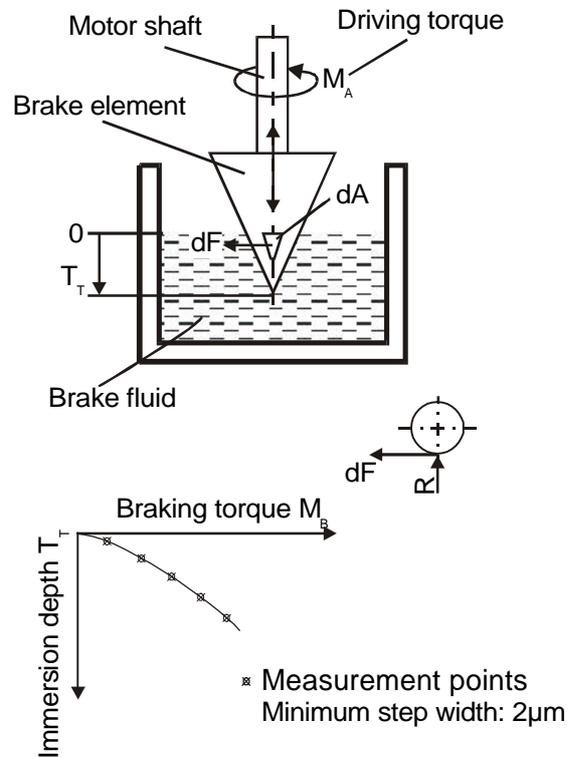
Figure 3. Schematic diagram of a conical brake design

The braking torque M_B exerted depends on the submersion depth T_T and can be calculated by means of an equation (eq. 3).

$$M_B = \int_A \boldsymbol{t}.R_{(A)}.dA \tag{3}$$

Here, $\boldsymbol{t}$ represents the shearing strain. A variety of braking characteristics (braking torque as a function of the submersion depth of the braking device) can be achieved by different brake designs.

The brake fluid container is fixed on a rigid element with low torsion resistance (the so-called measurement cross [5]). The resultant braking torque exerts a torsional force on the measurement cross, and this is measured by means of a contact-less measuring device (a laser system with a position sensitive detector (PSD) based on an optoelectronic sensor). A damping device absorbs the vibration occurring during the measurement procedures.

Measurement of the rotational speed of the motor to be tested is also contact-less, being performed by a laser system (fig. 4). To this end, a reflecting prism is fitted onto the motor shaft or integrated into the brake for very small motors. The prism reflects a laser beam onto a circular array of photodiodes. When the motor shaft fitted with the prism and the braking device is rotated, all the photodiodes are successively illuminated, so it is possible not only to measure the rotational speed but also to record rotational speed fluctuations or step width in the case of step motors.

The measuring procedure is automatic. The brake fitted onto the motor shaft is progressively submerged into the brake fluid container by a program-controlled step motor and then withdrawn. A characteristic curve of the rotational speed and torque can be automatically acquired in this way.
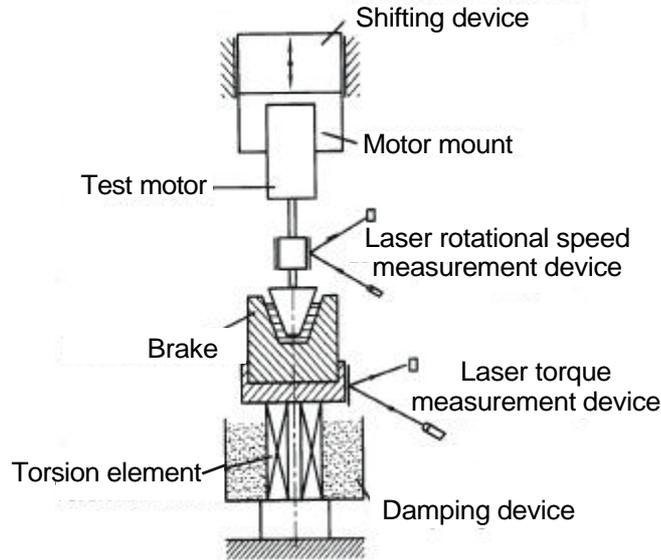

Figure 4. Torque measurement with the aid of the so-called measurement cross

3   EXPERIMENTAL RESULTS

The operating conditions of a DC motor are described by its static characteristic curve, which depends on the constructional parameters of the motor. A characteristic curve gives the useful torque of the motor corresponding to a specified speed at a nominal voltage. As mentioned previously, these two parameters are the basic factors required for obtaining a certain motor characteristic.

We performed experiments on a test minimotor, which is described in table 1. I_o, I_H, M_H, n_o, U_N and P_{max} represent no-load current, stall current, stall torque, no-load speed, nominal voltage and maximum power output respectively.

Table 1. Characteristics of the tested minimotor

Motor type	A4B-01-S
$\varnothing$ Motor (mm)	4.2
$\varnothing$ Shaft (mm)	0.7
I_o (mA)	40
I_H (mA)	105
M_H (μNm)	40
n_o (rpm)	15000
U_N (V)	1.3
P_{max} (mW)	15

The typical speed of rotation/torque characteristic for the minimotor A4B-01-S at the nominal voltage of 1.3 V is shown in figure 5.

As expected, the speed of rotation decreases linearly with increasing torque. The deviation from the theoretical characteristic curve is negligible. The reproducible accuracy of the test is good.
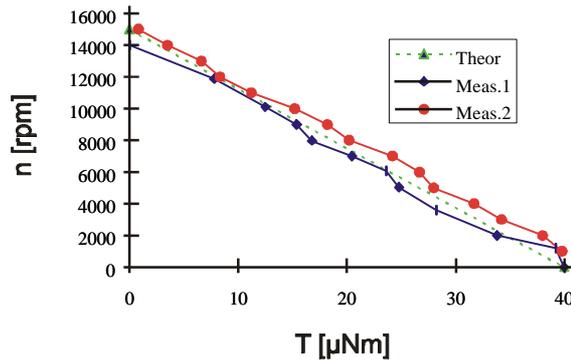
Figure 5. Speed of rotation/torque characteristic for the minimotor A4B-01-S (measured and theoretical)

In the first case the resolution of the system is 0.1 µNm by taking into account the resolution of strain gauges, the measuring instrument and the disc diameter. The relative error is 7.5%.

However, because of the friction between string and disc, this principle can be applied only to measurement of the torque generated by continuously rotating mini- and micromotors and other rotating elements such as microturbines, etc. and can not be applied to step motors. The start and stop behaviour between the steps would cause a stick-slip effect between string and disc. Hence, an accurate measurement of string forces would be impossible.

In the second case, it is possible to record micromotor characteristics at the sub-µNm range and rotational speeds up to 500,000 rpm.

4 CONCLUSION

The miniature cable brake permits the measurement of torque produced by miniature motors in the µNm range with a resolution of 0.1 µNm and rotational speeds up to 50,000 rpm.

The relative error is about 7.5 %. Work on further system miniaturization for application on micromotors is in progress.

The second measuring device permits uninterrupted recording of rotational speed, torque and characteristics of miniature and micromotors. It is therefore possible to record micromotor characteristics at the sub-µNm range and rotational speeds up to 500,000 rpm.

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AUTHORS: W. Brenner, Gh. HADDAD and A. VUJANIC, Institute of Precision Engineering, Vienna University of Technology, Floragasse 7/2, A-1040 Vienna, Austria, Phone Int. ++43 1 58801 35871, Fax Int. ++43 1 58801 35899, E-mail: haddad@ifwt.tuwien.ac.at