A testing stage for the assessment of rotating micro electro-- mechanical components

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1. Introduction

Micro-mechanical devices, and in particular rotating micro-mechanical devices such as micro motors and micro actuators, or passive components like micro ball bearings and spiral springs can nowadays be found in a variety of consumer goods. Before they can be used and implemented, however, their performance and quality has to be assessed, already during development and later on, in the production line. In the framework of a European project, CTM (Centre de Transfert des Microtechniques), a R&D centre in the field of micro technology, has developed a testing stage for characterizing such micro mechanical devices.

Generally speaking, characterizing a micro motor or any electric motor is based on a profound understanding of the electro-mechanical system in terms of the energy flow and transformation. Depending on the motor principle different approaches have to be applied, e.g. a piezoelectric motor has to be supplied with sinusoidal voltages near its eigen frequency whereas the rotor speed will be a function of the excitation frequency. The measurement principle for an asynchronous motor is different again, and for a DC or a synchronous motor, too. How can the torque-speed characteristic be determined for a variety of different motors?

The common sense approach will be to control the motor with the appropriate voltage and to use a brake system to control the rotor speed, i.e. the rotor speed is a result of the brake effort applied. Then the motor torque, speed and current can be measured, which yields the power consumption and hence the efficiency if the entire speed domain is scanned by changing the brake effort. This approach shows already that there must be a constitutive relation between speed and torque one of which can be fixed. The torque testing stage presented here employs the inverse principle to accomplish this characterization task: it imposes a speed whereas the resulting torque depends on the motor control and its synchronization to the rotor speed and angle. In order to accomplish this control task, the free and open source real time operating system RTLinux [1] is used. Before the measurement principle is explained in detail, however, the test system used is presented in terms of the principles employed.

2. Principles of operation

Before a test stage for assessing a micro-electro-mechanical device can be designed, the physical parameters to be characterized and measured have to be defined. Since the test bench presented here is used for rotating machinery, the torque exerced is the most interesting parameter, both as function of the rotation speed and the rotor angle. Therefore, a reliable torque sensor is needed.

2.1. Torque sensor principle

In general, a sensor applies some physical principles to extract the variable of interest from the physical system, in this case the torque created or caused by a micro component. Figure 1 gives a sketch of the MTE torque sensor principle used.

The heart of the sensor is a silicon cross mounted vertically between two rigid plates. The ensemble is rigid in radial direction, but very sensitive for torsion. In effect, this cross can be considered as linear angular spring, i.e. once a torque T is applied to it, the top plate will twist against the bottom plate by an angle proportional to the torque applied. Hence, the torque sensor used in this setup maps the torque T applied on an angular displacement ϕ. This small angular displacement ϕ is transformed into a linear displacement X of a laser spot on a sensitive surface by means of a mirror and a LASER beam, i.e. by LASER triangulation. Furthermore, the displacement is transformed into a voltage U corresponding to the linear displacement X, the angular displacement ϕ, and finally the torque T. If a probe micro component is mounted on the sensor top plate and some torque is applied to it, or the component creates some torque against the inertial system, exactly this torque is measured.

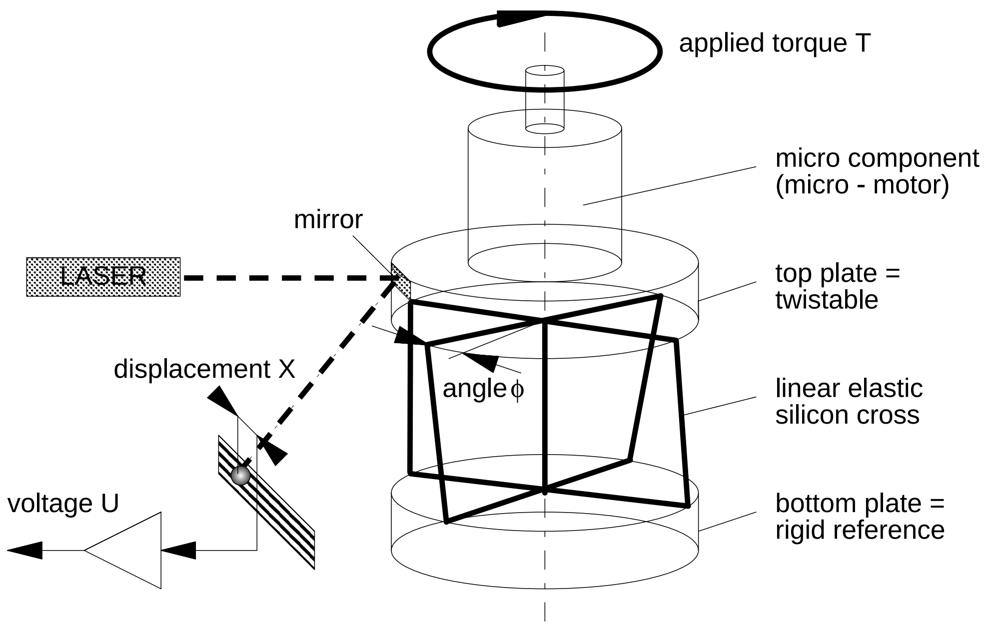

Figure 1: Principle of MTE torque sensor.

2.2. Measurement principles

As already mentioned in the introduction, a strong master motor imposes a speed and the torque created or caused by the micro component (active or passive) at this speed is measured. The torque exchanged between both master motor and the micro component can then directly be measured at this speed, synchronously to the rotor angle as function of this angle as all other variables measured. Figure 2 gives an idea of this principle.

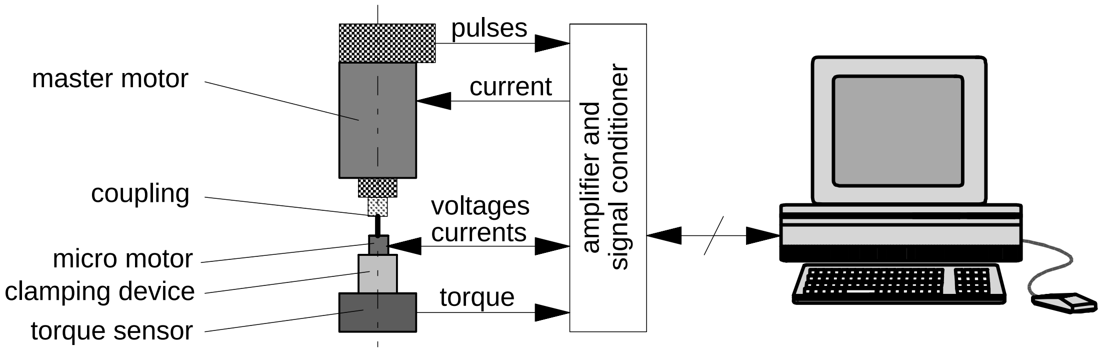

Figure 2: Principle of driven mode.

As for active components such as micro motors the torque depends on the control of the micro motor and its type. For example, a synchronous motor employes the principle of a rotating magnetic field dragging a permanent magnet at the same speed. The torque is then a function of the phase angle between field vector of the rotating field and the field vector of the permanent magnet, the so-called load angle. One possibility to assess the synchronous motor is to keep the rotor axis at zero speed and let the field vector rotate at a small speed. Then a figure torque versus phase angle can be traced which gives the maximum holding torque of the motor (see Figure 3).

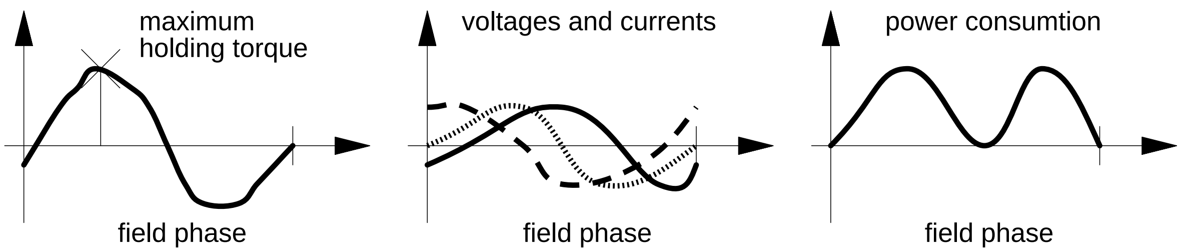

Figure 3: Torque-field phase characteristics of a stepper motor.

In order to determine this maximum torque at a given rotor speed, the magnetic field created by the motor coils has to be synchronized to the rotor speed with the phase between both controlled. Then the phase range has to be scanned through yielding a function torque versus phase angle with a definite maximum. This value has to be saved for all rotation speeds with the function maximum torque versus speed being the result (Figure 4).

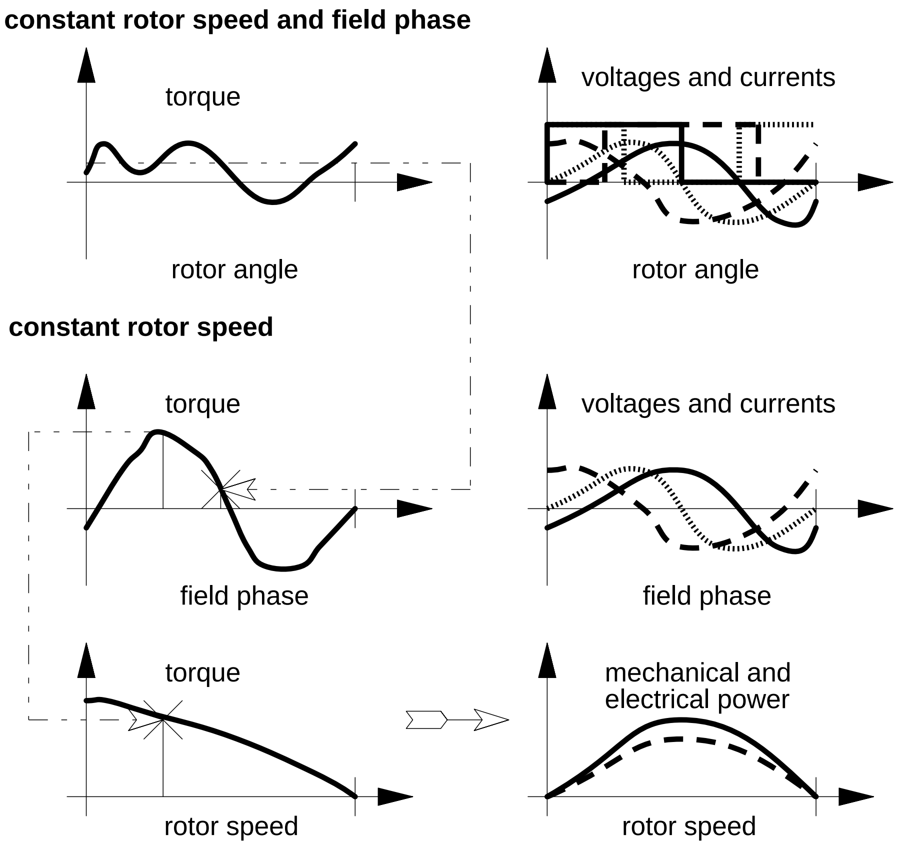

Figure 4: Torque-speed characteristics of a synchronous motor.

2.3. Software principle

Figure 2 already anticipated the measurement principle with an explanation for a synchronous motor. Now this procedure is explained in terms of software. At a given rotor speed the incremental coder will produce TTL impulses which are conveyed to a counter board in the computer. Note that the resulting frequency is 240kHz at 40000rpm for 360impulses per revolution which is too much to be treated by the computer in real time, at least for the computer used. For this reason the counter board is programmed to count from a speed dependent value (later on called ‘‘down sampling factor’’) down to zero and triggers an interrupt afterwards.

A synchronous motor is usually driven by sinusoidal functions creating a rotating magnetic field which takes the permanent magnet with it. If the computer outputs these voltage functions perfectly synchronized to the rotor angle during rotation, the load angle will remain constant. Thus, a load to the probe motor is simulated and this angle can simply be changed by changing an offset of a pointer to the functions to be output. At the same time the coil currents can be measured which together with the output voltage gives the power input into the motor. The produced torque can be measured synchronously to the external coder impulses which are equivalent to the rotor angle. The power losses and hence the efficiency can then be calculated.

3. Torque stage setup

Figure 5 shows how the experimental setup looks like. The essential parts of the system, the computer, a rack containing control electronics, and the mechanical setup itself are shown.

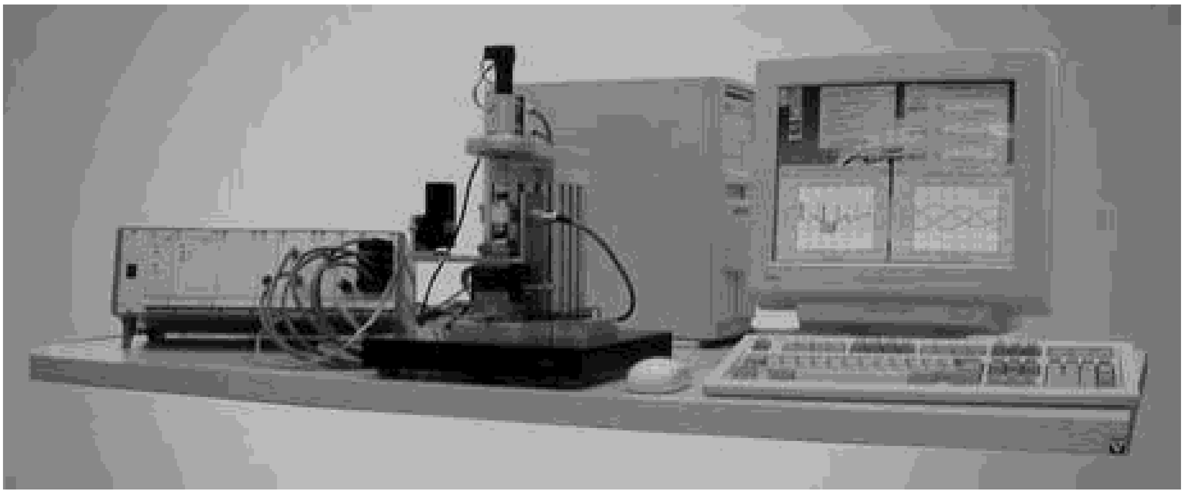

Figure 5: Micro torque testing stage.

The micro mechanical device to be tested is held by a clamping device which is directly mounted on the torque sensor (a cylindrical shiny box) for a range of ±50µNm which depends in general on the type used. This sensor is then mounted on another sensor, the ATI force sensor. The entire setup is fixed on a xyz translation table to make the correct alignment to the master motor on top of the setup. This master motor is equipped with an incremental coder of 360impulses per revolution and drives the micro mechanical device using a special micro coupling being rigid for torsion, but elastic for all other degrees of freedom. In case of an active probe device, a connector for 3 channels is mounted on the right of the setup.

All electronics necessary to drive the sensors and actuators is built into a rack. It contains the amplifier of the torque signal converting the laser spot displacement to ±5V, an amplifier for the ATI torque sensor mapping forces to 0-5V. Additionally, the coil currents of a micro motor are measured mapping ±1000mA to ±5V. Furthermore, the rack comprises the power stage for the master motor mapping ±5V to ±4A as current setpoint, and the power stage for the micro motor with three channels of ±12V output voltage mapped to a ±5V setpoint.

In order to output 4 signals, one for motor current setpoint and three for the coils of the micro motor, respectively, the ICPDAS 12bit output board pioda4 has been used. A ICPDAS pcidas1800 DAQ board has been employed to measure the torque, three currents, three voltages, the motor speed and the ATI forces at 12bit resolution. For the synchronization purpose, a ICPDAS piod48 has been utilized. A P200 was used with everything usually built in a desktop computer. On the OS side, FSMLab's RTLinux 2.0 [1] using kernel 2.2.10.

4. Experimental results

As an example for a measurement, the test bench has been used for testing a synchronous motor contributed by a project partner within the HAFAM project. The setup as described above creates a rotating field at 60rpm, but controls the rotor speed to be zero. With a typical tri-phase voltage functions of 1V amplitude applied to it, the torque depending on the phase angle between permanent magnet and field vector can be seen in Figure 6 for a rotor speed equal to zero.

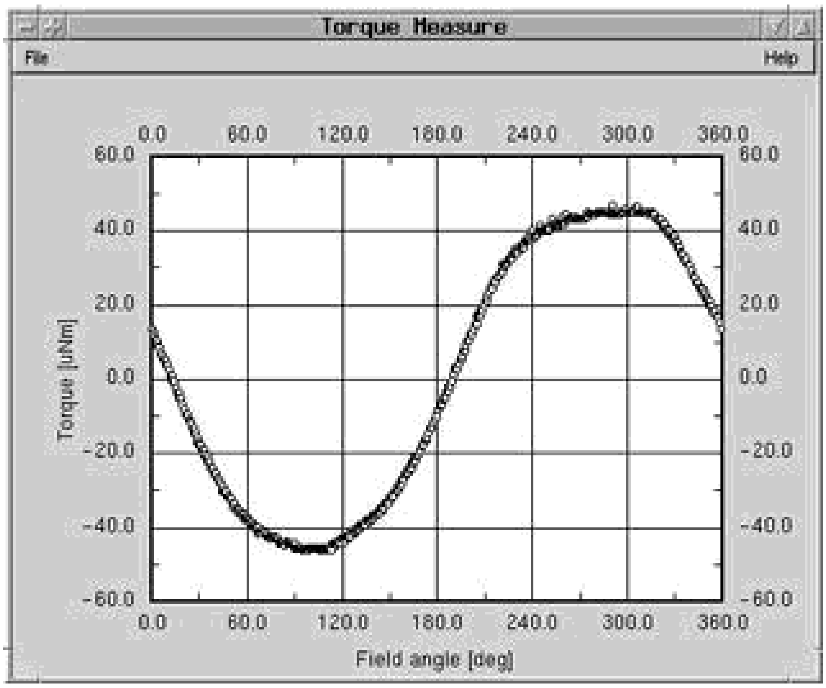

Figure 6: Measured torque over field angle for speed equal to zero.

5. Conclusion

It has been shown that the approach with a master motor imposing a certain speed and controlling the micro device by a computer is a versatile means for a torque testing stage and can be adapted to many types of motors and measurement, even for the measurement of the EMF for synchronous motors. The concept proposed was implemented using the free real time operating system RTLinux in order to guarantee synchronization and predictability.

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[1] RTLinux, FSMLab's Real Time Linux, http://www.rtlinux.org