Method of Indirect Measurement of Motor Output Torque

P. Klouček, Z. Braier
VÚTS, a.s., Liberec, Czech Republic
Email: pavel.kloucek@vuts.cz

Abstract. *A method of indirect measurement of a motor output torque by using actual values of the angular velocity and the input power quantities was tested. The motor output torque is an important parameter for designer for example during overhaul of older machines or for design of a new generation. It is not possible to place a torque sensor into a machine quite often, so this method can evaluate output torque indirectly in synchronous measurement with other important quantities. The testing stand with Siemens Sinamics/Simotion system and AC servomotor 1FT6 was used for verification of this method.*

Keywords: Output Torque, Indirect Torque Measurement, Dynamic Measurement.

1. Introduction

The method of indirect torque measurement was used in Measurement department, VÚTS, several times for machines with standard asynchronous motor. The motor output torque is an important parameter for designer for example during overhaul of older machines or for design of a new generation. It is not possible to place a torque sensor into a machine quite often, so this method can evaluate output torque indirectly in synchronous measurement with other important quantities.

The method application on servomotor was verified at the mechatronic stand with Sinamics/Simotion system and the three phase AC synchronous servo motor type 1FT6084-8AC71-3AA0 (all the servomotor parameters are in datasheet [1]). The control of servo motor was realized by modular system of converter Sinamics S120, control unit Sinamics CU320 with plug-in terminal board TB30 and controller Simotion. The torque sensor was connected between the output shaft of the motor and the input of the planetary gearbox using shaft couplings and diameter reductions. The torsion bar with the flywheel was connected to the planetary gearbox output. Figure 1 shows the schematic drawing of the stand with measured and calculated quantities. A multifunctional modular all-in-one portable analyzer Dewetron DEWE-2602 was used for synchronous data recording of all measured quantities.

All the measurements, evaluations and results are summarized in [2]. This paper is focused to the verification of the method.

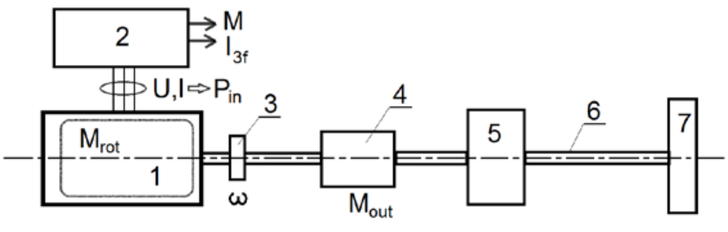

Fig. 1. Schematic view of the used stand and measured quantities: 1 - servomotor, 2 – Sinamics/Simotion system, 3 – encoder Renishaw Signum, 4 - torque sensor ESA DR-2477, 5 – gearbox Spinea, 6 – torsion bar, 7 – flywheel, M – total torque from Sinamics/Simotion, I_{3f} – total current from Sinamics/Simotion, U,I – voltages and currents for three phases, P_{in} – calculated input power, M_{rot} – torque for acceleration of motor rotor, ω – angular velocity, M_{out} – torque on motor shaft

2. Measurement conditions

The three phase AC synchronous servo motor type 1FT6084-8AC71-3AA0 was connected to the gearbox through the torque sensor ESA DR-2477 with measuring range 100 Nm. The planetary gearbox Spinea TS170-33 has a reduction ratio 33:1 and it is made as preloaded (backlash free). The flywheel with weight 13.825 kg and moment of inertia J = 0.0797 kgm^2 was connected to the output of the gearbox via the torsion bar. Natural oscillation frequency of this set is approximately 16 Hz.

The servo motor operated with three different position functions: polynomial, harmonic and parabolic. The stand output runs in function of a four step gearbox with holding time and position feedback. The output movement was made by rotation of the flywheel in angle 90° for each step. The three position functions use almost the same position curve and motion time, but they have quite different angular velocity and acceleration curves. The measurement and evaluation was made for standard control and also for control with special inverse filter applied [3]. The inverse filter was primarily designed for decreasing of the residual oscillations.

The signals measured by external sensors were voltage and current of phase U, V, W, the servo motor shaft torque and angular velocity and angle of the servo motor shaft. The motor torque signal was measured as the analog voltage output from the Sinamics unit and from the TB30 board. A sampling frequency of the measurement was set to 200 kHz with respect to basic switching voltage frequency of the converter 4 kHz.

3. Results

The two different analog outputs of motor torque from the Sinamics/Simotion system were measured. Basic shape of both signals is similar, but signal from the terminal board TB30 is limited by the time period used for the data bus. Minimal time for change of output values is 1.5 ms, so fast changes are misshapen by steps. For next evaluation the signal from the Sinamics unit was used. The torque of motor in the Sinamics unit is obtained from the total current quantity by multiplication by a “torque constant”. The torque constant for the used motor is 2.26 Nm/A. It can be easily verified, because current analog output signal from the TB30 board was measured, too. The current signal sent to output gives only absolute value and it doesn’t respect orientation, but for the torque calculation the orientation is reflected (see Fig. 2).

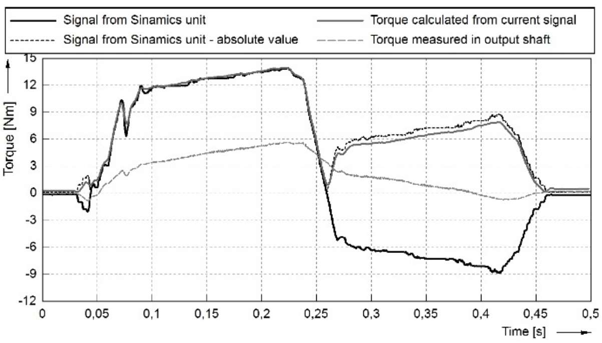

Fig. 2. The torque signals for one step of the output shaft with parabolic position function used.

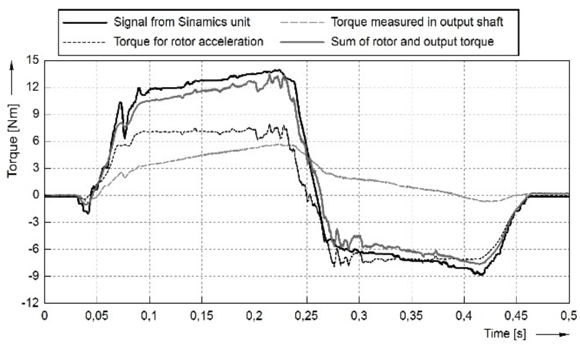

Fig. 3. The torque of shaft and rotor compared with the total torque signal for one step of the output shaft with parabolic position function used.

Figure 2 also shows that the torque measured in the servomotor shaft gives quite different results in comparison with signal from the Sinamics. It is because these measured signals represent different quantities. The signal from the Sinamics unit is the total torque of the servomotor and it consists of an output torque necessary for driving of connected load (measured by the sensor in output shaft) and of a torque necessary for the motor rotor acceleration. We can calculate the torque for the rotor acceleration as

$$M_{rot} = J_{rot}\ \varepsilon \tag{1}$$

where

- M_{rot} torque for the rotor acceleration
- J_{rot} the rotor moment of inertia
- ε angular acceleration of the rotor

The moment of inertia for rotor of the used motor is J_{rot} = 48*10^{-4} kgm^2 [1]. The angular velocity from external encoder placed on the motor output shaft was evaluated through measuring card DMU-PCI developed in VÚTS, a.s. This card is the fifth generation of the DMU device for dynamic measurement of angular velocity and position with patented principle [4]. The DMU device gives much precise results than convention methods of angular velocity measurement. The angular acceleration was directly calculated from the angular velocity signal using differentiation, only the low pass filter for reduction of frequencies higher than 3 kHz was applied. When we calculate sum of the measured torque M_{out} from the external torque sensor and the calculated torque for rotor acceleration M_{rot}, the result is quite similar to the output torque signal M from the Sinamics unit (see Fig. 3) but with lower amplitude. The main reason is the principle of the total torque calculation from the input current used in the Sinamics. Some part of the current is transformed to heat, there are some torque losses for example in bearings etc. and also the motor efficiency is not included.

The opposite calculation can be applied for verification. The input power of a motor P_{in} can be calculated from the measured voltages and currents of all three phases. The output power *Pout* can be calculated from the total torque M and the measured angular velocity ω as

$$P_{out} = M\ \omega. \tag{2}$$

The output power was calculated from the Sinamics torque signal and also from the torque obtained as sum of the output torque and the rotor torque M_{rot}. Figure 4 shows that output power calculated from the Sinamics torque has higher values than the input power in some parts. This would mean efficiency higher than one. This error is caused by the influences described above. The output power calculated from the measured torque is more accurate and the ratio between this output torque curve and the input power curve gives an approximate efficiency of the measured motor (see Fig. 4). Strong peaks in the efficiency curve at time approximately 0.27 s and 0.45 s are caused by the denominator values close to zero.

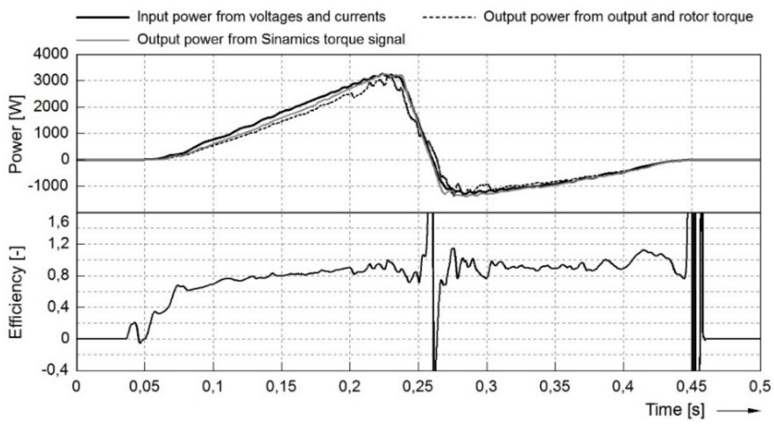

Fig. 4. The input and output power curves for one output cycle of the stand with usage of parabolic position function. Efficiency of the motor was calculated as ratio between output power and input power calculated from voltages and currents.

4. Conclusions

The method of indirect measurement of the motor output torque was tested on stand with the synchronous servomotor Siemens and Sinamics/Simotion system. The motor output torque is an important parameter for designer for example during overhaul of older machines or for design of a new generation. This method is useful for applications where output torque of a motor can’t be measured directly by a torque sensor, but synchronous measurement of torque together with other quantities is necessary. Typical application is measurement of a rotating machine with highly variable angular velocity, where is angular sampling instead of time sampling of signals used. The method was applied several times in the past in Measurement department, VÚTS, for measurement of an asynchronous motor with a frequency converter. The torque calculation for an asynchronous motor is easier because of known and nearly constant efficiency of motor.

The results from the test showed that the output torque can be calculated from the measured voltages and currents and the angular velocity/acceleration of the motor. For calculation, the motor rotor moment of inertia must be known. If the motor runs in some continuous mode or in standard range of angular velocity, we can calculate the efficiency close to 1. Much more problematic are modes where the motor stops and runs up again, because the efficiency for low velocities changes a lot and it strongly influences the results (the difference between the input and output power is high). In opposite way, if the real output torque is measured, the real efficiency curve of the tested motor can be evaluated.

The output signals from the frequency converter can be used only for a very rough estimation of the output torque. Both the angular velocity and the torque can be exported, but synchronisation with other quantities is problematic. Conversion to analog output values in control system are limited by resolution of the output A/D converters, by time period of the conversion and different time delays. The torque signal presented by the control system represents the total torque of the motor, which includes also the torque necessary for the rotor acceleration. This torque signal is calculated from the measured total current and doesn’t respect motor efficiency and other factors, so the value is quite incorrect. For highly dynamic tasks the rotor torque part can be bigger than the output torque.

Acknowledgements

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