DIGITAL TRANSIENT TORQUE OR FORCE MEASUREMENT FOR ROTATING OR LINEAR AC MACHINES
(Real time measurement)

M.T. Nguyen, M. Tu Xuan, J.-J. Simond

Swiss Federal Institute of Technology, Switzerland

Abstract : The digital transient torque measuring device presented in this paper is able to make a "real time" calculation in steady-state and transient conditions of the electromagnetic torque or force of an extremely wide range of ac electrical machines supplied with sinusoidal voltages or through frequency converters with frequencies up to 30 kHz. The device needs no shaft position or speed sensors, it uses exclusively the acquisition of the stator currents and voltages. The main fields of applications are : test shop, control, measurement, integration in a control or regulation unit, element of a monitoring system.

Keywords : torque, force, measurement, real time.

DESCRIPTION

Torques are conventionally measured on the shaft coupling a rotating machine to a load or a prime mover by means of strain gauges associated with an electronic conditioning equipment. Although these devices yield accurate values for a constant or slowly varying torque, they are no longer reliable for general transient measurements. Moreover, they are costly and cumbersome.

Figure 1 represents the synoptic diagram of the measurement device.

The instantaneous values of the phase currents and voltages are sampled at a frequency of 100 kHz and transferred to a microprocessor DSP, which transforms the phase values into Park values according to the well-known formulations in the stator reference frame.For that reason, the measurement device needs no shaft position or speed sensors.

The electromagnetic torque is given by

$$T_{em} = \frac{3}{2} p \left(\psi_d \, i_q - \psi_q \, i_d\right) \qquad (1)$$

with

ψ_d, ψ_q : total flux linkage of the stator in d and q axes

$$\psi_{d,q} = \int \left(u_{d,q} - r \, i_{d,q}\right) dt \qquad (2)$$

i_d, i_q stator currents in d and q axes
p pair poles number
r stator ohmic resistance
u_d, u_q stator voltages in d and q axes

A special attention has been devoted to the flux calculation in order to suppress any offset in the numerical integrations without influencing the current and flux aperiodic components.

Various simulations and tests in transient modes (starting-up, sudden short-circuit on the terminals, out-of-phase synchronization) as well as steady-state modes under sinusoidal and non sinusoidal current or voltage supply waveforms helped assess the accuracy of the implemented method. The digital transient torque-

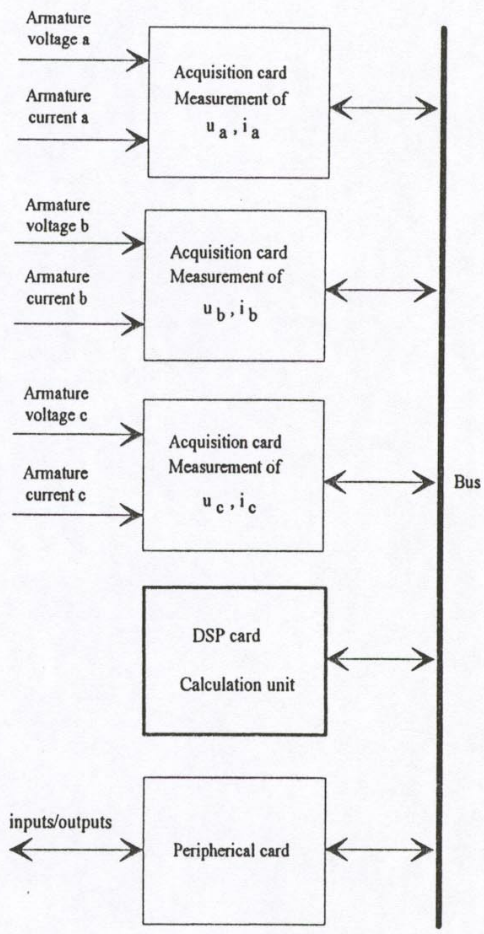

Fig. 1 : Synoptic diagram

measuring device can be used as a stand-alone instrument or may be integrated in a more complex control system of AC machines. Due to its low cost and compactness, the device can find use in numerous environments (test platform, electronic control of AC motors, monitoring).

APPLICATION EXAMPLES

Examples With Network Supply

Example 1 Starting-up of a three-phase induction machine

Figure 2 illustrates the electromagnetic torque and the speed vs time during the starting-up of a 3-phase AC machine (3,3 kVA, 380 V, 50 Hz, 1435 rpm). The small torque ripple visible with frequency 100 Hz at no load is a consequence of a stator current asymmetry due to unequal end-winding leakage reactances in each phase.

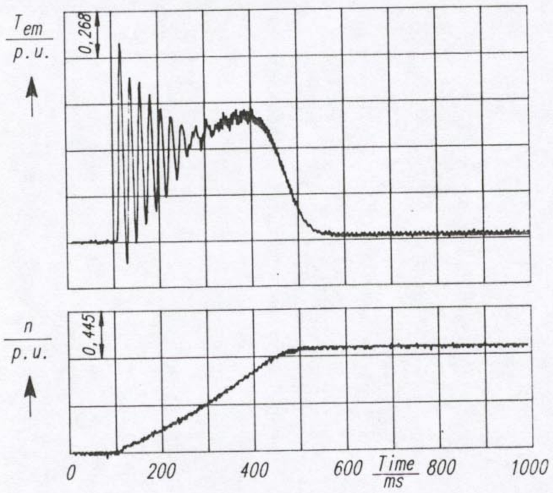

Fig. 2 : Starting-up of an induction machine

Example 2 Asynchronous starting-up of a synchronous machine

Figure 3 illustrates respectively the electromagnetic torque, the stator current and the speed vs time during an asynchronous starting-up of a synchronous machine (2,3 kVA, 380 V, 50 Hz, 1500 rpm). One notices the important decrease of the mean asynchronous torque around half the synchronous speed, which constitutes a well-known phenomenon (Görge effect) in small synchronous machines.

Example 3 : Sudden three-phase short-circuit of a synchronous machine

Figure 4 illustrates respectively the electromagnetic torque, the stator current, and the field current during a sudden three-phase short-circuit of the same synchronous machine as in example 2. For this example, in order to increase the armature short-circuit time constant, a coil of 0,3 p.u. is inserted in series with the stator winding.

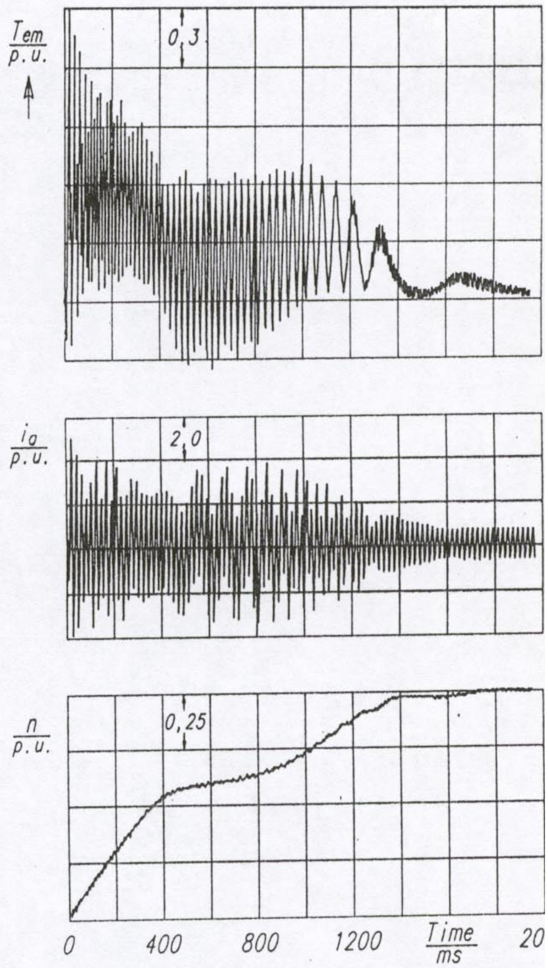

Fig. 3 : Asynchronous starting-up of a synchronous machine

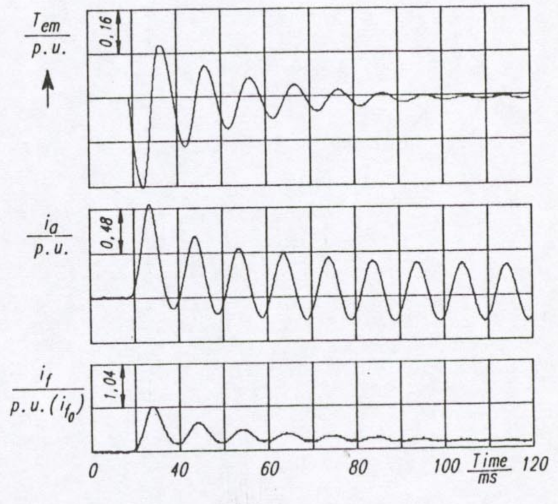

Fig. 4 : Sudden three-phase short-circuit of a synchronous machine

Example With Frequency Converter Supply

Example 4 Induction motor fed by a PWM voltage source inverter

Figure 5 is relative to a medium size induction motor (800 kVA, 100V, 50 Hz, 1483 rpm) fed through a PWM inverter having a control system based on different carrier and reference waveforms. This example shows a 3-fold PWM mode.

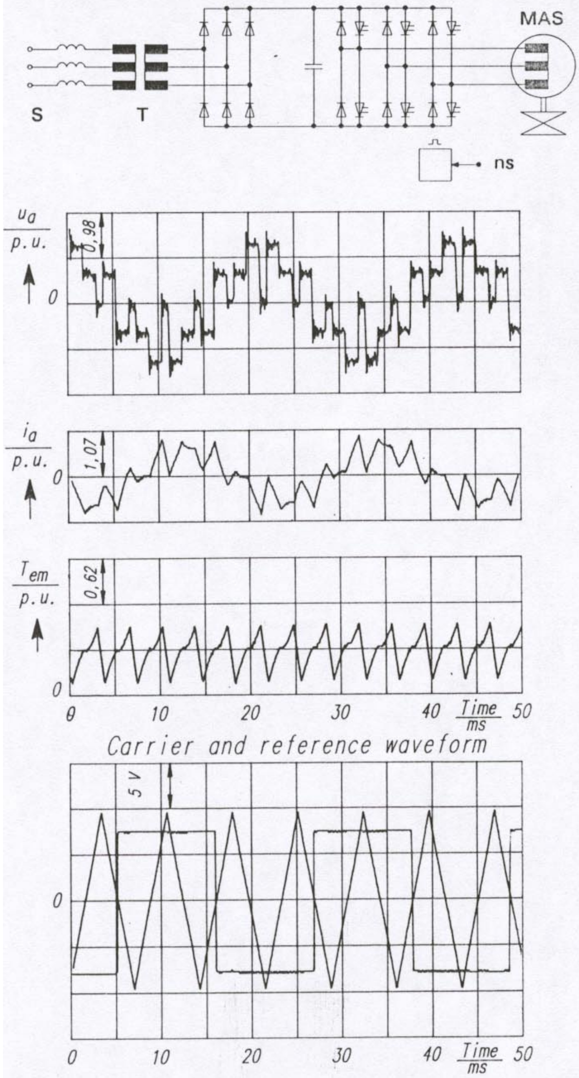

Fig. 5 : PWM inverter-fed medium size induction motor

CONCLUSION

A digital transient torque measuring device for AC machines using exclusively the acquisition of the stator currents and voltages, i.e. no speed or rotor position sensors, has been described. Four application examples illustrate the wide utilization field of this device useful for a real time measurement of a network - or converter fed AC machine by steady-state or transient conditions.

References

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Addresses of the authors

Nguyen, M.T., Swiss Federal Institute of Technology, Electrical Engineering Dept, CH-1015 Lausanne, Switzerland

Tu Xuan, M., Swiss Federal Institute of Technology, Electrical Engineering Dept, CH-1015 Lausanne, Switzerland

Simond, J.-J., Swiss Federal Institute of Technology, Electrical Engineering Dept, CH-1015 Lausanne, Switzerland