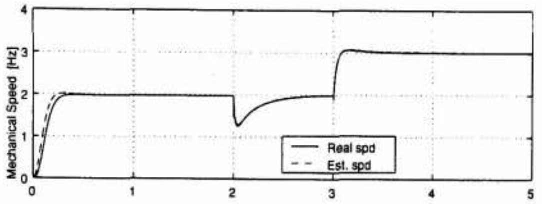
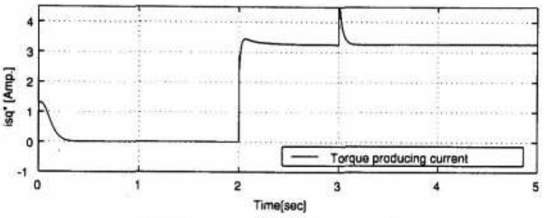


(a) Speed response to step command



(b) Torque producing current

Fig. 3. Simulation results with T=0.25 ms as a sampling period.

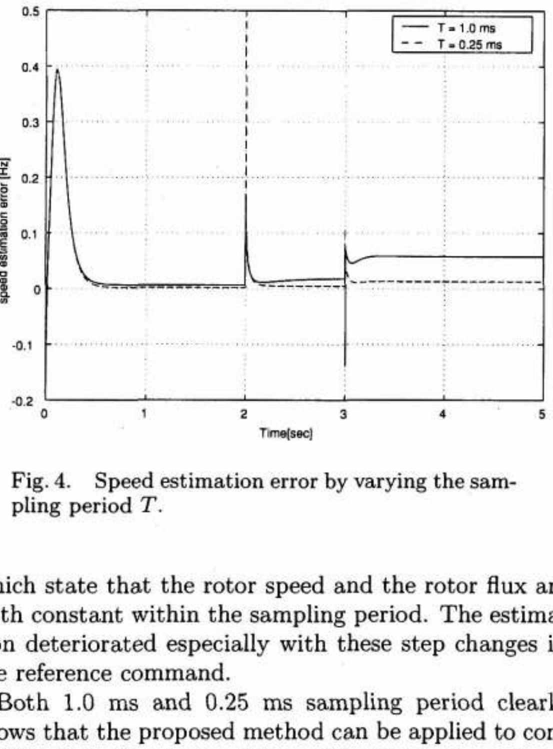


Fig. 4. Speed estimation error by varying the sampling period T.

which state that the rotor speed and the rotor flux are both constant within the sampling period. The estimation deteriorated especially with these step changes in the reference command.

Both 1.0 ms and 0.25 ms sampling period clearly shows that the proposed method can be applied to control the induction motor drives without using speed sensor. At the steady state simulation results show that a shorter sampling period results in a less estimation error as in Fig.4.

5. Experimental Results

The following are some experimental results achieved with 1.0 ms as a sampling period.

Fig.5 shows a view of the experimental system, where two similar induction motors are coupled, one is regarded as load or acts as generator. A speed sensor is used to monitor the real speed of the induction motor. Moreover, the driver (inverter) in the experimental system is adjusted to produce the exact voltage as ordered by the instruction. That is, this driver is designed to compensate the errors by dead time at the PWM control and voltage drops at switching devices.

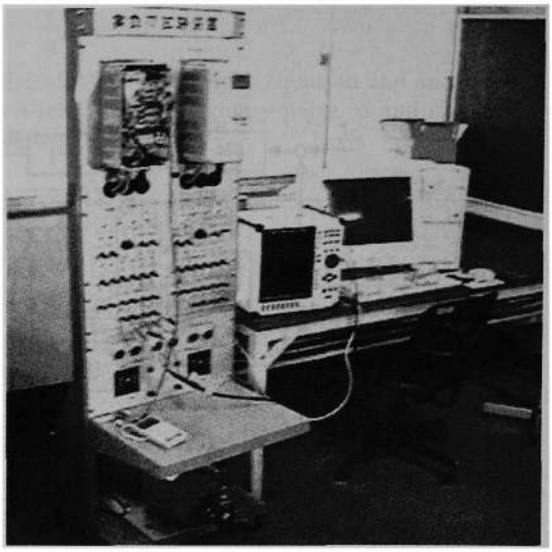


Fig. 5. View of the experimental system.

Fig.6 shows the experimental result of the response from 0.0 Hz to 0.2 Hz (almost 6 rpm) as the speed command and no disturbance load is applied. The solid line is the real speed ω_r, dashed line is the estimated speed $\hat{\omega}_r$. Since we are dealing with a very low speed where interference and measurement error is relatively large, satisfactory result is assumed.

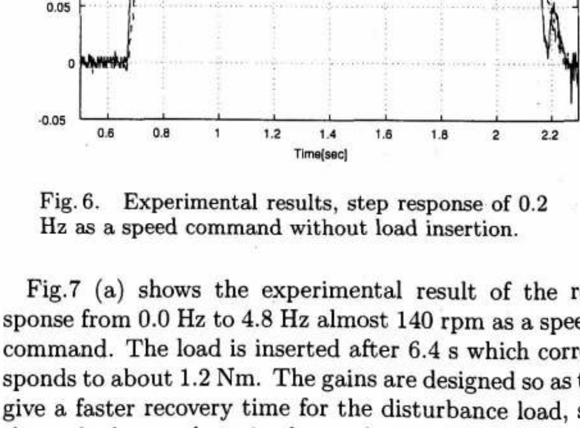
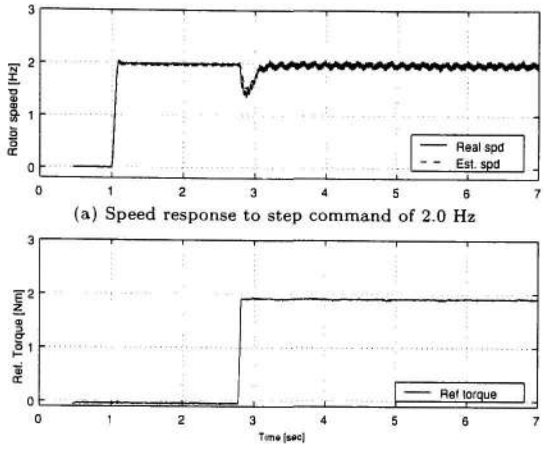


Fig. 6. Experimental results, step response of 0.2 Hz as a speed command without load insertion.

Fig.7 (a) shows the experimental result of the response from 0.0 Hz to 4.8 Hz almost 140 rpm as a speed command. The load is inserted after 6.4 s which corresponds to about 1.2 Nm. The gains are designed so as to give a faster recovery time for the disturbance load, so that a little overshoot is observed. This overshoot can be eliminated by varying the gains of the PI controllers



(a) Speed response to step command of 2.0 Hz

(b) Reference load

Fig. 11. Experimental results, response to load insertion and with PI controller gains variation.

6. Conclusions

The proposed estimation method has been successfully applied to control the induction motor drives without using speed sensors. Stability to a very low seed range has been demonstrated, which shows excellent performance. Since the whole idea based on a short sampling period and a faster microprocessor can realize this condition, a parameter estimation error becomes smaller and as a result improves the system response.

As was mentioned throughout this paper, direct slip estimation (8) did not achieve the desirable result due to zero divide, so that another method is used in (10). Accumulation error in the rotor flux estimation prevent us from using it for the angle estimation (11), instead, the integration was used and successfully estimated the desired angle as was mentioned in (12). Equation (10) and (12) are effective to estimate the slip angular speed and the rotational angle in both simulation and experiment.

Experimental testing shows that it is better to apply the different PI controller gains for the transient response and for the response to the disturbance load respectively.

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References

(1) Peter VAS, *Vector Control of AC Machines*, Clarondon press, OXFORD, 1990.
(2) Min-Huei Kim, James C. Hung, "VECTOR CONTROL SYSTEM FOR INDUCTION MOTOR WITHOUT SPEED SENSOR AT VERY LOW SPEED", Tran. of IEEE Power App., Sep. 1995.
(3) Jung-Ik Ha, Seung-Ki Sul, " Sensorless Field-Orientation Control of an Induction Machine by High-Frequency Signal Injection", Trans. of IEEE Industry Appl. Vol. 35, No. 1, Jan. 1999.
(4) H. Kubota, K. Matsuse, " Speed Sensorless Field Oriented Control of Induction Motor with Rotor Resistance Adaptation", Proc. of IEEE IAS Conf 1994.
(5) C. Attaianese, A. Perfettp, I. Marongiu, " An Observer for Speed Sensor-less Induction Motor Drive Estimating Rotor Resistance Variations", Proc. of Oct. 1994 IEEE IAS Conf.

Hasan Zidan (Student Member) was born in the West Bank, Palestine on Feb. 6, 1968. He received the B. S. from the AMTA university, Egypt in 1991. He received the M. S. from Kyushu Institute of Technology, Japan in 1998. Currently, he is a Ph. D. student in the Department of Electrical Engineering, Kyushu Institute of Technology, Japan. His research interests include adaptive control, variable structure control, and applications to AC drive systems.

Shuichi Fujii (Non-member) was born in Yamaguchi, Japan on sep. 1969. Currently, he is in a M. Sc. student in the Department of Electrical Engineering, Kyushu Institute of Technology, Japan. His research interests include applications to AC drive systems.

Tsuyoshi Hanamoto (Member) was born in Yamaguchi, Japan on July 22, 1961. He received the B. S. and the M. S. from Kyushu Institute of Technology, Japan, in 1984 and 1986, respectively. In 1986 he joined Kobe works of Kobe Steel, Ltd. In 1990 he was engaged with the Center for Cooperative Recearch of Kyushu Institute of Technology. From 1997 to 2000 he was with the Department of Electrical Engineering. Since April 2000 he has been with the Graduate School of Life Science and Systems Engineering, where he is presently an Associate Professor. His research interests include motor control, motion control and sensorless control of AC machines.

Teruo Tsuji (Member) was born in Nagasaki, Japan on May 1940. He received the B. S., M. S., and Dr. Eng. degrees in Electrical Engineering from Kyushu University, Japan, in 1963, 1965 and 1978 respectively. Since 1968 he has been with the Department of Electrical Engineering, Kyushu Institute of Technology, where he is presently a Professor. His research interests include control, identification, and control application to magnetic levitation systems and power electronics systems