Košice
Slovak Republic
2000

INVESTIGATION OF SLIDING MODE POSITION SERVODRIVE CONTROL

K. Vincze, L. Számel, S. Halász, I. Schmidt
Budapest University of Technology and Economics, Department of Electrical Machines and Drives,
1111 Budapest, Egry József u. 18, Hungary
tel.: 36-1-463-3605; fax:36-1-463-3600; e-mail: vinkat@eik.bme.hu; szamel@eik.bme.hu; halasz@eik.bme.hu; schi@eik.bme.hu

Abstract. The theoretical and experimental investigation of servo drives with a sliding mode position control is given. The sliding mode control (SMC) prescribes the position, speed and acceleration (deceleration) time functions and the quality of the drive transient phenomena as well. The control surface is performed by given four sliding mode errors: position, speed, acceleration and deceleration errors. It is shown that the smooth control is insured. The simulation and experimental results of the sliding mode controlled dc chopper drive verify the theoretical results.

Keywords: Sliding mode control, Servo drives, DC machines, Microcontrollers.

1. INTRODUCTION

In motion control systems the robustness against parameter changes and disturbance rejection are of main importance. It is well known that the sliding mode control, which belongs to the group of variable structure control, has the following features:

- Insensitivity to parameter variations and disturbances,
- No requirement of the accurate model of the controlled system,
- Simple realization of the control algorithm.

In this paper the application of sliding mode control to permanent magnet DC servomotors is presented.

2. THEORETICAL CONSIDERATIONS

The synthesis of sliding mode control (SMC) can be broken into three parts. The first part is the design of the sliding surfaces, the second part is the design of the control, which holds the system trajectory on the sliding surface and the third part is the chattering-free implementation.

Sliding mode position control
The sliding mode control should be investigated by the limitation of the current, the speed and the acceleration (deceleration) of the drive.
The sliding surfaces at this restricted mode are determined by the sliding surface equation of the position control [7] (1) and by the additional equations (2-4), which take into account the possible restrictions:

$$s_\alpha = \Delta\alpha + \lambda_1 \frac{d\Delta\alpha}{dt} + \lambda_2 \frac{d^2\Delta\alpha}{dt^2}, \tag{1}$$

$$s_\omega = \Delta\omega + \lambda_\omega \frac{d\Delta\omega}{dt}, \tag{2}$$

$$s_a = \varepsilon_a - \frac{d\omega}{dt}, \tag{3}$$

$$s_d = -\varepsilon_d - \frac{d\omega}{dt}, \tag{4}$$

where $\Delta\alpha = \alpha_{ref} - \alpha$ is the position error, α_{ref} is the position reference signal, α is the position, λ_1, and λ_2 are parameters and $\Delta\omega = \omega_{max} - \omega$,

ω_{max} is the prescribed limit of the speed,
ε_a is the limit of the acceleration,
ε_d is the absolute value of the deceleration limit.

The solution of a second order differential equation

$$\Delta\alpha + \lambda_1 \frac{d\Delta\alpha}{dt} + \lambda_2 \frac{d^2\Delta\alpha}{dt^2} = 0$$

with $\lambda_1 = 2\sqrt{\lambda_2}$ (damping factor $\xi = 1$) are:

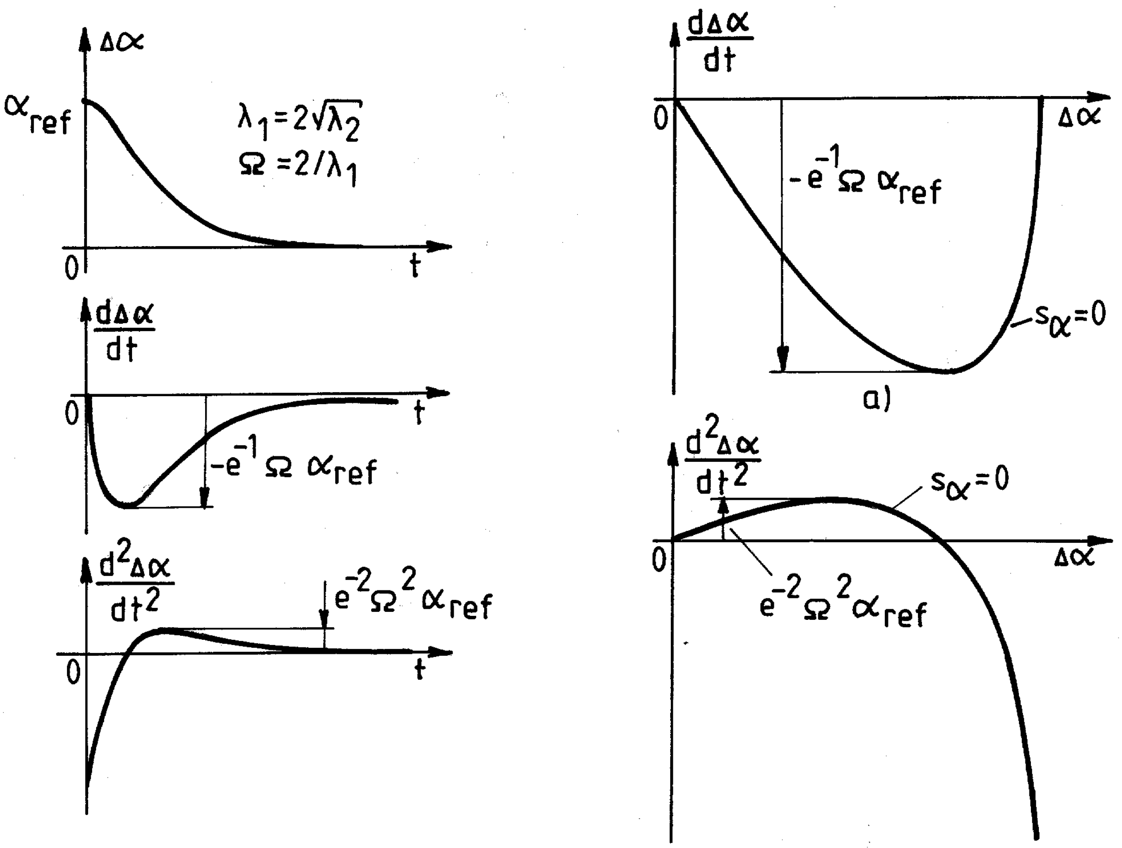
$$\Delta\alpha(t) = [\,\Delta\alpha_0 + (\Delta\alpha_0\,\Omega - \omega_0\,)\,t\,]\,e^{-\Omega t}, \tag{5}$$

where $\Omega = 2/\lambda_1$ and ω_0 is the speed when the SMC switches the system to the position surface according to (1), providing the smooth setting of the drive.
For small position reference the system from beginning to end stays on the position surface thus $\Delta\alpha_0 = \alpha_{ref}$ and $\omega_0 = 0$. Then the solution is as follows:

$$\Delta\alpha(t) = \alpha_{ref}\,(1 + \Omega\,t\,)\,e^{-\Omega t}, \tag{6}$$

$$\Delta\dot{\alpha}(t) = -\alpha_{ref}\;\Omega^2 t\,e^{-\Omega t}, \tag{7}$$

$$\Delta\ddot{\alpha}(t) = -\alpha_{ref}\;\Omega^2 (1 - \Omega\,t\,)\,e^{-\Omega t}. \tag{8}$$



a) b)

Fig. 1 a, b. Transient time functions and sliding curves (unrestricted case)

In this case neither speed nor acceleration (deceleration) are limited as it can be seen in Fig. 1a.-b where the theoretical transient time functions and the projections of sliding curves in phase plain are shown. The selection of the damping factor ξ = 1 ensures the motion performance without overshot.

The projections of sliding curves on phase plain and transient time functions for restricted modes of operations are presented in Fig. 1c.-d. If in Fig. 1.c-d the operation region is in dashed region the (+U) motor voltage, in opposite case the (-U) voltage is switched to the motor. The acceleration and deceleration limits prescribe the motor current limits therefore the maximal acceleration (deceleration) is limited by current limit.

In the first part of the motion in Fig. 1.-d the system space trajectory is performed in $\varepsilon = \varepsilon_a = const$ plane. In the second part the speed limitation according to (2) - beginning from the speed $\omega = \omega_{max} - \Delta\omega_{\omega}$ - leads smoothly the system speed to the prescribed maximal speed $\omega_{max} = const$. Further the system trajectory stays in the plane $\Delta\alpha - \omega$ since the acceleration $\varepsilon = 0$. The third part of the trajectory is lying in the deceleration plane $\varepsilon = -\varepsilon_d = const$. When this trajectory reaches the plane determined by (1) the last part of motion starts, namely the position control with a smooth stop of the system, that is the system trajectory reaches the origin of the coordinate system.

Realization of SMC

The system motion is performed according to sliding performance (1)-(4) as it was shown above. But there is some freedom in the selection of the braking start time. According to (5) the last part of the trajectory will be realized without position overshooting if

$$\Delta\alpha_0\, \Omega - \omega_0 > 0\,, \qquad (9)$$

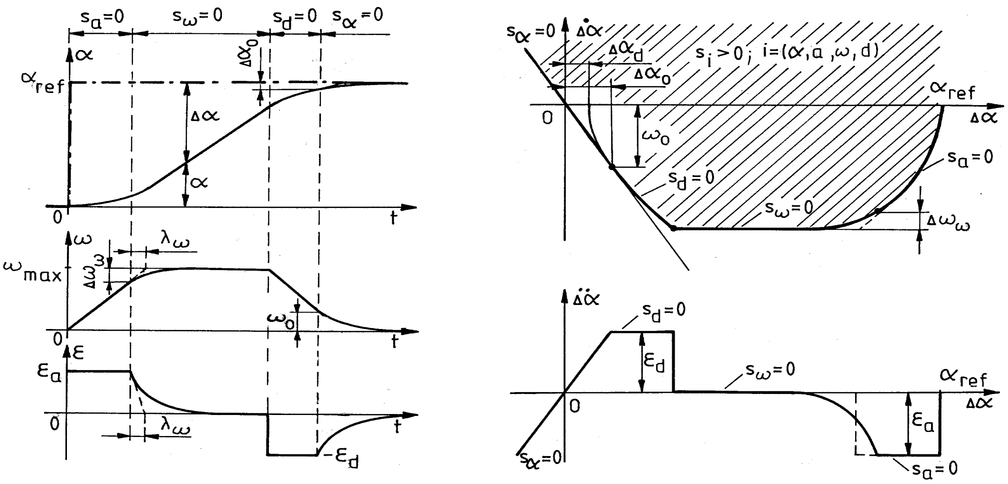
that is $\Delta\alpha > \omega_0 / \Omega$. If the condition of (9) is fulfilled one can prescribe the initial value of the last trajectory part speed ω_0. Then the position error in this point will be:

It should be noted that the SMC according to (1) provides the smooth transition from the braking with $\varepsilon = -\varepsilon_d = const$ to the sliding surface (1) since the initial deceleration will be in any case equal to ($-\varepsilon_d$)

When the braking with $\varepsilon_d = const.$ must start the position error will be:

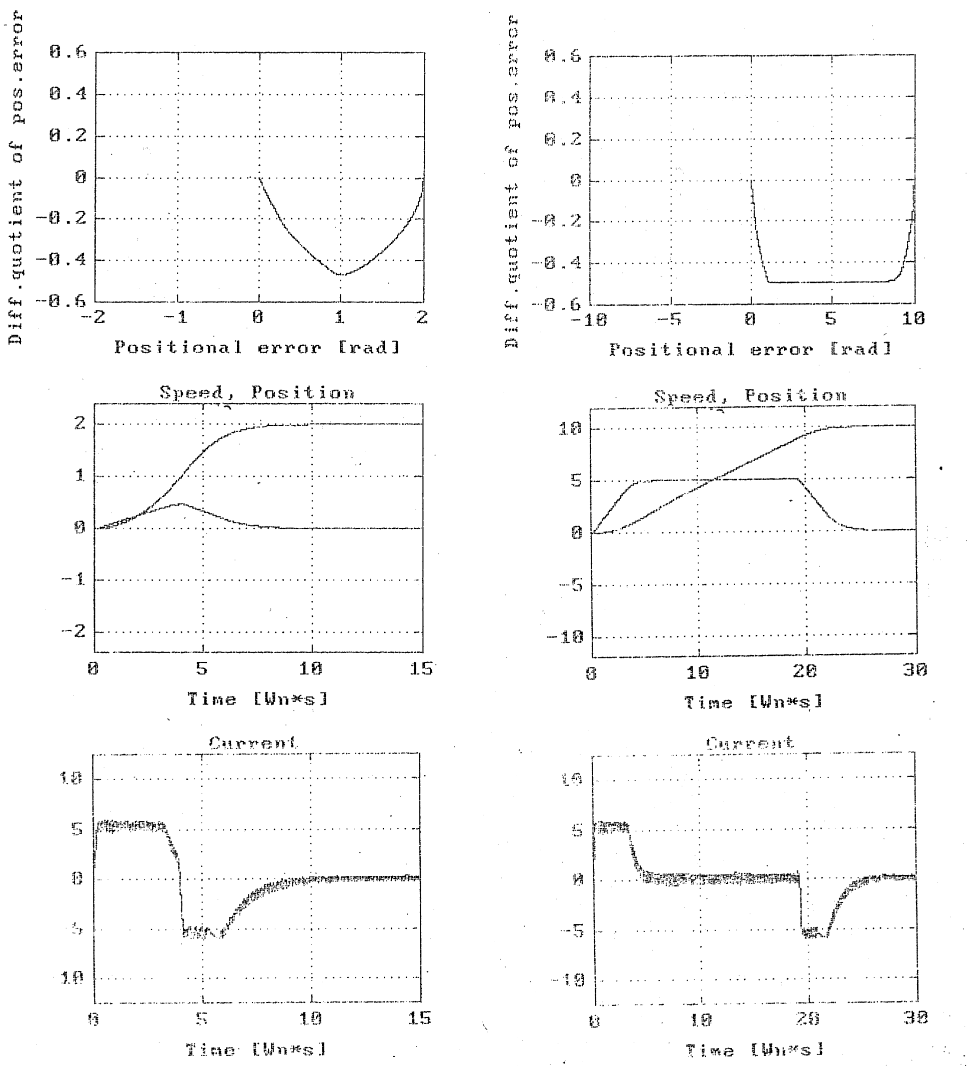
$$\Delta\alpha_{br} = \frac{\omega_{max}^2 - \omega_0^2}{2\,\varepsilon_d} + \Delta\alpha_0 \qquad (11)$$

and in the instant when $\Delta\alpha = \Delta\alpha_0$ the transition to the sliding surface (1) must start.



c) d)

Fig. 1. c, d. Transient time functions and sliding curves for SMC with restrictions of speed, acceleration and deceleration



a) $\alpha_{ref} = 2$ b) $\alpha_{ref} = 10$

Fig. 2. Results of simulations

The SMC simulation of a permanent magnet dc motor drive was performed. The motor dates that have been used for both simulation and experimental investigations are: $U = 63V, I = 13A, \omega = 262 rad/s$. Motor electric time constant is $3ms$, the starting time constant is $161ms$.

The results of SMC simulation for a small reference signal $\alpha_{ref} = 2$ and a relatively big one $\alpha_{ref} = 10$ are presented in Fig. 2. In Fig. 2b. the scale of the speed is increased by 10 times and $\omega_{max} = 0.5$. Due to no-load motor operation and $\varepsilon_a = \varepsilon_d$ there is $I_{\max a} = I_{\max d} = 5I_{rated}$. The dc voltage of the chopper drive is 2.5p.u. (157.5V). The chopper frequency was 20kHz.

Chattering free implementation

SMC laws present discontinuities on the sliding line which cause chattering and a strong control activity which are amplified by the effect of time delays (limited switching frequency and computation time) and of unmodelled small time constants. Usually, all state variables are not measurable (for instance the acceleration), the system parameters are not known and the unmodelled dynamics may cause chattering.

To solve this problems the asymptotic state observer has been proposed [6]. Even if the real states are measurable, the switching surfaces and the control are calculated from the observer states. Since the observer structure and all the observer parameters are exactly known, an ideal sliding mode might occur in the observer-controller loop. According to the theory of singular perturbation, the small time constants of the real system can be ignored in the observer model.

3. HARDWARE REALIZATION

The experimental results are obtained using two identical permanent magnet DC motors, which are joined together by a clutch as it is shown in Fig. 3. One of them is used as a motor whose position is controlled and the other is used as a load. Both of the DC motors are driven separately by two identical servo drivers containing a four-quadrant chopper amplifier.

The sliding mode controller is implemented on a DSP (TMS320) equipped with the counter for the encoder, digital-analogue converters (DAC) and analogue-digital converters (ADC). The armature current given by the servo amplifier is converted by ADC in every T_2=100µs which is the sampling period of the sliding mode controller. The output of the sliding mode controller is the voltage reference for the motor.

4. EXPERIMENTAL RESULTS

The experiences show that the sliding mode control suggested in this paper works without overshooting and chattering. Though the method SMC requires a longer calculation period it is less sensible to the variations of parameters. The position, speed and current time-functions are shown in Fig. 4. for no-load motor operations, In Fig. 4a. these functions are given for a small reference signal $\alpha_{ref} = \pi$, while in Fig. 4b. they are given for a considerable signal $\alpha_{ref} = 4\pi$. In the first case the motor speed doesn't reach the maximal speed, while in the second case there is a part of motion with the constant restricted speed. In both cases the SMC provides the acceptable time functions and a good quality of the position control with smooth setting.

5. CONCLUSIONS

This paper presents the theoretical and experimental investigation of servo drives with sliding mode position control. The control surfaces are performed by given four

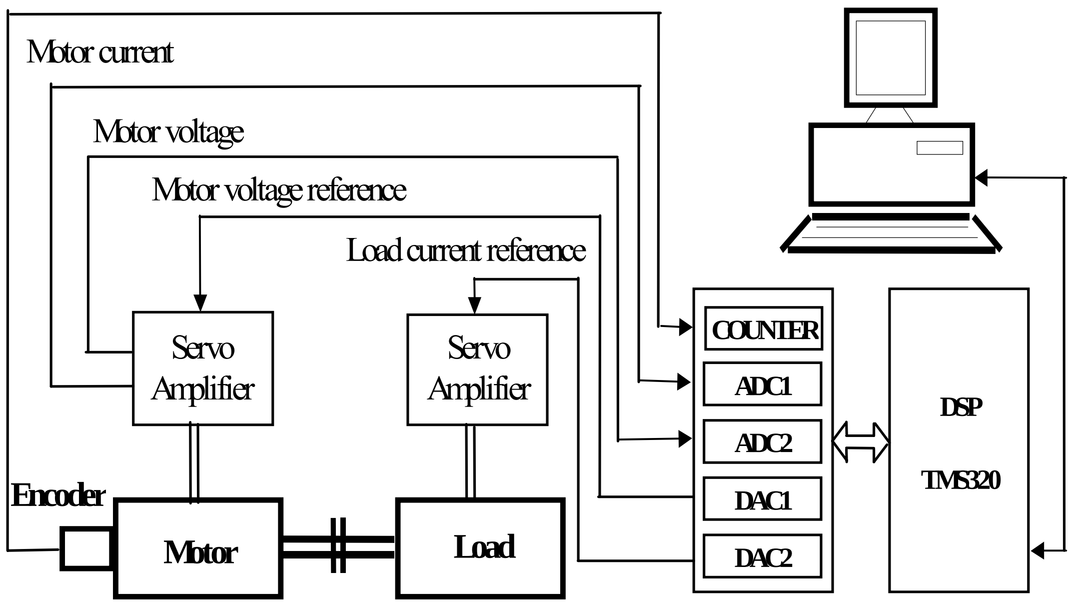


Fig. 3. Experimental setup

sliding mode errors: position, speed, acceleration and deceleration errors. The simulations and experimental results demonstrate that the proposed sliding mode control is a promising tool to control the servo drives and it is shown that the smooth and accurate control is insured.

6. ACKNOWLEDGMENTS

This paper was supported by the Hungarian National Scientific Found (OTKA No. T30529) and by the Hungarian Ministry of Education and Culture (FKFP No. 21294) for which the authors express their sincere gratitude.

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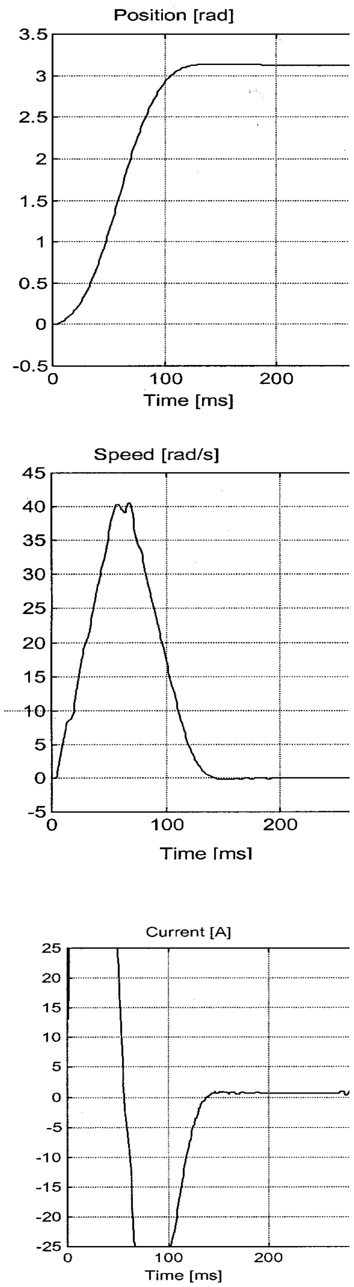

Fig. 4a. Experimental results for small reference signal

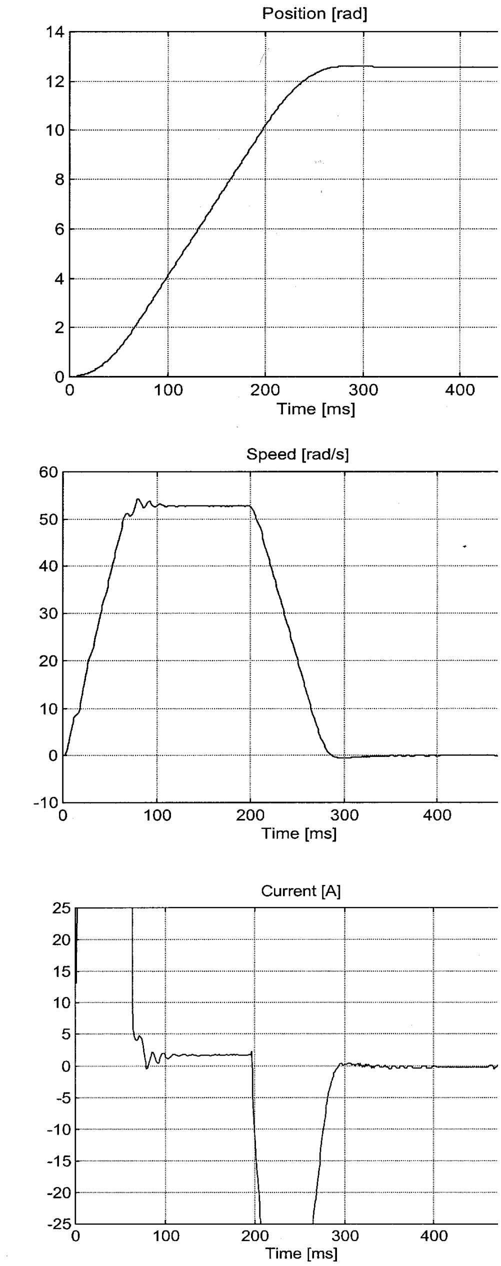

Fig. 4b. Experimental results for big reference signal

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THE AUTHORS

Mrs. Katalin Vincze was born in Budapest, Hungary, in 1945. She received the M.S.. and dr. univ. degrees from the Budapest University of Technology and Economics in 1968 and 1986, respectively. From 1968 to 1978, she was with the Ganz Electric Works, Budapest. She has been working with the Dept. of Electrical Machines and Drives at the university since 1978. Her research interests include servo and robot drives, vehicle electronics, controlled AC drives.

László Számel was born in Budapest, in 1964. He received the M.S. and dr. univ degrees in electrical engineering from Technical University of Budapest in 1988 and 1995, respectively. Until 1997 he worked for Computer and Automation Research Institute of Hungarian Academy of Science, since then is with Budapest University of Technology and Economics. His educational and research fields are electrical drive control, servo and robot drives, digital systems, switched reluctance motor drives, high-accuracy position and speed measurements of electrical drives.

Sándor Halász received the M.S. degree in electrical engineering from the Polytechnic University of Leningrad, USSR, in 1957 and the Ph.D. and Doctor of Science degrees from the Hungarian Academy of Science in 1968 and 1983 respectively. Until 1959, he was with the TRANSZVILL factory in Budapest, and since then has been with the Department of Electrical Machines and Drives, Budapest University of Technology and Economics. He became a full Professor in 1985. His search interests include control of ac drives, PWM techniques, VSI inverters etc. He has published over 110 papers and 8 books. Prof. Halász is a member of IEEE, the Hungarian Electrotechnical Association and several Committees of Hungarian Academy of Science

István Schmidt was born in Budapest, Hungary, in 1941. He received the M.S. and Ph.D. degrees from the Budapest University of Technology and Economics (formerly Technical University of Budapest) and DSc. degree forms the Hungarian Academy of Science in 1964, 1978 and 2000, respectively. He has been working with the Dept. of Electrical Machines and Drives at the same university since hisgraduation. His research interests include converter controlled AC drives, advanced control methods, servo and robot drives.