ON THE NON-LINEAR CHARACTERISTICS OF A POSITION CONTROL SYSTEM

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Abstract
The paper presents the results of a study made by the author on a position digital control system of a permanent magnet synchronous motor. Theoretical analysis of the non-linear and the linear system was made: stability, transient regime, the state portrait and the limit cycles. Also experiments were made with the digital equipment.

Key words: non-linear control systems, electrical drives, permanent magnet synchronous motors,

INTRODUCTION
The control systems of the electrical drive present many non-linearities. Traditionally the attention is focused on the local performances around the operating point, where a linear model may approximate the system. A study of a non-linear control system with dead zone and saturation is made in [Ortega2000]. A simple servomechanism with a d.c. motor is analyzed. Based on that study the more complex position control systems of a.c. drives may be also analyzed. In this paper a position control system of a permanent magnet synchronous motor is analyzed based on the above study. Practical experiments were made with the digital control system based on a DSP.

THE POSITION CONTROL SYSTEM
The position control system has the block diagram from fig. 1. The electrical motor ME is fed with a power converter CONV, with a command block BC. There are current i, speed Ω and position θ control loops. Sensors for current Ti, speed TΩ and position Tθ are used.

A simplified control system, shown in fig. 2, may be used to do theoretical analysis.
The non-linearity of the control system may be seen in the equivalent block diagram from fig. 3. The input-output characteristic of the non-linear part with dead zone and saturation is presented in fig. 4.
To assure limit cycles a transfer function of the linear part may be used:

$$H_L(s) = \frac{K_L}{s(T_1 s + 1)(T_2 s + 1)}$$

where T_1 is the mechanical time constant of the motor, T_2 is the time constant of the converter and the integral character described the pass from the speed at the position.
The two loci of the linear and non-linear parts are presented in fig. 5. Limit cycles may appear.
For the position control a proportional controller may be used. The tuning of the proportional controller may be done using a frequency analysis. The Bode diagrams of the open loop linear position control system are presented in fig. 6. A phase reserve of 70^o was chosen.
The step transient response of the position for the linear system is presented in fig. 7.
The non-linear control system has a very complex state portrait. It has different bifurcation points. The state variables are the position $x_1=\theta$, the speed $x_2=\Omega$ and the current command x_3 from the converter. Some diagrams of the state portrait, for different values of the controller coefficient and the initial values of the third state variable are presented in fig. 8.
The step response of the non-linear system is presented in fig. 9 and 10 for two different values

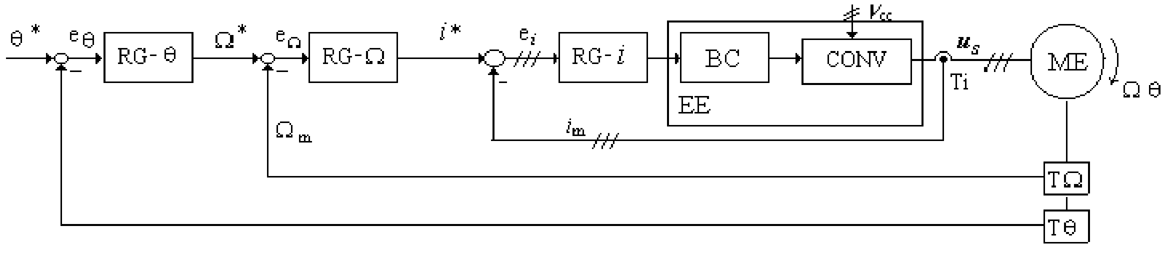

Fig. 1. The block diagram of the position control system

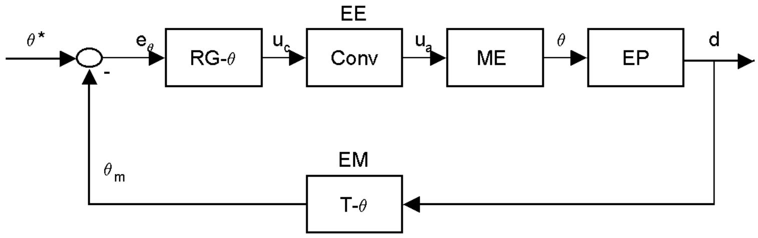

Fig. 2. The equivalent position control system

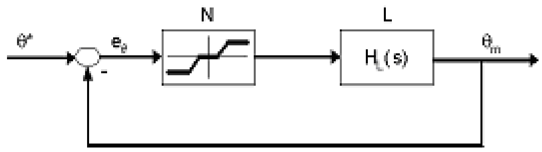

Fig. 3. The block diagram with the non-linear part

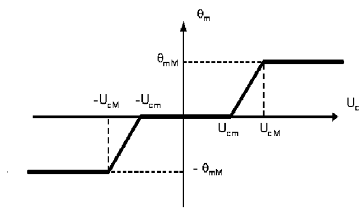

Fig. 4. The characteristic of the non-linearity

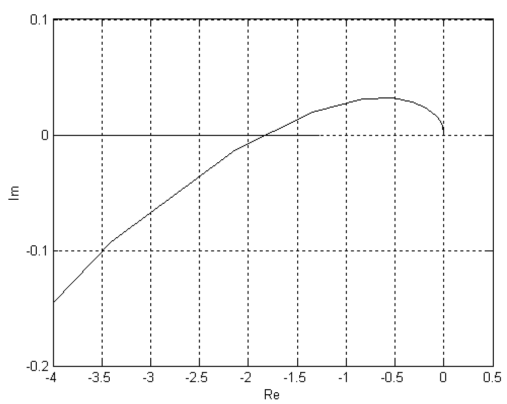

Fig. 5. The diagram of the two loci

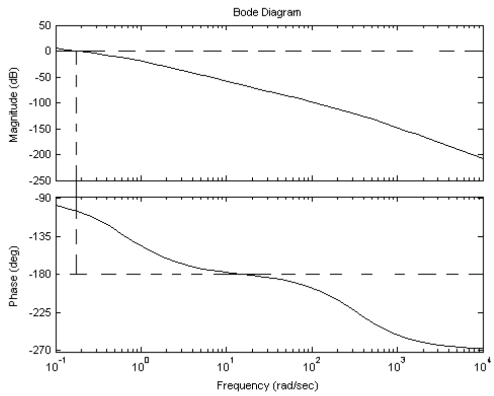

Fig. 6. The Bode diagram of the open loop

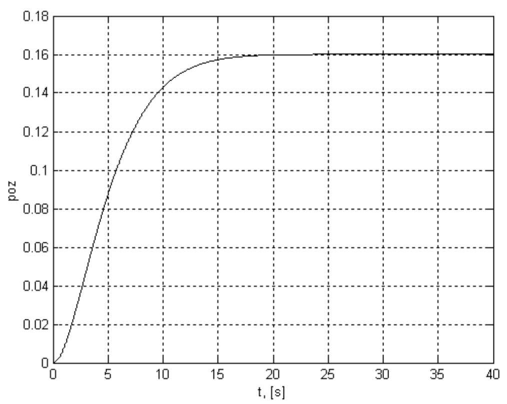

Fig. 7.The transient characteristic of the position for the linear system

of the proportional coefficient.
The stability of the position control system may be analyzed using Hurwitz criterion for the linear system and using Popov's criterion for the non-linear system. The same stability sector results in both cases.

EXPERIMENTAL RESULTS

Experiments were made using a Technosoft digital control system with a permanent magnet synchronous motor and an motion chip realized in ASIC technology. The block diagram of the digital equipment is presented in fig. 11. The user interface is presented in fig. 12.
Transient characteristics of the position, speed, position error and command current for tuned parameters, are presented in fig. 13.
Limit cycles are presented in fig. 14.

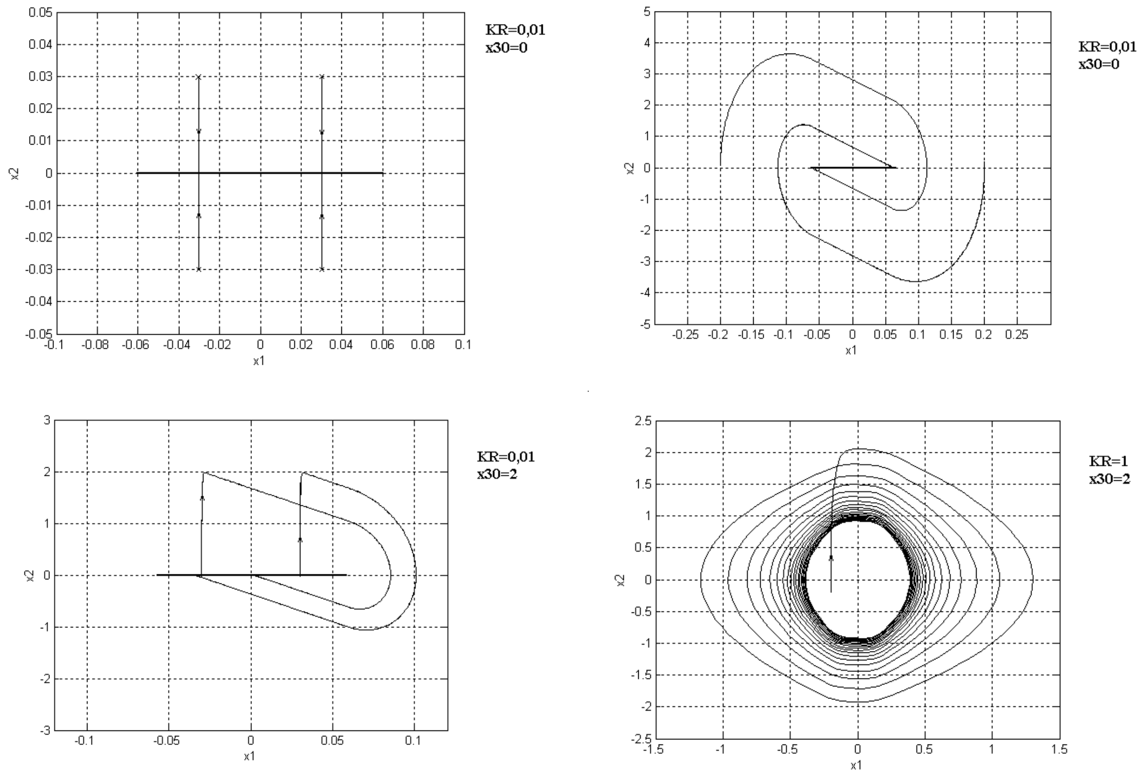

Fig. 8. State space characteristics of the non-linear system

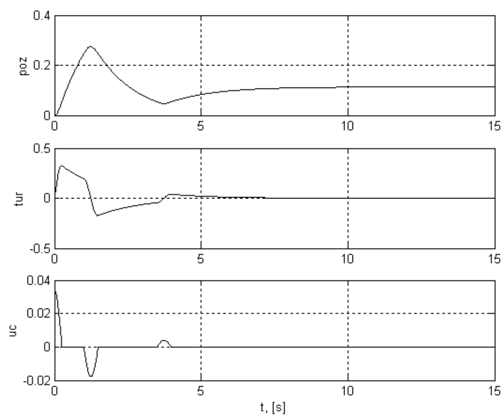

Fig. 9. The step response of the non-linear position control system for tuned parameters

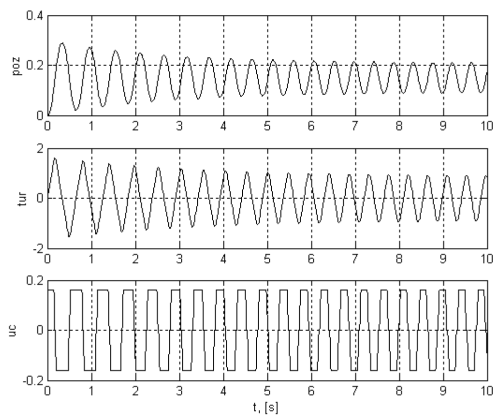

Fig. 10. The step response of the non-linear control system for the coefficient equal to 1

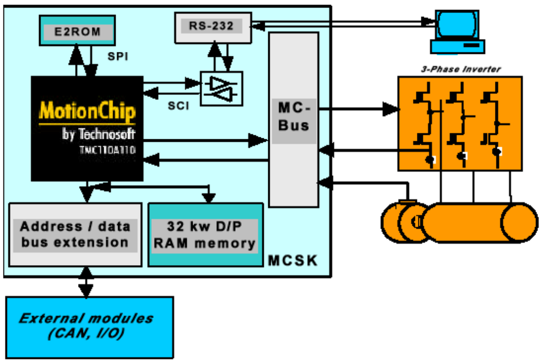

Fig. 11. The motion chip based control equipment

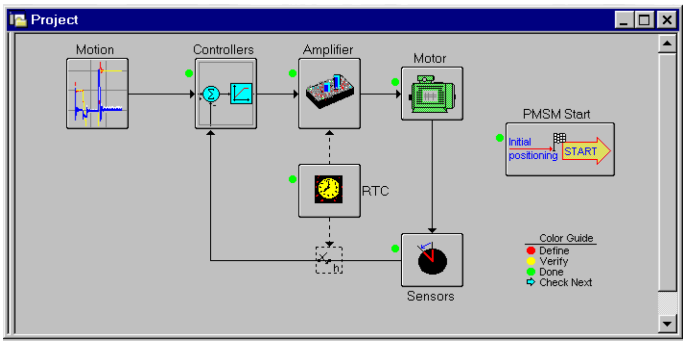

Fig. 12. The window of the user interface

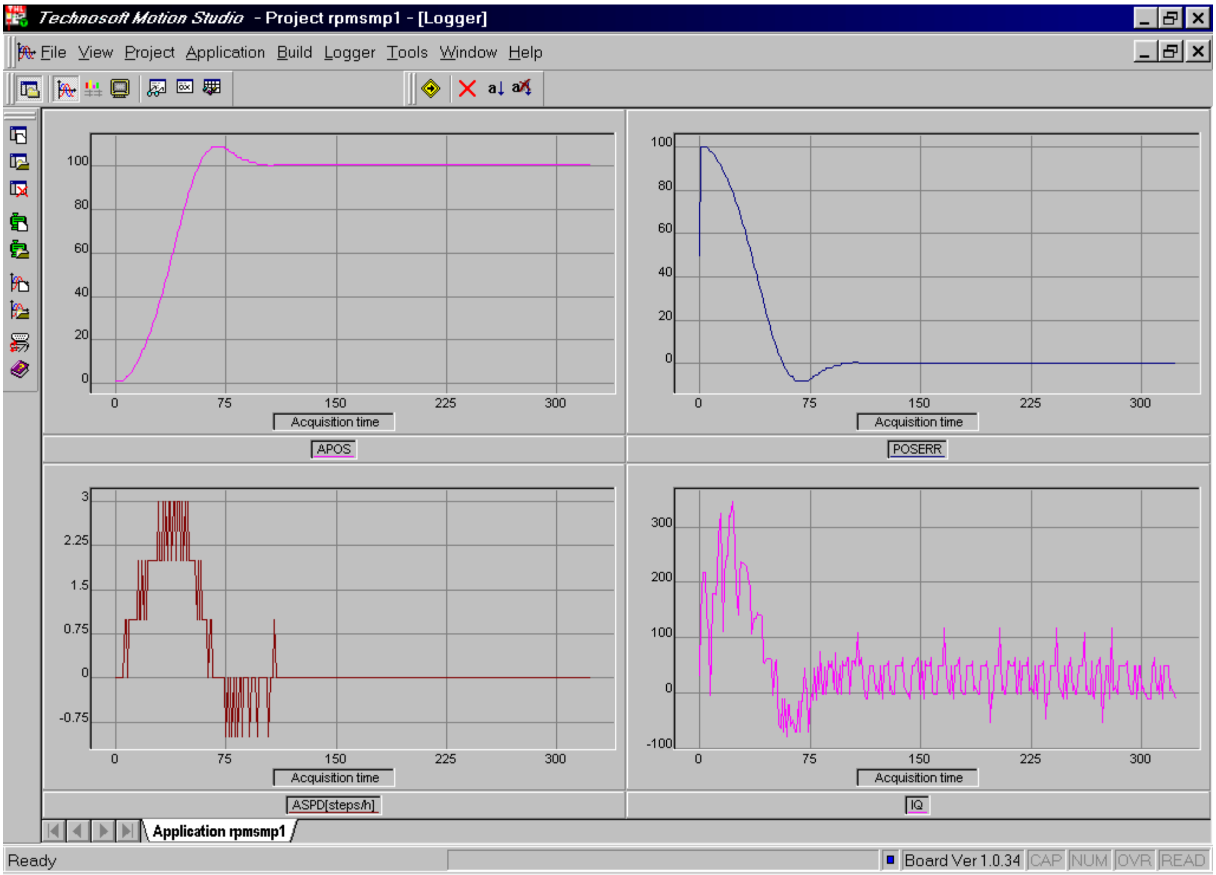

Fig. 13. Transient characteristics of the position, speed, position error and comand current

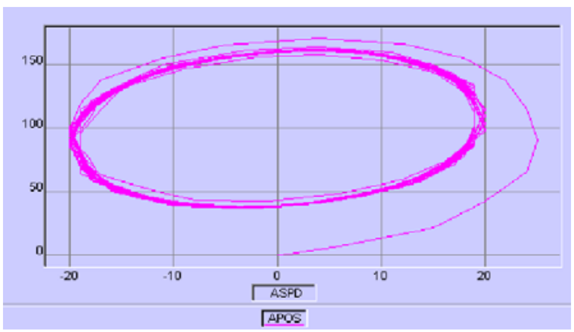

Fig. 14. The limit cycles in the state space

CONCLUSION

In this paper a theoretical analysis of some properties of a non-linear position control system of a permanent magnet synchronous motor was presented. A simplified non-linear model with 3 poles presents limit cycles. The control system may also be approximated as a linear system. A stability analysis based on Hurwitz criterion is possible on the linear system. The position controller may be tuned based on the frequency characteristics of the open loop linear control system. A stability analysis of the non-linear control system may be done using Popov's criterion. Transient characteristics of the simplified control system were obtained with a Matlab simulation for different values of the gain coefficient of the controller. For great values limit cycles appear. Characteristics in the state space were obtained. On these characteristics bifurcation points appear.

Experiments were also made with a digital control system based on a DSP for a permanent magnet position control system. Position, speed and current controllers were tuned to obtained good control quality criteria. For some values of the position controller was proved the possibility of the limit cycles.

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BIOGRAPHY

Constantin Voloşencu is with The Department of Automatics and Industrial Informatics of the University "Politehnica" of Timişoara from 1991. He graduated in 1981 as an engineer of automatics and computers at The Polytechnic Institute of Timişoara. He is a doctor in automatics from 2000, with a doctor thesis on control of the electrical drives based on fuzzy logic and neural networks. He is author of more then 60 scientific papers, 7 books and 27 patents. Member of IEEE, affiliated at IEEE Control System Society and Neural Networks Society.