Design of a microcontroller based state control for a magnetic levitation transport system

GRÖNING, Ingolf; BUTZ, Stefan; HENNEBERGER, Gerhard
RWTH Aachen
Institute of Electrical Machines
Schinkelstraße 4, 52062 Aachen, Germany

ABSTRACT

This paper deals with the development and the construction of a microcontroller based state control for a magnetic levitation system. It carries a transportation vehicle with a linear homopolar motor. Both systems are supplied by contactless energy transmission. The bearing magnet only needs a simple and cheap track for levitation and guidance. The vehicle is stabilised by a state control. Loading and unloading is possible without putting down the system..

A reduction of the costs of the state control and its peripheral parts (A/D- & D/A-converter) is presented in this paper, which has been realised by minimisation of the used components and a consequent optimisation of the software with reference to the accuracy and the speed. A control of the four bearing magnets at a frequency of 2 kHz with an accuracy of 13 bit is possible.

0-7803-4503-7/98/$10.00 1998 IEEE

Introduction

Magnetic levitation technique combined with a linear drive as described in [1] makes a contactless and frictionless operation of a transportation system (Fig. 1) possible.

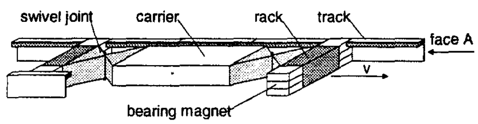


Figure 1: Outline of the vehicle

The vehicle is driven by four linear homopolar motors with a passive track. The velocity comes up to ten meters per second. The energy needed for the whole vehicle is provided by a contactless energy transmission. Therefore only energy saving levitation techniques are suitable. A hybrid excited magnet with a current, which is set to zero by a controller, is such an energy saving technique.

This vehicle has no maintenance parts so the site of operation is where high reliability is requested. Other appropriate sites are clean rooms and food industries for example.

The high costs of a controller, which bases on a digital signal processor, and its peripheral parts (A/D- & D/A-converter) complicate the success on the market.

Construction of the Vehicle

The vehicle consists of a carrier with two racks fixed with swivel joints to the front and the rear (Fig. 1). On both sides of both racks the single sided bearing magnet is mounted. The reaction rail is slotted (Fig. 2) to produce a lateral force (reluctance force), if the bearing magnet is displaced from symmetrical position.

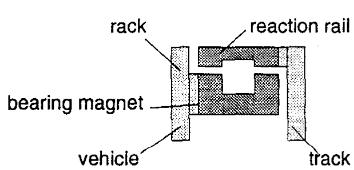


Figure 2: Bearing magnet viewed from face A

State Control

In order to design a state controller, one has to formulate the state equations of the system. Each of the four bearing magnets has an independent set of state equations. The air gap, its first derivative and the ampere turns are the components of the state vector, whereby the index 'i' stands for the bearing magnet number 'i':

$$\mathbf{x}_i = \begin{pmatrix} \delta_i \\ \dot{\delta}_i \\ \Theta_i \end{pmatrix} \qquad (1)$$

Each of the four bearing magnets can be controlled separately because of the stiffness of the vehicle. The ordinal number of the state vector amounts to twelve.

Due to the different load of the vehicle, which would result in a stationary deviation of the set value of the air gap, an additional digital P-T_1-term has been realised. This digital P-T_1-term represents an integral part of the control. The schematic of the digital state control is displayed in Fig. 3.

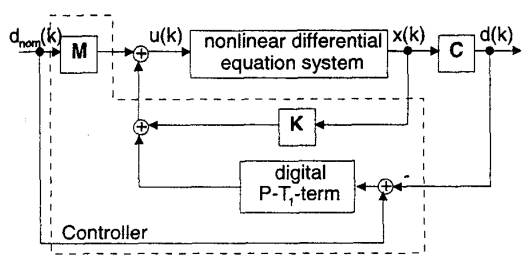


Figure 3: Schematic of the digital state control

Choice of the Microcontroller

The microcontroller has to take over the functions of reading the input data, calculating and writing the output data and controlling the external peripheral parts. Therefore the internal programming of the microcontroller must be balanced between accuracy and speed.

For each bearing magnet the air gap δ_i and the ampere turns Θ_i is measured separately. The velocity of the air gap $\dot{\delta}_i$ is calculated with the differential quotient within the microcontroller.

0-7803-4503-7/98/$10.00 1998 IEEE

In addition to the eight measured state variables (δ_1 - δ_4, Θ_1 - Θ_4) the nominal value of the air gap δ_{nom} has to be read as input data. This nominal air gap is valid for all four bearing magnets. Furthermore the four nominal voltages $U_{nom,i}$ for each of the four quadrant current supplier have to be written as output data.

The desired accuracy of the controller is 13 bit at a frequency of 2 kHz. Therefore the desired microcontroller should have at least an accuracy of 16 bit and a high clock rate. In order not to complicate the construction of the whole controller the microcontroller should provide 'On Chip RAM'.

Therefore a microcontroller has to be chosen, which offers a huge number of input/output ports, a sufficient 'On Chip RAM' and a good clock rate. The 80C167 from Siemens [2] offers these features.

Peripheral Parts

A further reduction of the costs is achieved by using only one A/D-converter [4] and one D/A-converter [5] for the nine input channels and the four output channels. This aim is reached by using a multiplexer [3] before the A/D-converter on the input side of the microcontroller. In the same way a demultiplexer is put after the D/A-converter. Due to having the output signals $U_{nom,i}$ applied permanently to the specific current supplier, four sample and hold amplifiers [7] have been added to the circuit. The schematic of the signal flow and the arrangement of the components are displayed in Fig. 4.

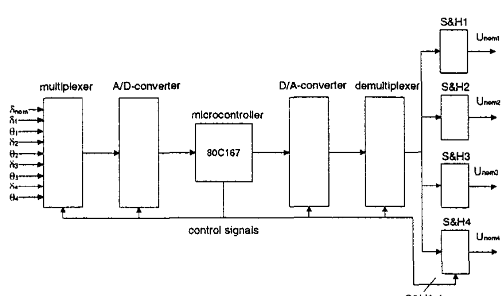
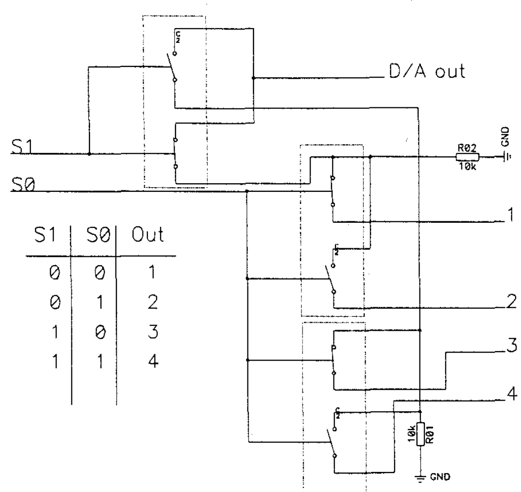


Figure 4: Schematic of the signal flow

The chosen peripheral parts have a high processing speed, exceed the desired accuracy of 13 bit and are economy-prised. The demultiplexer is an exception, because of the lack of a demultiplexer with the specified values as a mass product. Therefore its function is reproduced by three complementary switching analogue double-switches [6]. The schematic is revealed in Fig. 5.



S1	S0	Out
0	0	1
0	1	2
1	0	3
1	1	4

Figure 5: Demultiplexer with switches

Programming of the Microcontroller

The software for the microcontroller is written in the programming language 'C' in order to gain a good interface to the existing software at the Institute of Electrical Machines and to establish an easy maintainability and a fast adaptation of the parameters of the state control.

The speed of the program is raised by avoiding time-expensive structures as 'if then' or 'case of' for example. A minimisation of these structures reduces the time for one pass by about 10%. The resulting increase of the size of the program is without any importance because of the existing memory.

The clock rate of the control is achieved using a general purpose timer of the 80C167. This timer sets an interrupt request flag every 500µs. This flag starts a new pass of the program. It must be ensured that the old pass has been finished before starting a new one.

0-7803-4503-7/98/$10.00 1998 IEEE

Much time can be saved by using the conversion time of the A/D-converter for intermediate calculations. Due to the use of only 80% of the conversion time for these calculations it is ensured that directly after the A/D-converter finishes a conversion the microcontroller accepts the data. This is done for both input channels of each bearing magnet successively, which is illustrated in. Fig. 6.

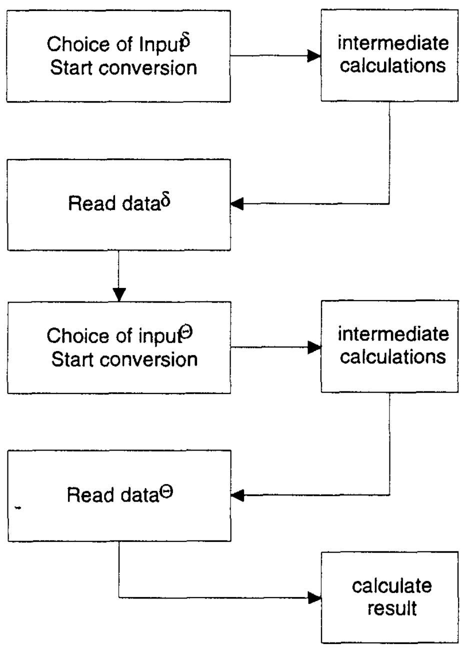


Figure 6: Flow chart of the data input

IMPLEMENTATION OF THE CONTROL

The calculations of the output data can be done on the one hand with floating point calculations. This leads to very exact results, but every multiplication needs about 70 µs. So the desired clock rate can not be realised using only floating point calculations.

On the other hand a calculation with 16 bit integer variables is very fast (1 µs), but needs rounding of the parameters of the control algorithm. The truncation error would result in a loss of performance of the control.

This problem is solved using the following strategy: Intermediate calculations with high accuracy are carried out with 32 bit variables (double precision). Wherever possible the remaining calculations are done with 16 bit accuracy.

Due to a further reduction of calculations the adaptation of the measured data of the input channels to the corresponding numbers is combined with the equations of the state control. The equation of the state control is:

$$U_{nom} = K_1 \cdot \delta + K_2 \cdot \dot{\delta} + K_3 \cdot \Theta + M \cdot \delta_{nom} + P \cdot \left(\delta_{nom,old} - \delta_{old}\right) \qquad (2)$$

The air gap δ lies between 1 mm and 5 mm, but after the sensor and the converters the air gap is equivalent to a value between -2^{16} and $+2^{16}$-1. For the use in equation (2) these values have to be converted once again, whereby the variables which represent digital input or output data are signed with '*':

$$K_1 \cdot \delta = -\left(a_1 \cdot \delta^* + b_1\right) \qquad (3)$$

This conversion is done in advance for the sensor signals δ and Θ. In addition with the fixed clock rate equation (2) can be written as:

$$U_{nom}^* = R_0 + R_1 \cdot \delta^* + R_2 \cdot \delta_{old}^* + R_3 \cdot \Theta^* + R_4 \cdot \delta_{nom}^* + R_5 \cdot \delta_{nom,old}^* \qquad (4)$$

The value U_{nom}^* has to be right shifted to be of a 16 bit format and is then written to the D/A-converter.

MEASUREMENTS

With the use of a signal generator signals steep edges are put on the input channels. This input channel and the accompanying output channel are plotted in the same diagram.

Fig. 7 shows the reaction of the output channel on a rectangular signal on the input channel of the air gap δ. The clock rate of the microcontroller based state controller can be seen, because of the holding of the output signal by the sample and hold amplifiers for one pass of the program.

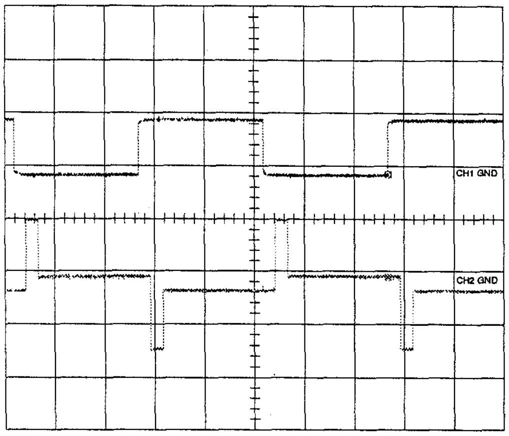


Figure 7: Rectangular signal on channel δ

After the high values of the output signal, which result from the contribution of the state variable $\dot{\delta}$ because of the steep edge of the input signal, the output signal is constant. The delay between the input and the output signal can be determined to 500 µs, which is equal to one pass of the program.

Fig. 8 reveals the same facts as Fig. 7. In addition the reactions on raising and falling signals are displayed. The accuracy of the controller is determined to a minimum of 13 bit and typical 14 bit.

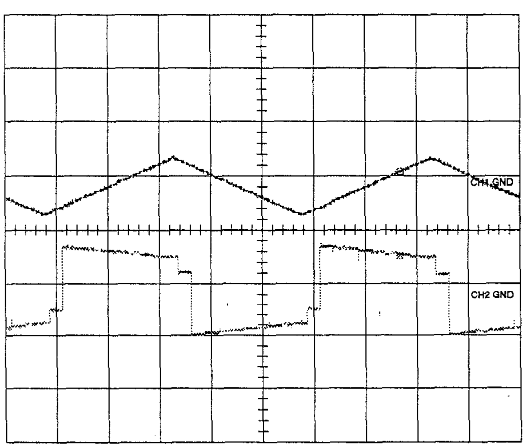


Figure 8: Triangular signal on channel δ

Conclusions

This paper presents methods, how a state control can be implemented on a microcontroller with regard to an accuracy of 13 bit by a clock rate of 2 kHz. This leads to a reduction of the costs of a state controller, which allows further sites of operation of the transportation system

References

[1] W. Evers, G. Henneberger, H. Wunderlich, A. Seelig
A Linear Homopolar Motor for a Transportation System
LDIA 1998, Tokyo, 1998

[2] N.N.
16-Bit CMOS Single Chip Microcontroller C167 User's Manual, Version 2.0
Siemens AG, München, 1996

[3] N.N.
LC^2MOS 8-/16-Channel High Performance Analog Multiplexer
Analog Devices, Norwood, 1997

[4] N.N.
Burr-Brown Data Conversion Products
Burr-Brown, Tuscon, 1994

[5] N.N.
16-Bit Digital to Analog Converter with 16-Bit Bus Interface
Burr-Brown, Tuscon, 1997

[6] N.N.
Monolithic CMOS Analog Switches
Harris Semiconductor, Melbourne, 1995

[7] N.N.
Precision Sample and Hold Amplifier
Harris Semiconductor, Melbourne, 1996