Optimization of a Low-Cost Position Sensor for a Permanent Magnet Linear Drive

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Abstract—This paper deals with a custom made low cost sensor for measuring the position of a permanent magnet linear motor. The sensor based on two hall sensor elements provides an adequate accuracy for lower ranking control loop of the position if an upper control loop is needed. The achieved accuracy is around 0.2mm.

Two different sensor layouts are presented and the optimization steps are described to develop this kind of sensor. The electromagnetic interferences are eliminated by the design of the sensor element.

The proper operation of the sensor is proven by measurements with a linear drive in comparison to a commercial high precision linear sensor.

Keywords—Position Sensor, Permanent Magnet, Linear Drive

Topic—Motor Drives & Motion Control — Advanced Sensor Concepts for Motor Drives

I. MOTIVATION

In some application fields linear drives are not used for precise positioning but to regulate pressure, flow or force of an industrial process, for example in squeezing machines. The position is only needed for lower control loops and the force is the higher ranking closed-loop control. In this special application it is hardly possible to control the linear drive sensorless, without any linear positioning sensor, but the usage of a standard sensor with accuracies from 50µm up to 10µm is very expensive. In this case a linear sensor with an accuracy of 200µm to 1mm is absolutely sufficient. A positioning sensor with this accuracy can be designed by two low-cost hall sensor elements, some surface mounted devices and a small pcb. The permanent magnets have to provide a sinusoidal field outside the winding area of the machine to control the linear drive. In most cases the sinusoidal field can be detected by placing the small positioning sensor in an optimal distance. The sensor can be mounted nearby the magnets and the windings and needs no extra space like the rod of a conventional linear sensor.

II. CONSTRUCTED SENSOR

In some application fields linear drives are not used for precise positioning but to regulate pressure, flow or force of an industrial process, for example in squeezing machines. The position

An integrated sensor element is used for the measurement which is very easy to assemble (see figure 3). The output of the hall-sensor element is amplified already inside the package of the sensor. The current source is included, too. Only the two measured signals from the A- and B-Trace have to be adapted to the inputs of the converter. This is done by two operational amplifiers (A and B) with a differential output. This is used to eliminate electromagnetic interferences on the wires. In addition two
other operational amplifiers correct the offset of the sensors. A final operational amplifier provides a constant voltage for the common mode input of the operational amplifiers A and B. The voltage corresponds with half of the power supply of the sensor. The complete circuit is shown in figure 3.

III. PROVED OPERATION OF THE SENSOR
The principal operation of the sensor is proven by the simple measurement of the magnetic field relative to the position of the armature shown in figure 4. The measured signal, printed in green, is approximated with a sinusoidal signal (blue). The difference between these signals is shown in red. To prove the operation of the sensor in cooperation with the closed loop control of the linear machine, the small sensor shown in the right part of figure 10 is mounted in the machine. The resulted position signal is compared to the reference signal of an optical linear sensor with an accuracy of 10µm shown in figure 5. It shows the two measured signals printed in blue and green and the error between them is printed in red. The absolute error of the position is very low during the whole measurement range.

IV. OPTIMIZATION OF THE SENSOR
As already shown in [2] the sinusoidal signals are overlaid by a significant noise twice over a full rotation of the electric field (see figure 6).
This is caused by a high current through the coil nearest to the sensor. In order to provide a suitable position signal these signals can be filtered to reduce the interferences. The optimization of the sensor is done by minimizing noise before overlaying the sinusoidal signals. This is realized in three steps. First of all a box of a copper coated pcb is used to shield the whole sensor. Furthermore a twisted pair cable replaces the normal shielded cable and is contacting the sensor with the converter. Figure 7 shows the measurement of the sinusoidal signals which are recorded with the shielded sensor. It is obvious that the interferences of the signals can be reduced. In comparison to figure 6 the amplitude of the overlaid noise is much lower, but the quality of the signals is not exact enough to run the linear machine without any vibrations.

In the second optimization step the analog circuit is reduced because analog parts are vulnerable to interferences. Therefore the used hall sensor is replaced by a programmable one. In this context the above mentioned analog devices for the calibration and offset correction of the sensor can be left out. The block diagram of one new hall sensor is presented in figure 8.

An advantage of the sensor is the internal digital signal processing which enhanced the sensor accuracy and reduces the influence of manipulations by analog offsets, temperature shifts, and mechanical stress. In addition the sensor has an EEPROM memory and a serial interface for programming the EEPROM. This enables the calibration without changing the resistor ratio on the pcb. The parameters of the sensor can be changed even if it is mounted in the linear machine without dismounting. In conjunction with the new hall sensor the minimization of the pcb is the last optimization step. Therefore the devices are placed on a 4 layer pcb. In comparison with a 2 layer pcb the 4 layer pcb is just a little bit more expensive but it has the advantage of better EMC-compliances. Due to this property an expensive shielded box around the sensor is not necessary any longer. Consequently the 4 layer pcb is economical reasonable. Figure 9 presents the new functional description of the sensor. Three of the five operational amplifiers could be abandoned. The function of the sensor is still the same as before. The reduction of components causes a downsizing of the new pcb. The dimension is scaled down to 40% of the old one. Figure 10 shows the two sensors in comparison.
V. MEASUREMENTS

The optimized sensor gives the measurement results shown in figure 11. The position plotted in green cannot be distinguished from the reference position (blue) measured with a high precision optical position sensor. In difference to figure 5 the position error is magnified to a percent scale and plotted in red. The position error of this particular sensor had been reduced to 1.6% which is sufficient for the described application.

VI. CONCLUSION

The measurement results of the custom made position sensor shown in this paper have demonstrated the possibility of a low cost sensor with sufficient accuracy to provide the lower ranking position control loop. This sensor can be mounted inside of a permanent linear drive without extra space consumption. The costs of this sensor compared to a commercial optical sensor are very low.

REFERENCES
