Low Cost Position Sensor for Permanent Magnet Linear Drive

Ralf Wegener\textsuperscript{1}, Student Member, IEEE, Florian Senicar\textsuperscript{2}, Christian Junge\textsuperscript{2}, Stefan Soter\textsuperscript{1}, Member, IEEE

\textsuperscript{1}Institute of Electrical Drives and Mechatronics, University of Dortmund, Germany
http://eam.e-technik.uni-dortmund.de; Fax: +49 231 755 7374; ralf.wegener@uni-dortmund.de; stefan.soter@ieee.org

\textsuperscript{2}Electrical Machines and Drives Group, University of Wuppertal, Germany
http://www.ema.uni-wuppertal.de

Abstract—This paper deals with a custom made low cost sensor for measuring the position of a permanent magnet linear motor. The principle how to measure position and movement direction with two analog hall sensor elements is described. The following simulated and detailed error and failure treatment is very important to know exactly the performance and the possibilities of this low cost sensor element. Afterwards this position sensor is build and some measurements with a linear machine is done. After filtering, the accuracy of the two signals is high enough to be an input of a converter control to determine the correct current which has to be injected. If there is another higher ranking closed-loop control, e.g. pressure, flow or force, in the control system this low cost sensor is sufficient and works very well. It is possible to implement the very small sensor in the housing of the linear drive. This sensor costs less than 15 dollar and can not be compared to a very precise working linear sensor for some hundred dollar in order to position the linear drive very exact but the accuracy is high enough to build a lower ranking closed-loop control and to stabilize a complex control system of converter, linear drive and load.

Keywords—Position Sensor, Permanent Magnet, Linear Drive

Topic—Motor drives and motion control

I. MOTIVATION

In some application fields linear drives are not used for precise positioning but to regulate e.g. pressure, flow or force of an industrial process. If two parts have to be pressed together the force is the higher ranking closed-loop control and the position is only needed for lower control loops. In this cases it is not possible to control the linear drive sensorless, without any linear positioning sensor but the standard types with accuracies from 50\(\mu\)m up to 10\(\mu\)m are very expensive. In this application field a linear sensor with an accuracy of 200\(\mu\)m to 1mm is sufficient. New analog hall sensors are available on the market for less than two dollar. To build a positioning sensor with these attributes two low cost hall sensor elements, some surface mounted devices and a small pcb is enough. A requirement is, that the permanent magnets provides a sinusoidal field outside the winding area of the linear drive, which is fulfilled in most cases in an optimal distance. This small linear positioning sensor can be mounted nearby the magnets and the windings and needs no extra space like a conventional linear sensor.

II. MEASUREMENT OF THE MAGNETIC FIELD

The magnetic rotor field of a permanent magnet linear motor outside the stator windings has different shapes depending on the distance of measurement. At the surface of the magnets the field has a nearly rectangular characteristic. When the distance between sensor and magnets increases the shape becomes softer and in the optimal position the curve can be described as a sinu-

Fig. 1. Characteristic of the magnetic field based on the permanent magnets on the rotor, measured in the optimal distance.

Fig. 2. Sensor element for measuring the magnetic field using the hall effect.
soidal wave along the rotor of the linear machine. It is based of the permanent magnets stringed together in opposite magnetic directions shown in figure 1.

The magnetic field can be measured using the well known Hall-Effect with a sensor shown in figure 2. The magnetic field $B$ is penetrating the sensor element which is fed with a constant measurement current $I$. The Hall effect diverts the electrons which results in a voltage $U_H$ measurable in orthogonal direction of the sensor element. The voltage $U_H$ is proportional to the absolute value of the magnetic field like in equation (1).

$$U_H = \frac{1}{n \cdot q} \cdot \frac{I \cdot B}{d}$$  \hspace{1cm} (1)

The principal function of the sensor is proven by the simple measurement of the magnetic field relative to the position of the armature shown in figure 3. The measured signal, printed in green, is approximated with a sinusoidal signal with the error printed in red.

### III. Constructed Sensor

To give the possibility to determine the direction of the movement it is necessary to measure the magnetic field with two sensors in a distance of 90° of the sinusoidal approximation. This equals the half length of the magnet.

The measured signals have to be adapted to the inputs of the converter. This is done by an operational amplifier with a differential output and a second operational amplifier to correct the offset of the sensor. The circuit is shown in figure 4.

### IV. Possible Errors

In the following chapter the possible errors of the position sensor is researched. This is done by simulations of the incorrect sensor signals with determination of the position error.

#### A. Reduced Amplitude

The first possible error is an unbalanced gain of the operational amplifier or the sensor in one direction as shown in figure 5. The same error can be caused by an unequal magnetization of the positive and negative magnet which is much more likely. In the simulation the magnetic field of the magnets with the north pole in front of the sensors is scaled by 0.7. As shown in figure 6 the maximum position error is around 10°. In a real linear machine, which is also used for measurements, this equals a distance of 1.7mm because the magnets are arranged with a period of 60mm. This is an error of approximately 2.8%.

#### B. Phase Error

As described in chapter III the position sensor consists of two separate hall sensors which are positioned with an angle of 90° relative to the magnet period. The exact distance of the sensors can be varied because of factory tolerances. In the simulation the
two sensors are positioned with an extra distance of 1mm which equals an angle of 96°. The results are shown in figure 7. This error results in a permanent offset of the measured value related to the calculated position. This is irrelevant for the position control, because the position is measured in a relative way and the offset is neglected. In addition the position signal is deformed in a nonlinear way, caused an absolute position failure in the area of 1mm.

C. Range Error

The magnetic field of the used permanent magnets is too high for the used hall sensors. Therefore the sensors distance to the magnets have to be increased till the sinusoidal signal is not cut any longer at high amplitudes. In case of an overload of the two sensors the measured values are shown in figure 8. The calculated position results in an error but this failure can be easily detected (see figure 9). Because of that the overload condition is not relevant to the motor control.

V. MEASURED RESULTS

In order to test the built sensor it is mounted at a distance of approximately 20mm in the above mentioned reference linear drive in orthogonal direction from the permanent magnets of the armature. This is now moved with a fixed speed and the measured signals are recorded. The results are shown in figure 10. The two sinusoidal signals are faulty at two positions. This is explainable with the near placement of the sensor to the coils which currents interferes with the signals.
The measurement can be visualized in x-y diagram (figure 11) where the sine and cosine signals are plotted in both axis. With an optimal sensor the resulting diagram has to be a perfect circle.

VI. BUILT FILTER

The results of the built filter structure are shown in figures 12 to 15.

The position signals, presented in figure 12, are measured with a movement of the armature in both direction for approximately 10cm. These signals are filtered in order to produce a suitable position signal shown in figure 13. The interference of the coil current is magnified in figure 14. The noise is pulsating because the current in only one coil nearest to the hall sensors interferes the measurement. The resulted position signal is compared to the reference signal measured with a 10µm optical linear sensor in figure 15. The absolute error of the position is very low during the whole measurement range.

VII. CONCLUSION

The simulation and measurement results, shown and described in this paper, have demonstrated that it is possible to build a low cost linear sensor with elements available at the market. The dimensions are small enough to implement the sensor pcb in the linear drive itself in order to need no extra space and to get a compact linear drive system. If the highest ranking closed-loop control is not the position, the accuracy of the custom made sensor is sufficient to be a part of the lower ranking converter control system. With very low costs of less than 15 dollar this linear sensor can be used in spite of the very expensive standard solution. Further detailed measurements have to be done to improve accuracy and interference resistance.

REFERENCES

[5] Yong Ho Yoon; Mu Sun Woo; Seung Jun Lee; Chung Yuen Won; You
