Design of Hall Effect Gear Tooth Sensors by Using Magnetic Field Simulation

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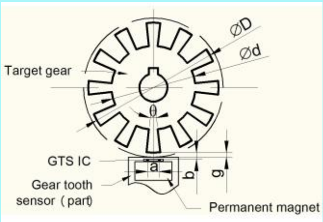
1. Hall Effect Gear Tooth Speed Sensors

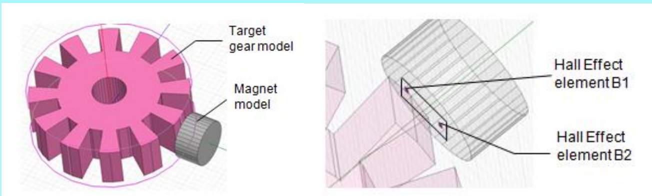
- Hall Effect gear tooth sensors are widely used for rotational speed measurements.
- The sensing distance of a Hall Effect gear tooth sensor can be improved by using a Hall GTS IC based on differential magnetic field detection:



- Two Hall Effect elements, which are positioned in distance a, and built in the GTS IC, are used for detecting the magnetic field change during the rotation of the target wheel. The GTS IC generates output impulses by using the difference between the output voltages of the two Hall Effect elements caused by differential magnetic field.
- The goal of developing such a measuring system is to get duty cycle 50% of output signal and a large sensing gap, which is more convenient for applications.
- This type of gear tooth sensor was used as example for the magnetic field simulation.

2. Magnetic Field Simulation (MFS)

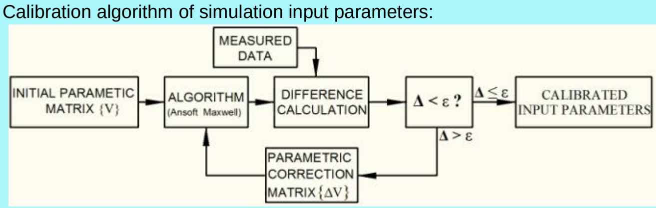
- The task of the magnetic field simulation (with Ansoft Maxwell) is to calculate the magnetic flux density passed through the two Hall Effect elements on the GTS IC during rotating the target gear.
- Target gear, permanent magnet and Hall Effect GTS IC under simulation:



- The differential magnetic flux density between the two Hall elements is approximate to a sinusoid function.
- The output impulse of the GTS IC can be generated by using a digital detection algorithm according to the operating point and releasing point of Hall GTS IC.
- The duty cycle and maximum sensing distance can be determined after simulation.

3. Calibration Algorithm

- The accuracy of the simulation mentioned above cannot be satisfied with the design of Hall Effect gear tooth sensors because the simulation system is not calibrated.
- Therefore the input parameters of the MFS must be calibrated by approximating the magnetic flux density calculated by the Ansoft Maxwell simulation to the corresponding value measured with a Gaussmeter.
- Calibration algorithm of simulation input parameters:



- Relative error between simulation and measured flux density (with CYGTS101DC-S):

Air gap g (mm)	1.5	2	2.5	3	3.5
Error of B_{max} (%)	-1.95	-0.58	0.19	0.50	0.78
Error of B_{min} (%)	2.00	1.42	1.09	0.73	0.85

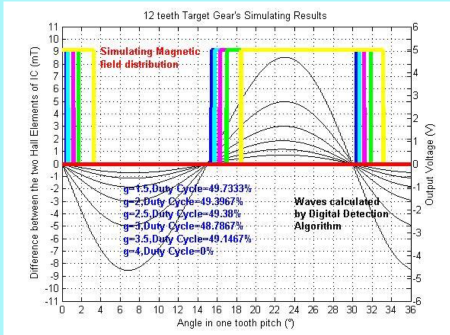
- The relative errors are limited within ±2.0%.

5. Application to Speed Measurement of Rotors

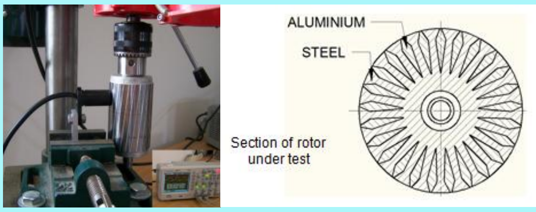
- The methods mentioned above are applied to the design and optimization of rotational speed measuring systems.
- **Task 1:** A suitable sensor should be designed by simulation under optimizing the magnet parameters (sizes, material and grade) and Hall GTS IC. In this case the target gear is existed and cannot be changed.
- The Hall gear tooth speed sensor CYGTS101DC-S is designed in this way.
- Comparison between simulation and measured duty cycle of sensor CYGTS101DC-S:

Sensing gap (mm)	1.5	2	2.5	3	3.5
Duty cycle η_m(%)	49.2	49.5	50.2	50.3	50.8
Duty cycle η_s(%)	49.4	49.7	49.2	49.3	48.9
$(\eta_s - \eta_m)/\eta_m$ (%)	0.4	0.4	-2.0	-2.0	-3.8
$(\eta_m$-50)/50 (%)	-1.6	-1.0	0.4	0.6	1.6

- After the optimization the duty cycle of the output impulse of the sensor is about 50% with relative error within ±2%, and the sensing gap reaches 3.5mm.
- Simulation results with 12 teeth gear:



- Speed Measurement of rotor with Hall Effect Gear Tooth Sensor CYGTS101DC-S:



- **Task 2:** The sensor used under simulation is already optimized. In this case the target wheel (teeth number, tooth shape and height) should be optimized by simulation for special applications.
- Duty cycle of sensor CYGTS101DC-S under using different target gears:

Air gap(mm)	1.5	2.0	2.5	3.0	3.5	4.0
Gear 1 (with 6 teeth)	46.1	43.8	42.5	42.1	41.7	40.6
Gear 2 (with 12 teeth)	49.4	49.7	49.2	49.3	48.9	-
Gear 3 (with 18 teeth)	49.4	48.8	51.5	-		
Gear 4 (with 20 teeth)	52.4	50.0	-			

6. Conclusions

- The magnetic flux density passed through the Hall elements in a Hall Effect gear tooth sensor can be calculated by magnetic field simulation effectively.
- The sensor output impulse can be generated by a digital detection algorithm under using the simulation magnetic field density and according to the operating and release points of the Hall GTS IC.
- In order to improve the accuracy of the magnetic field simulation, the simulation algorithm must be calibrated by using reference measuring value. The accuracy of the magnetic field simulation can be improved by using the proposed calibration algorithm of simulation input parameters. It can be controlled within ±2.0%.
- The proposed methods are applied to the design and optimization of speed sensor CYGTS101DC-S and its target gear. After the optimization the duty cycle of the sensor output impulse is about 50% with relative error within ±2%, and the sensing gap reaches 3.5mm.
- The developed Hall Effect gear tooth sensor is applied to measure the speed of motor rotors and other rotational machines with good results.

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