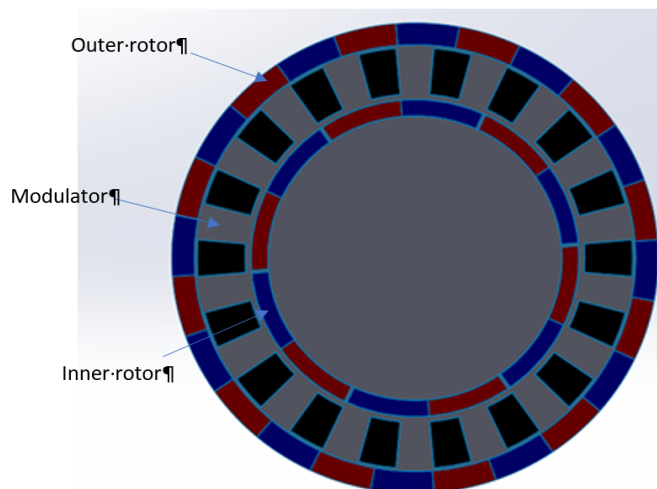


# Magnetic Gear Analysis, Optimization and Construction using EMWorks2D

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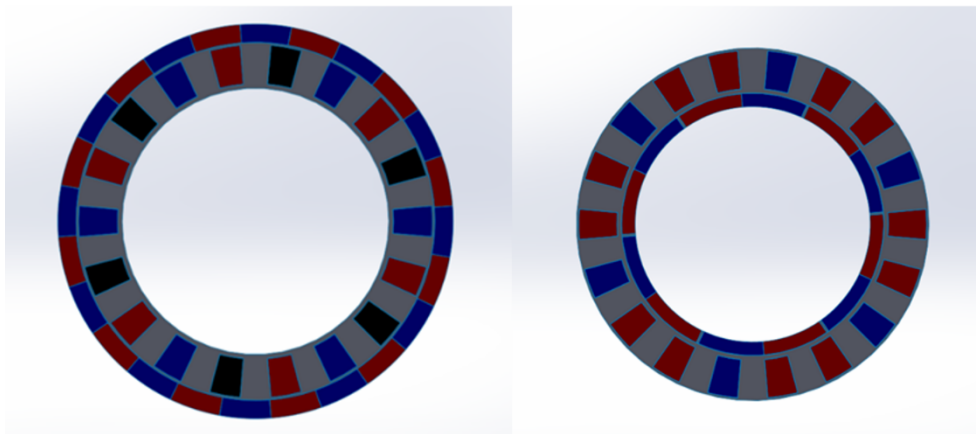
My Bachelor thesis consisted of researching, simulating and building a concentric magnetic gear. Figure one shows the three main components of a magnetic gearbox: The inner rotor, the modulator and the outer rotor. Unlike any other gearbox one of the components must be fixed, while the other two can rotate. On my gearbox I fixed the modulator. The magnets are radially oriented, which means their south-pole or their north-pole are facing to the center of the gearbox.



*Figure 1 Main components a magnetic gearbox*

In order for a magnetic gearbox to work, the number of the pole-pairs on the inner and outer rotors combined must equal the number of iron-pole pieces in the modulator. One magnetic pole-pair consists of two magnets, when they are arranged in a conventional layout like in figure one. If they are arranged in a Halbach-array, four magnets are required.

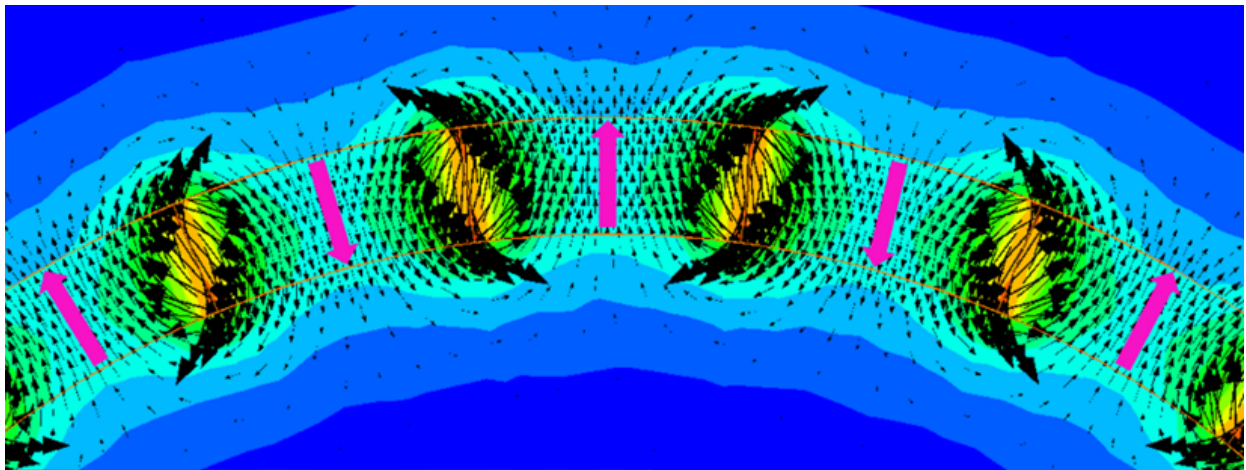
The gearboxes which I simulated consisted of twelve pole-pairs on the outer ring and six on the inner. Figure two shows the effect of the modulator. The radial component of the magnetic flux of the outer magnets gets modulated by the iron pieces. The iron pieces modulate the magnetic flux to get six



pole-pairs on the inner air gap. The number of pole-pairs of the modulator then matches the number of pole-pairs on the inner ring. When you look at the magnetic flux generated by the inner magnets, the modulator forms twelve pole-pairs, which interact with the outer magnets.

In my bachelor thesis it was important to calculate the maximum torque, which can be transmitted and the magnetic flux in the air gaps. Both tasks are easy to accomplish thanks to EMWorks simulation solution EMWorks2D.

One of the fundamental questions was, which layout gives better results, a conventional or a Halbach one? NASA also built two magnetic gearboxes and their report suggested that a Halbach layout can transmit more torque. Figure three shows the magnetic flux density of a conventional layout while Figure four displays the magnetic flux density of Halbach layout.



The red circle shows one pole-pair. The Halbach array can concentrate the magnetic flux to the inside, which is desired on the outer rotor.

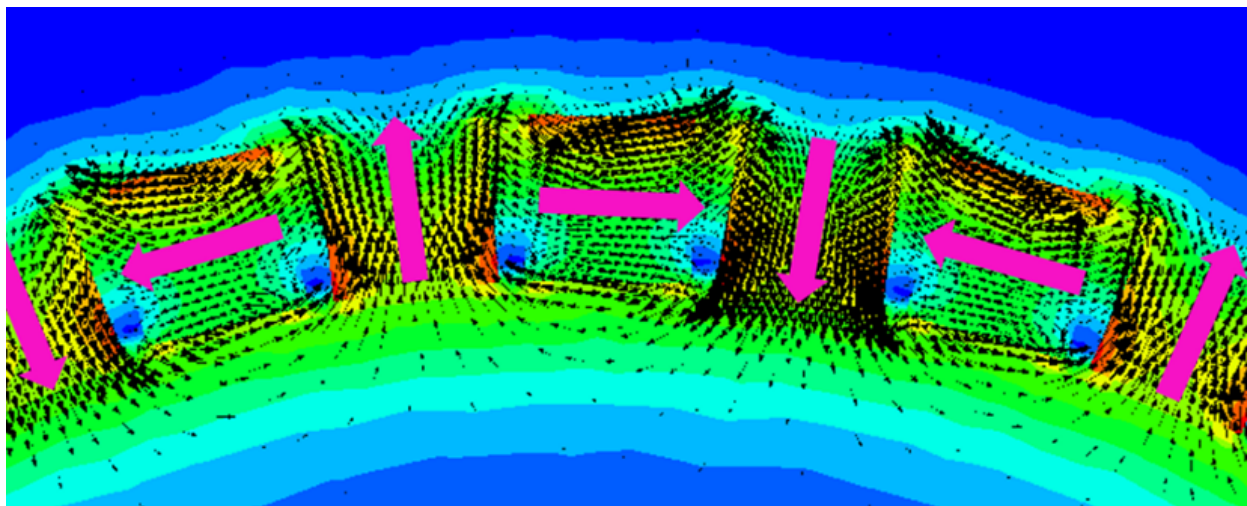


Figure 4 Magnetic flux density of Halbach Rotor layout

The cross-section of both gearboxes can be seen in figures five and six.

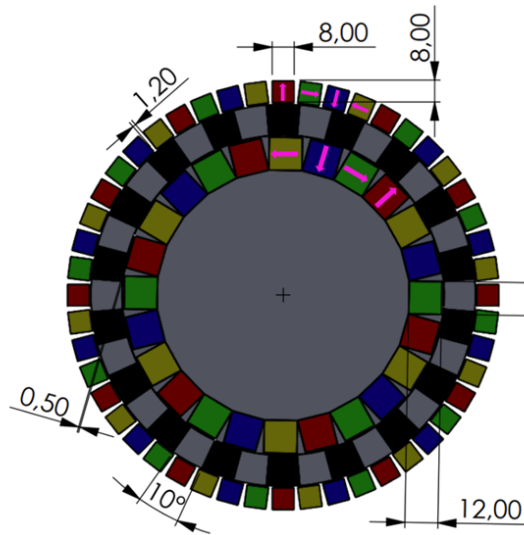


Figure 5 Cross-section of the Halbach-gearbox

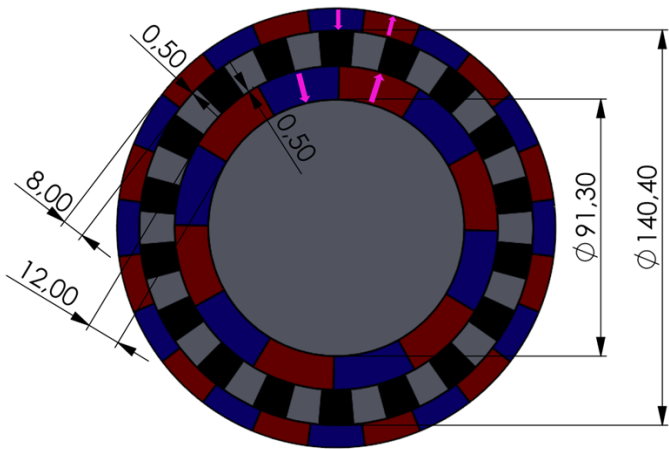
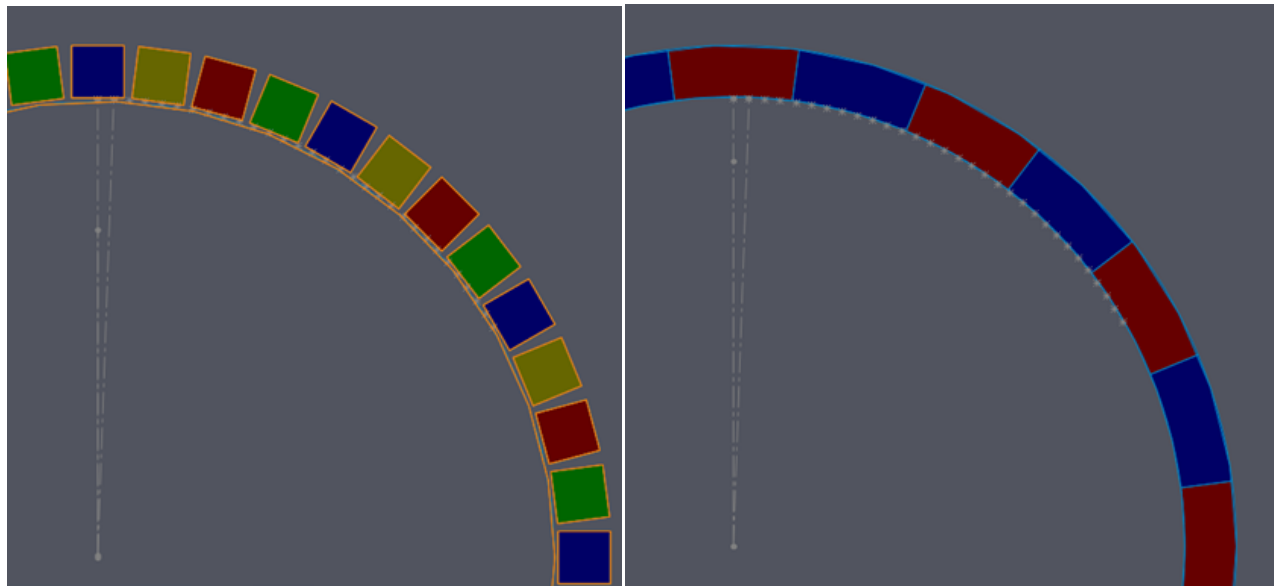


Figure 6 Cross-section of the conventional gearbox

The torque which can be transmitted is dependent on the radial flux component generated by the magnets. In order for the gearbox to operate properly the flux-distribution has to look like a sinus-wave. To examine the radial flux, 30 points which “measured” the magnetic flux, were created along the magnets. With EMWorks2D it is possible to automatically generate multiple points, between two manually generated points. So, it is easier to obtain a high resolution when the flux is plotted on a diagram. Figures seven and eight show the location of the manually generated points.



The x and y-components of the measured flux have to be converted into the radial component. It is a simple Excel task. As seen in figure nine, the Halbach-layout has a higher magnetic flux and is similarly shaped like an ideal sinus wave. The Fourier-spectrum, which depicts the harmonic flux distribution (figure 10), demonstrates that the Halbach-Rotor has much higher unwanted harmonics. This leads to a higher transmittable torque and also a smoother torque-curve as seen in figure eleven.

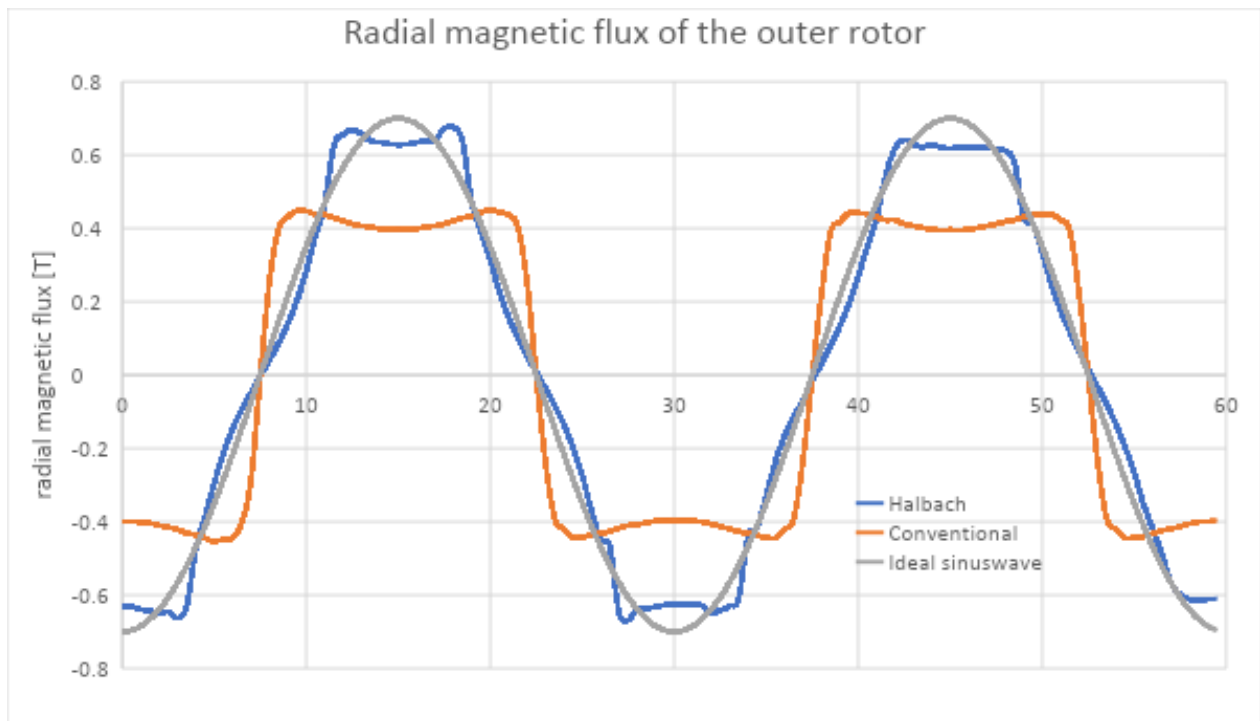


Figure 9 Radial magnetic flux of the outer rotor

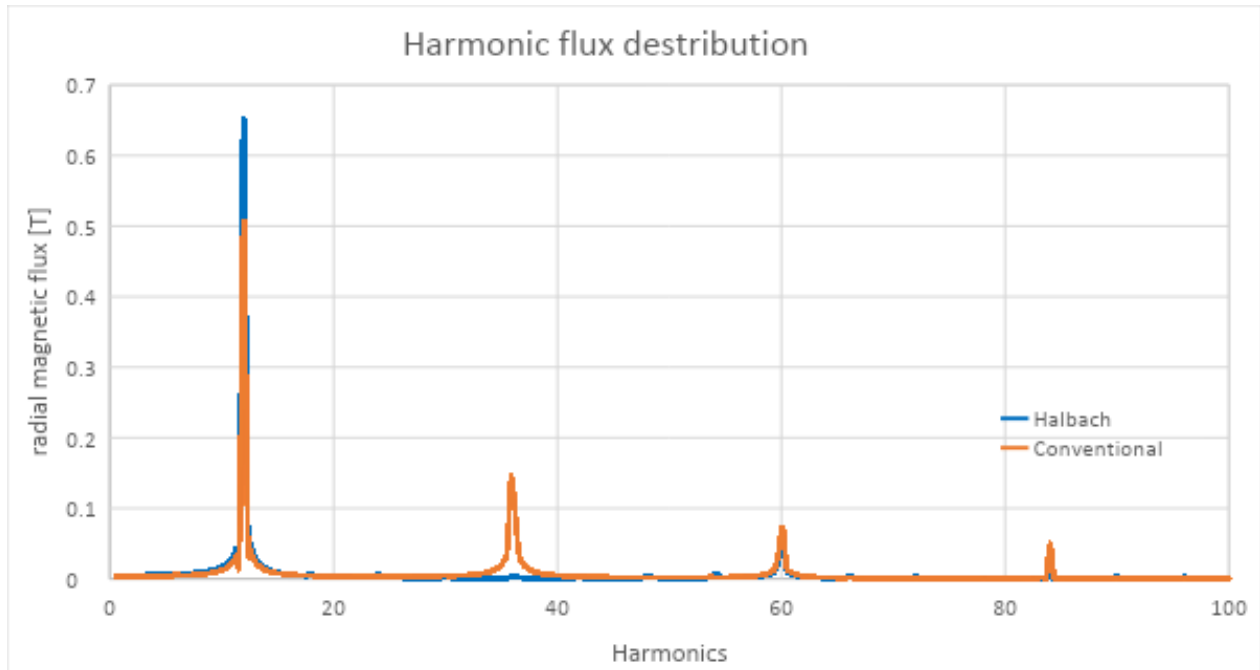


Figure 10 Harmonic flux distribution

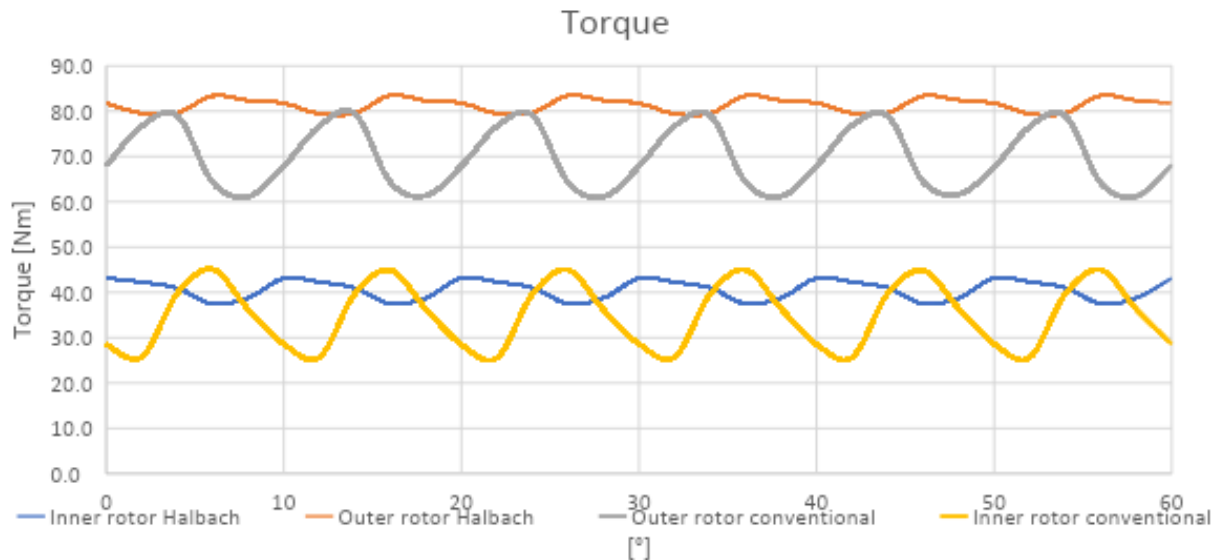
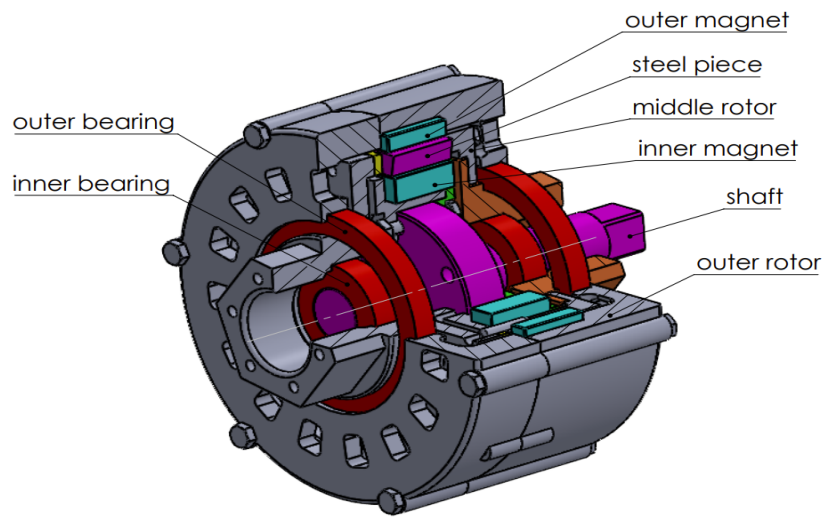


Figure 11 Torque-curves of the Halbach and conventional gearbox

The simulations corroborate the idea that the Halbach layout is superior to the conventional layout. The form of the modulator has been altered over 20 times in order to increase the torque in the later generation. This process was very easy since EMWorks2D is seamlessly integrated inside SOLIDWORKS. The maximum torque is restricted by the inner rotor. In an ideal gearbox with the same transmission ratio the inner rotor should transmit half the torque of the outer, but it's lower in this case (see figure 11). The minimum inner torque can be increased from 37,5 Nm to 39,6 Nm by changing the modulator.

A 3D-printable CAD-model which was based on the simulation was constructed (figure 12) and built (figure 13). The inner torque of the real gearbox is 30 Nm. It is lower than simulated one because the end effects are neglected in a 2D-simulation.



EMWorks2D made the simulation of the magnetic gearbox an easy task with its user-friendly interface, smooth workflow, and seamless integration inside SOLIDWORKS. It was very useful for my application and helped me obtain my simulation results in a short period of time. I would recommend it for students who are working on symmetric models. Thanks EMWorks team for your support!

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