Transfer of torque using magnetic couplings

Made by TechnoFlex in collaboration with BuusMag

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Version: 1.1 – 2024

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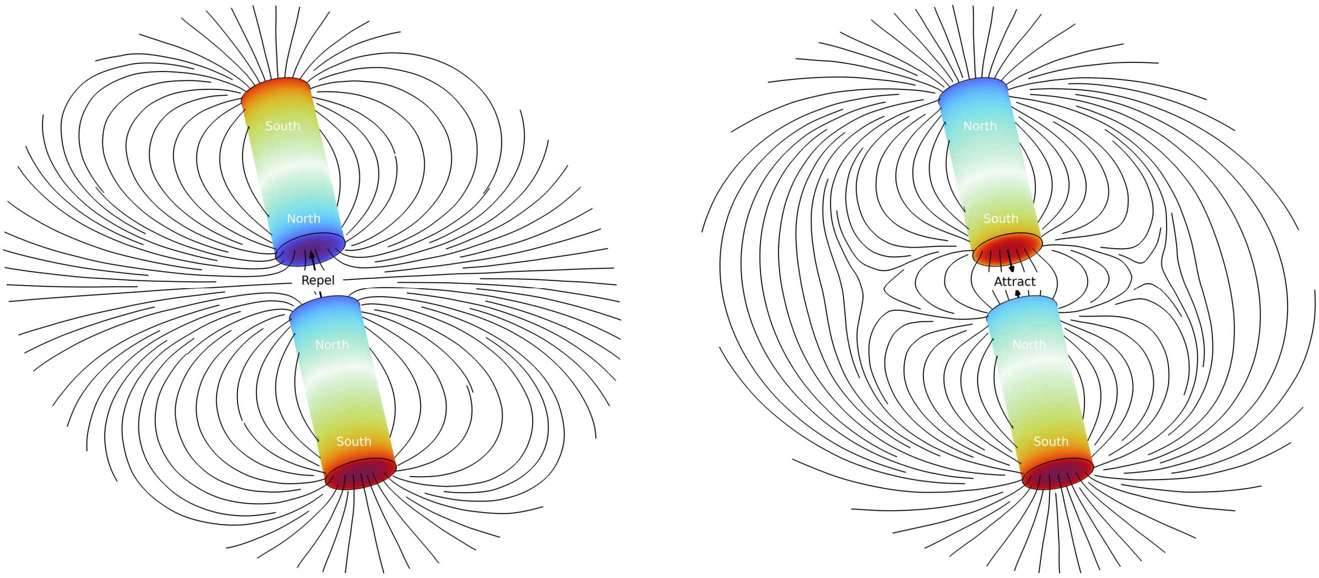
Introduction

Magnetism is a phenomenon that is magical to many people. Think about the first time you played with a magnet and felt its invisible force pull or repel other objects. Magnetism plays a crucial role in everyday life, from powering electric motors to guiding compass needles. It's a fascinating force that continues to captivate scientists and inspire technological advancements. Below are two illustrations showing 2 magnets each that repel (left) and attract (right) each other. The colours show the magnetic scalar potential, and the lines show the flux lines that runs from pole to pole. Flux lines can be thought of as rubber bands. If the rubber bands (flux lines) shared by the magnets are stretched, they would like to attract the magnets (right). And if they are pushing together by the other magnet, they repel each other (left).



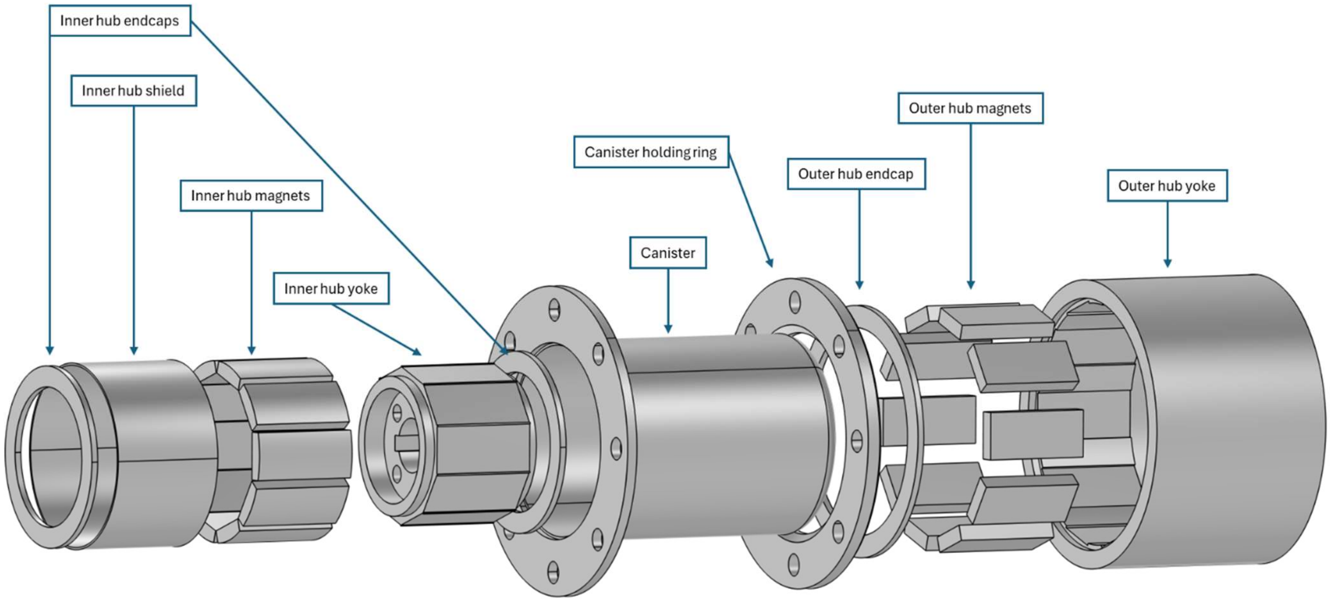
Permanent magnets trap the magnetic field when they are magnetised. They can be used to transfer force and torque from one object to another, without physical contact. The force and torque can cross almost any material. Iron, nickel, and cobalt, however, can partially shield and direct a magnetic field.

Rotating machines are one of the most widely used technological applications of magnetism. Magnetic couplings are mechanisms that use magnetic fields to transfer torque from one rotating shaft to another without direct mechanical contact. They consist of two sets of permanent magnets separated by a non-magnetic barrier, called a canister, typically made of materials like ceramics, stainless steel or plastic.

When one set of magnets rotates, it creates a rotating magnetic field that passes through the barrier and interacts with the other set of magnets, causing it to rotate as well. This allows torque to be transmitted between the two shafts while maintaining a hermetic seal, preventing leakage of fluids or gases. Magnetic couplings are commonly used in pumps, mixers, and other machinery where a sealed connection is required, such as in chemical processing plants or medical devices. They offer advantages such as reduced maintenance, improved reliability, and increased safety compared to traditional mechanical couplings.

Description of components

This illustration shows the components of a 10 poled magnetic coupling. All the individual parts are assembled to 3 units called an outer hub, a canister and an inner hub.



Permanent magnets

The permanent magnets in the hubs generate the flux between the couplings. The units of flux density is measured in Tesla. The flux varies with temperature and depends on the material type used. Care must be taken not to overheat the magnets, because this could demagnetize parts of the magnets. We have more than 25 years of experience with permanent magnets and how to select and use the magnets correctly without the risk of demagnetization. Here is a list with some of the most popular permanent magnets.

Parameter	Description	Sintered NdFeB	Sintered SmCo	Ferrite SrFeO
Remanence [T]	Torque is proportional to remanence squared	1.05 to 1.45	0.81 to 1.10	0.25 to 0.43
TBr[%/°C]	Temperature stability of flux	-0.11	-0.05 to 0.01	-0.2
T maximum [°C]	The maximum temperature	70-240	250-450	250
T minimum [°C]	The minimum temperature	-200	-100	-40 to 0
Price index [%]	Price index relative to N45	100-250	250-500	10-20

Back iron

The permanent magnets are connected/glued together with the back iron, which carry the magnets and transfer the torque. It also increases the flux and therefore the peak torque of the coupling considerably because it makes an easy passage for the flux from one magnet/pole to the next. Back iron is typically made of pure iron, with low carbon content.

Shaft connector

Connection of the back iron to the shaft is sometimes carried out by a connecting unit. It also works as a protection of the back iron and magnets. Therefore, it is often made of stainless steel, which is very strong and corrosion stabile.

Canister

The canister is a very important component in the coupling if separation of media and environment is necessary. It is a component with multiple functionalities, which affect the size, production method and selection of materials. See more in section about pumps and mixers.

Connection to drive and driven part

The inner and outer hub of the magnet coupling can be connected in numerous ways to both the drive (i.e. electrical motor) and the driven part (i.e. a centrifugal pump). This could for example be a simple round shaft with a bolt, a shaft with a notch/key or a spline (https://en.wikipedia.org/wiki/Spline_(mechanical)). At TechnoFlex we customize every pump we deliver.

Applications

Magnetic couplings can be applied across a variety of different applications and products. Here we describe some of the most popular applications.

Pumps

Here the outer hub is typically connected to an electrical motor, using a spline or a notch/key. The inner hub is connected to a shaft that is kept in place, but still able to rotate, by a wet bearing system and the shaft is connected to a centrifugal pump. The pump is placed inside a hermetically sealed system, by the canister between the inner and outer hub. In this way the media is separated from the surroundings. This has two benefits, the media cannot escape or leak from the container/pipes, and the nonsterile environment cannot pollute the pumped media. At the same time there can be huge differences of the temperature of the media and the motor. Some of our couplings can be used to pump 350°C hot fluids/media using SmCo magnets. We are also developing a new type of coupling capable of withstanding more than 600°C in the media.

The magnet coupling is a good replacement for a rotating sealing. Because it removes the problems with wear and tear leading to leakage and it keeps the media separated from the environment even if the media is under high pressure.

Mixers

In the food and chemical industry, the process of blending different medias in a big container often is done by a spinning/cutting/grinding mixer head. Just like in the above case, the mixing can be done in a hermetically sealed environment, by using a magnetic coupling.

In pumps and mixers one of the hubs often come in contact with aggressive or sensitive materials. We have several possibilities to coat and protect the magnets against corrosion, but we often end up encapsulating the hub fully in a hermitically sealed stainless steel can.

Torque limiter

The magnetic coupling can also be used as a torque limiter. Due to the reliability and precision of the magnetic coupling, it can effectively limit the torque i.e. on grinders. If the torque is suddenly increased above the peak torque of the coupling, the coupling slips one or more pole pairs. This protects the motor and the grinder from extreme forces, that potentially can destroy the components. Compared to torque limiters made mechanical pressurized connections the torque is much more consistent and precise and not affected by wear and tear.

Alignment

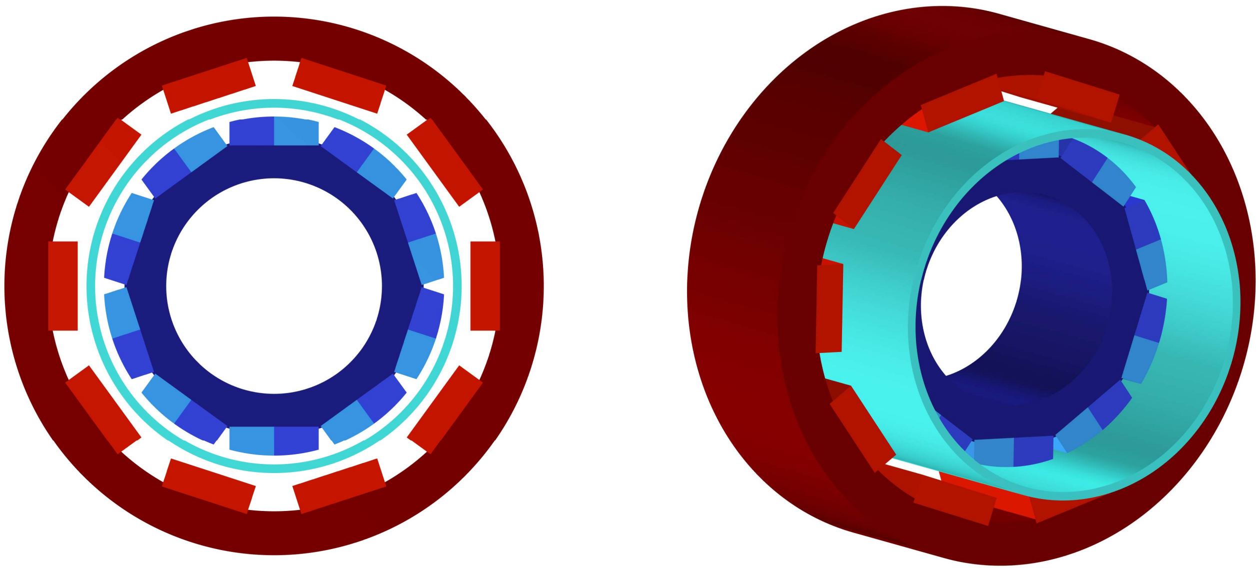
If two rotating shaft with individual bearings have to be connected, they have to be mechanically aligned very precise, to avoid uneven loading and premature failure of the bearings. Alternative to this, they can be connected through a soft or flexible component or a magnetic coupling. The advantage of the magnetic coupling is that the alignment of the shafts doesn't have to be very precise and that there is no wear on the coupling.

Calculation of performance

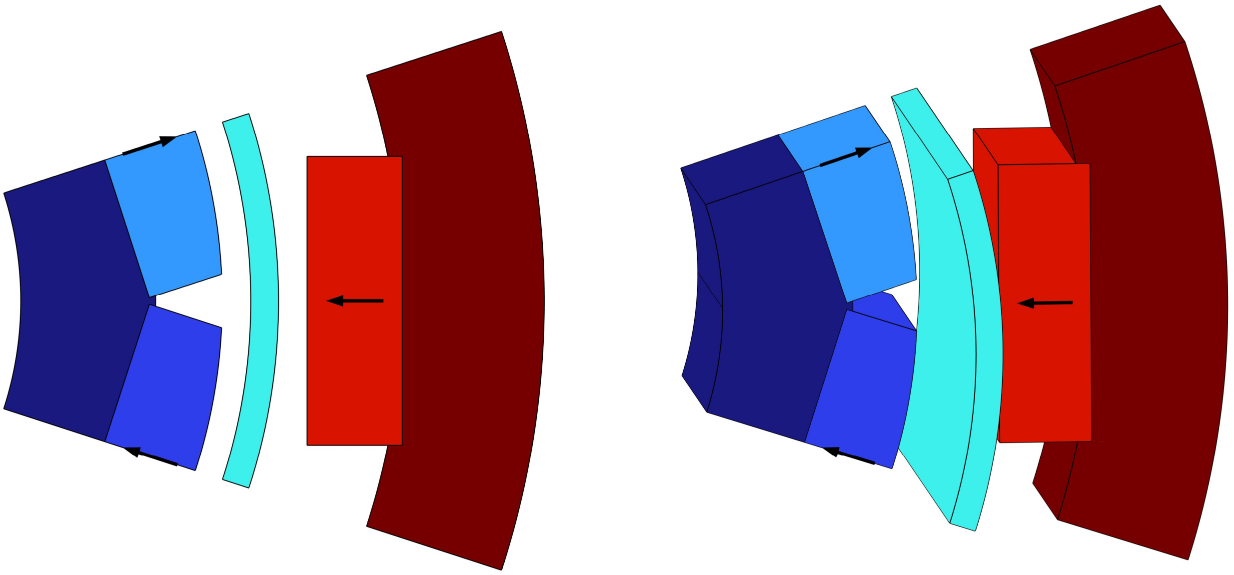
Development

At TechnoFlex, we collaborate closely with you, our customer, to develop magnetic couplings. We can fine tune and optimize the coupling peak torque, size, price, pressure, temperature, and corrosion stability.

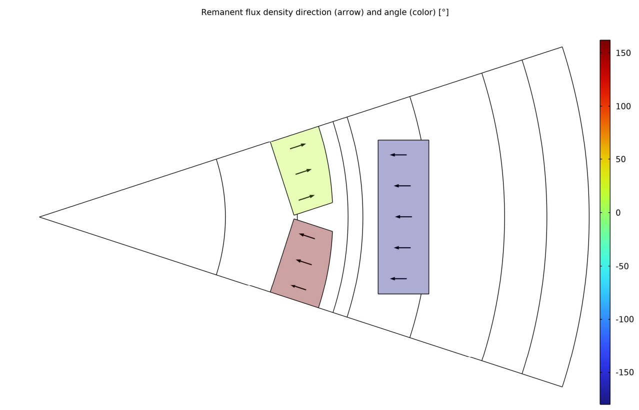
First, we build a finite elemente model of the electromagnetic part in the coupling. The modelled parts are shown below. The dark red is the outer hub back iron, that guides the flux from the outer magnets (light red). The canister inside (cyan) is modelled as a ring. Inside the dark blue region is the inner hub back iron, and the lighter blue colours show the inner magnets.

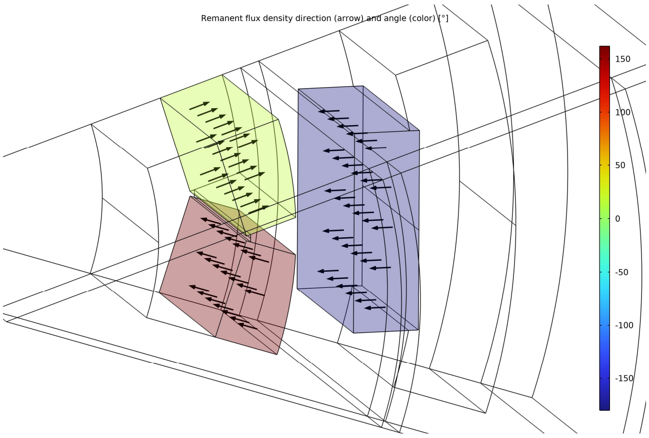


There is symmetry in the magnet coupling, and this can be used to simplify the model, and make the simulation faster and more precise. Only one pole and half the length of the coupling is modelled. This can be seen below where only one pole is shown. At the same time the arrows indicate the magnetization direction of the magnets. Note the angle difference between the hubs, this is called the torque angle, and in this case the angle is defined to be 90°, because the coupling is identical for every 360°. At 90° the torque is maximum.

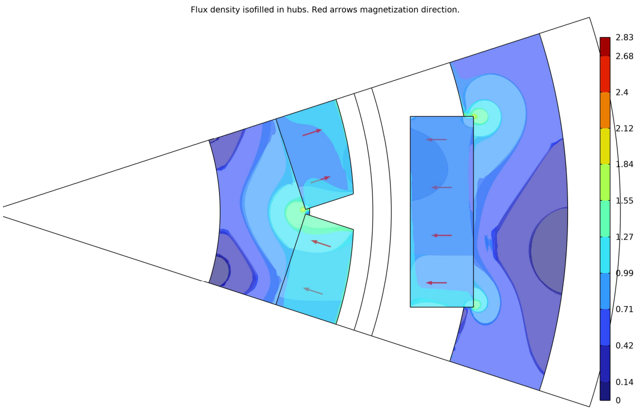


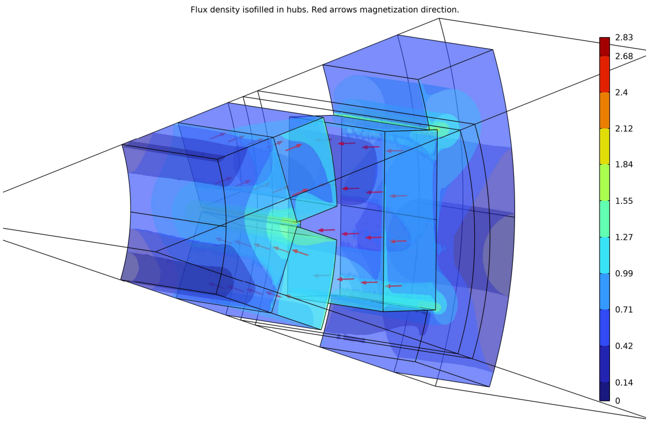
The simulation is run and the magnetization direction and angle (colours) are checked.



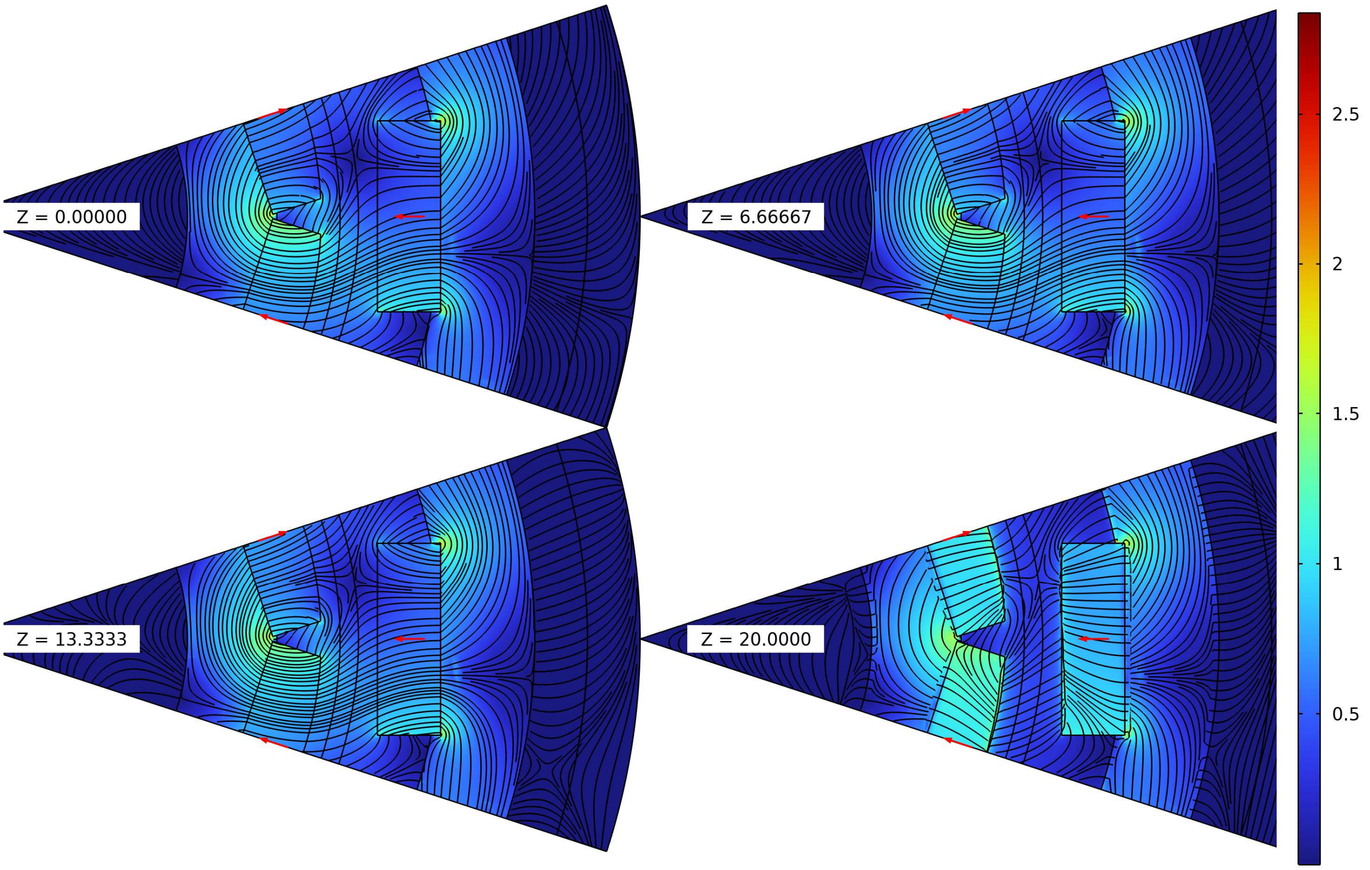


Here the flux density in the materials is shown with different colours in zones.

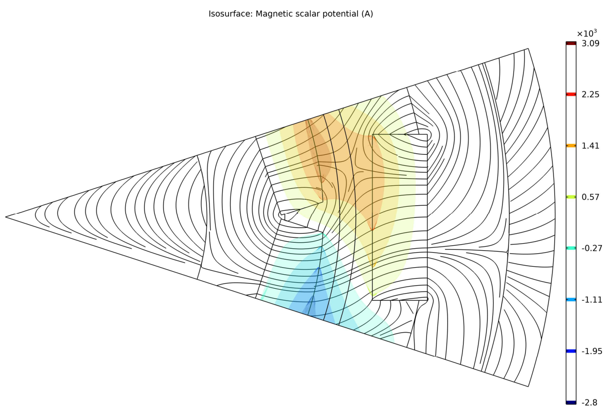


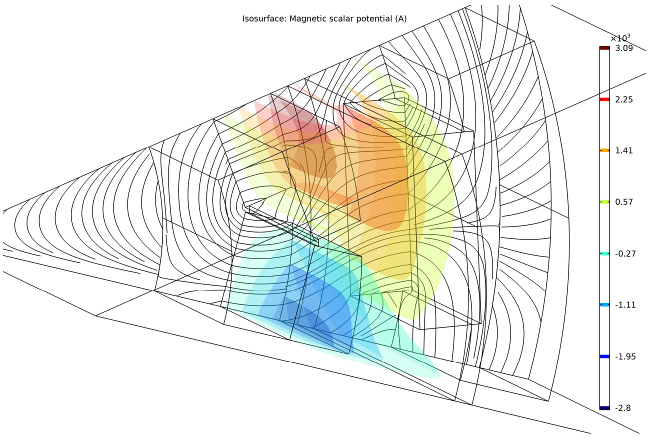


We plot in different ways to highlight different details, in the next plots the flux density in the air is also shown. Here the colours again show flux density amplitude, and the black lines are flux lines, the red arrows are the magnetization direction. The coupling is plotted at different axial cut planes.



Next the magnetic scalar potential iso-surface plot is shown as colours, and the flux lines at a plane perpendicular to the shaft in the centre of the coupling.

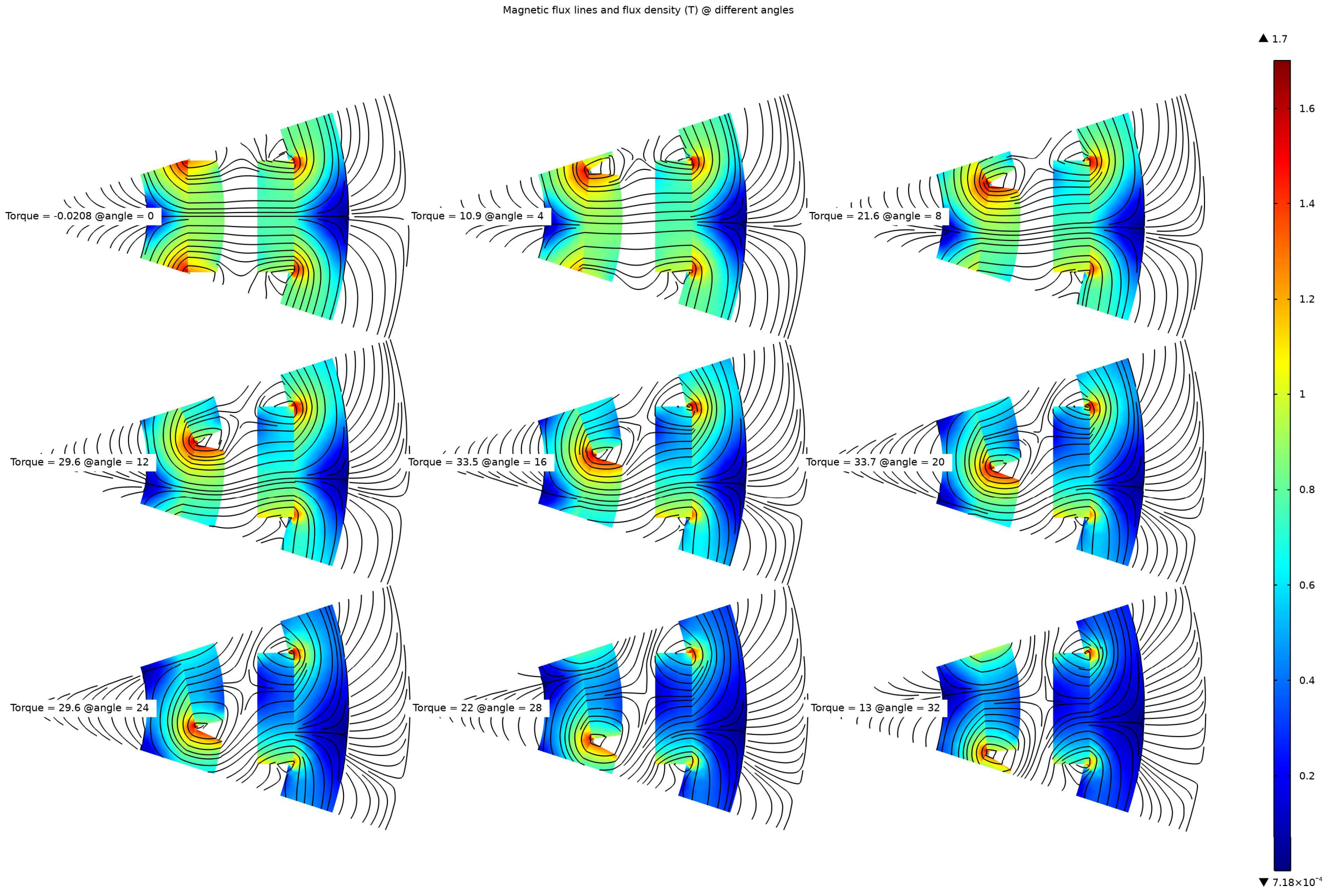




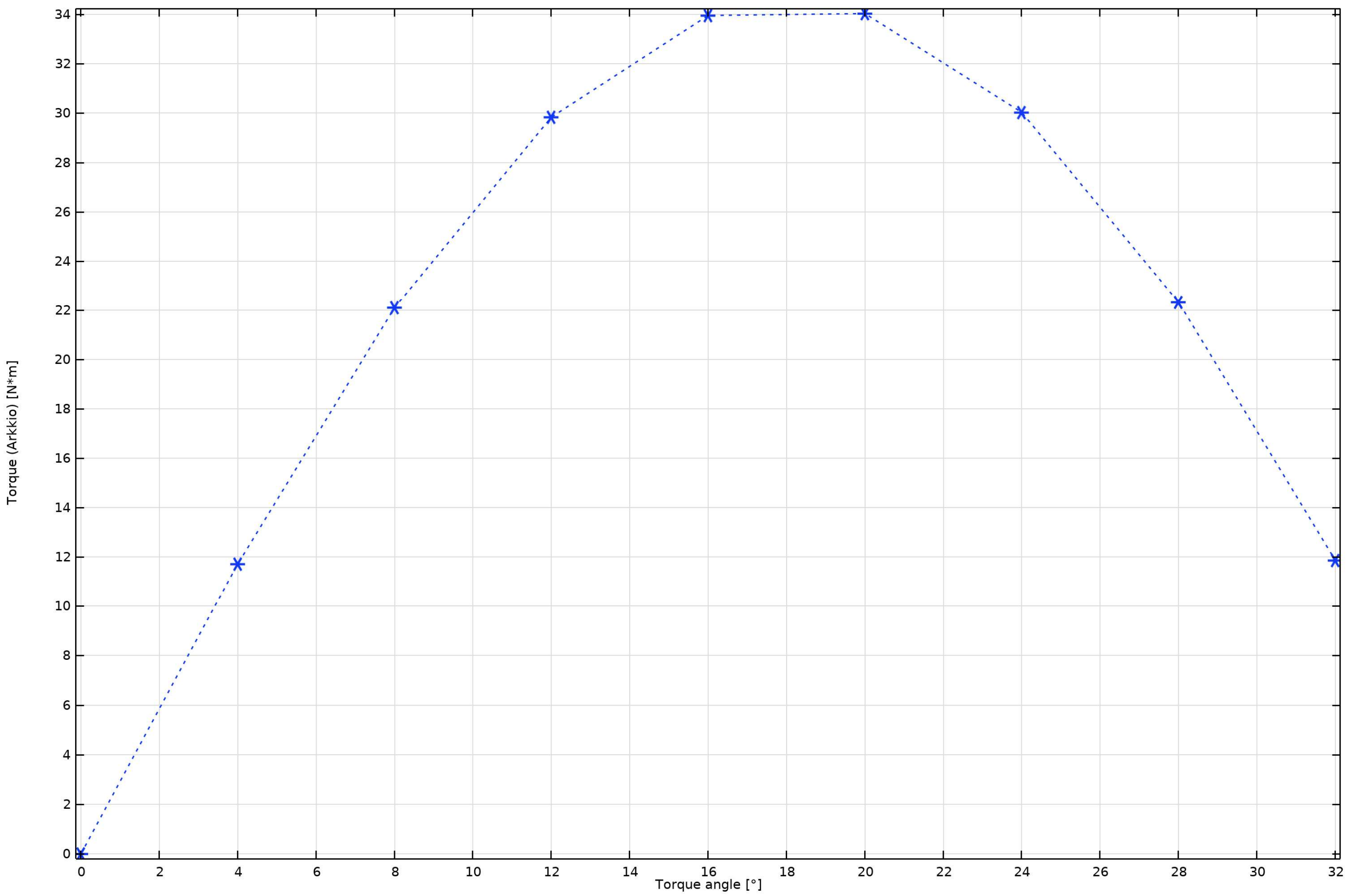
Peak torque

When the two hubs are put together in the application, they align in a relaxed starting angle, where no torque is transferred. If this angle is increased or decreased a torque will be transferred from one hub to the other.

Below the torque, flux lines and flux density is shown for 9 different angles.



The torque can also be plotted as a function of the angle, see below.



The peak torque is found between 16° and 20°, which fit with the theoretical angle peak torque angle (θ_{peak}), which is 18°. Calculated simply by $\theta_{peak} = \frac{360°}{2 \cdot Poles}$, where Poles is the number of poles on each hub.

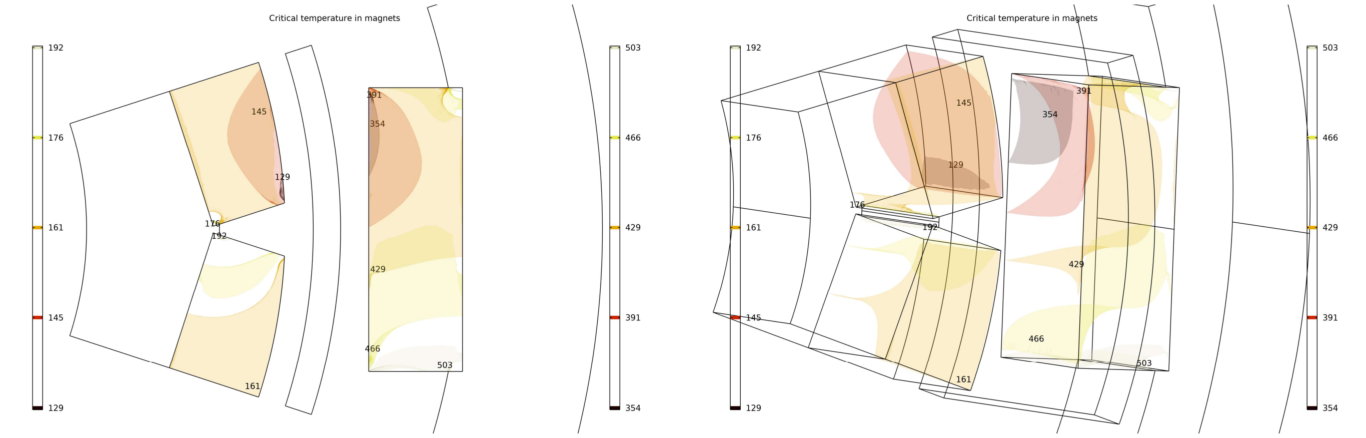
The peak torque is calculated using different methods to evaluate when the mesh (accuracy) is good enough. In this case we get 34.5Nm @ 20°C. But note that it depends on the temperature. At 100°C on both hubs, the peak torque is reduced to 29.8Nm.

The torque depends heavily on the size of the outer diameter and length of the coupling, but also the distance between the inner and outer magnets, called the air gap, is very important. The number of poles also change the torque for a given size of coupling. Few poles typically is optimal if the air gap is big relative to the other measures, and in case a smaller relative air gap is obtainable, the optimal number of poles is high.

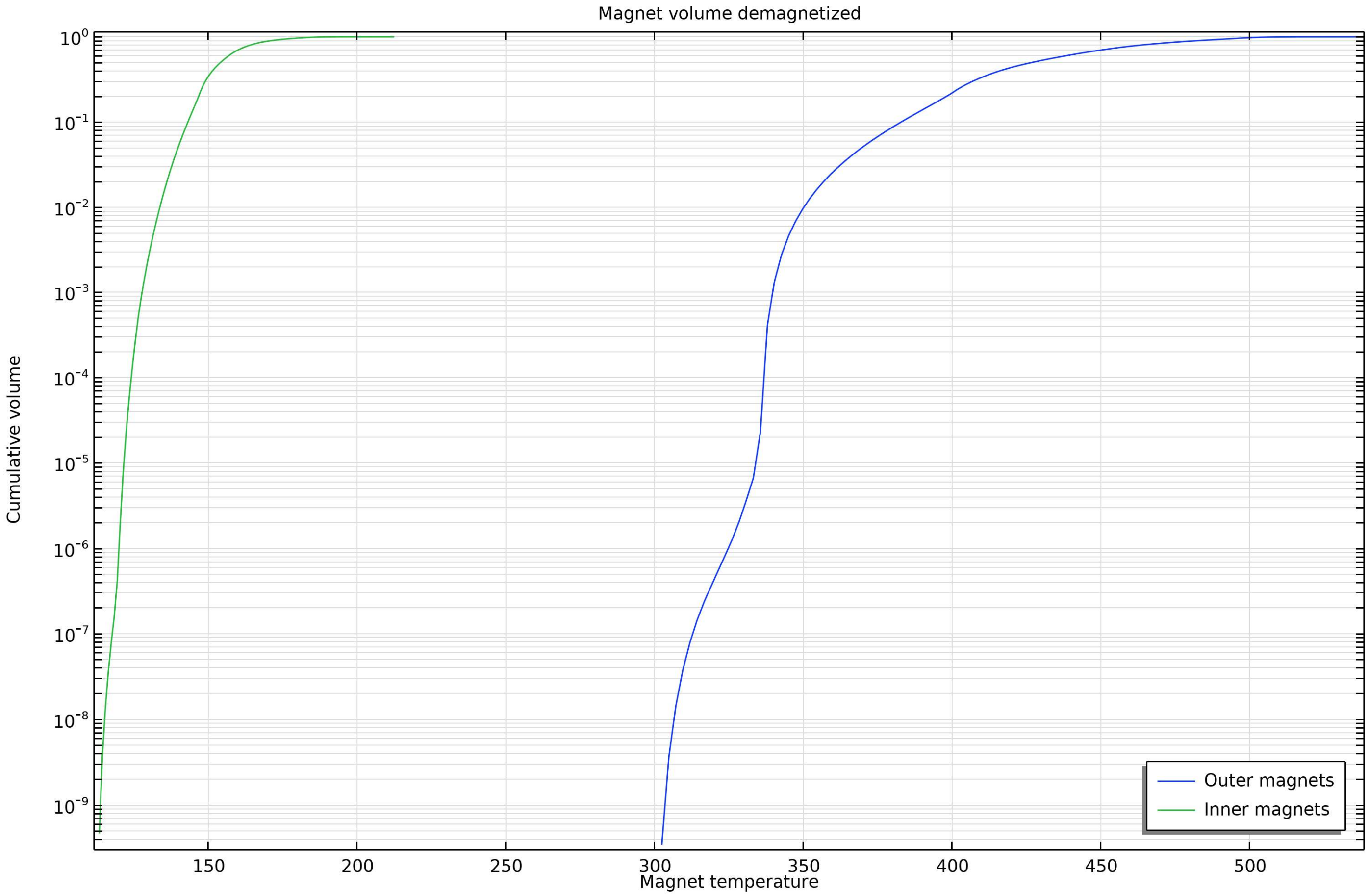
Thermal considerations

In the above example the inner hub magnets are sintered neodymium magnets grade N45UH. The magnets on the outer hub are samarium cobalt grade Sm2Co17-30. The reason for this difference is that the inner drive does not need to withstand very high temperatures, but neodymium magnets are cheaper than samarium magnets. Soo this is an optimization of the product for price and performance.

We clearly see the difference between the magnets, when looking at the temperature, at which the locations inside the magnets risk demagnetization due to thermal activity.

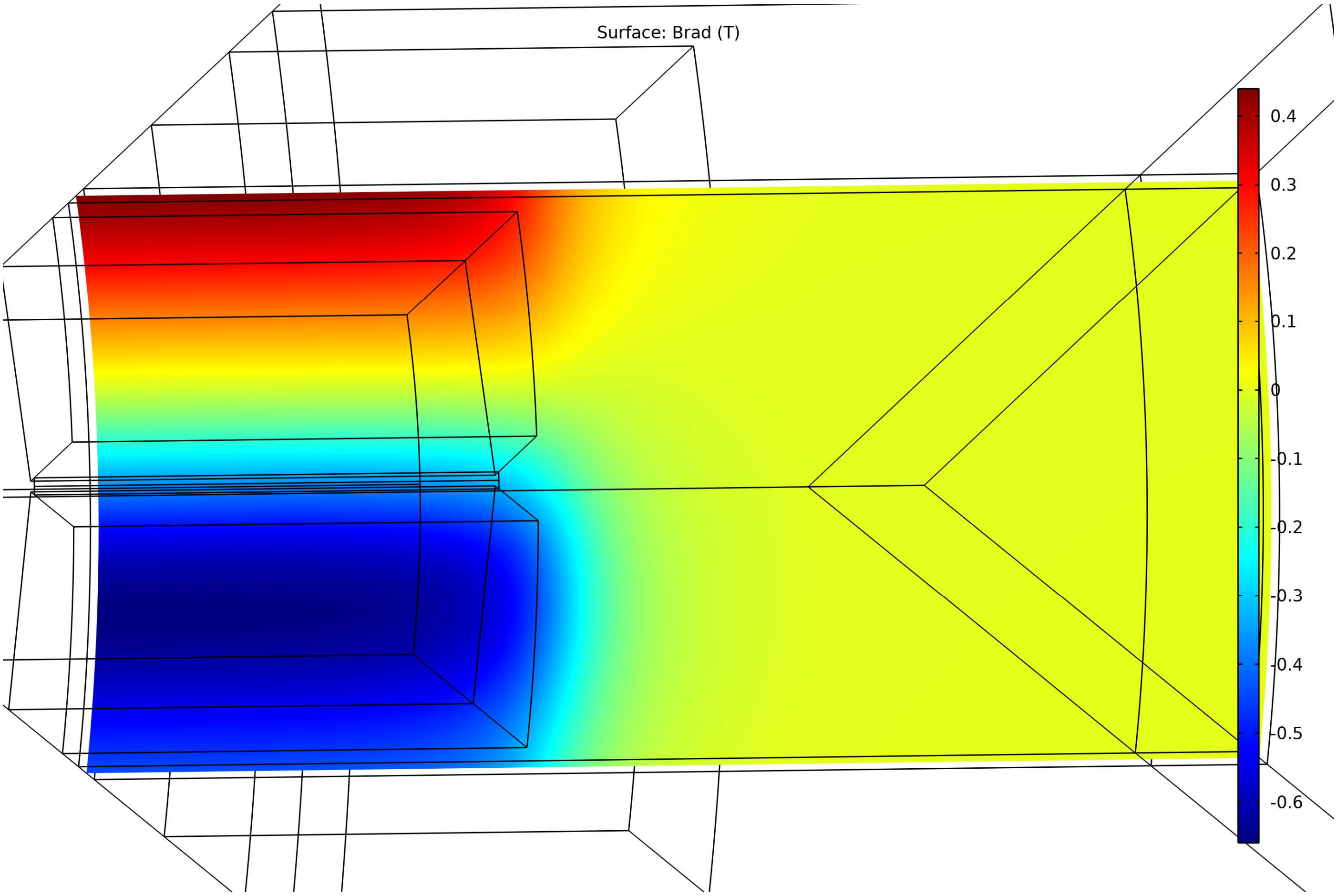


The volume amount of the total magnet volume that potentially is demagnetized as a function of temperature can also be plotted as a function of critical temperature. With this plot we can i.e. see that less than 1% of the inner magnet risk demagnetization at 133°C, for the outer magnet it is 350°C.

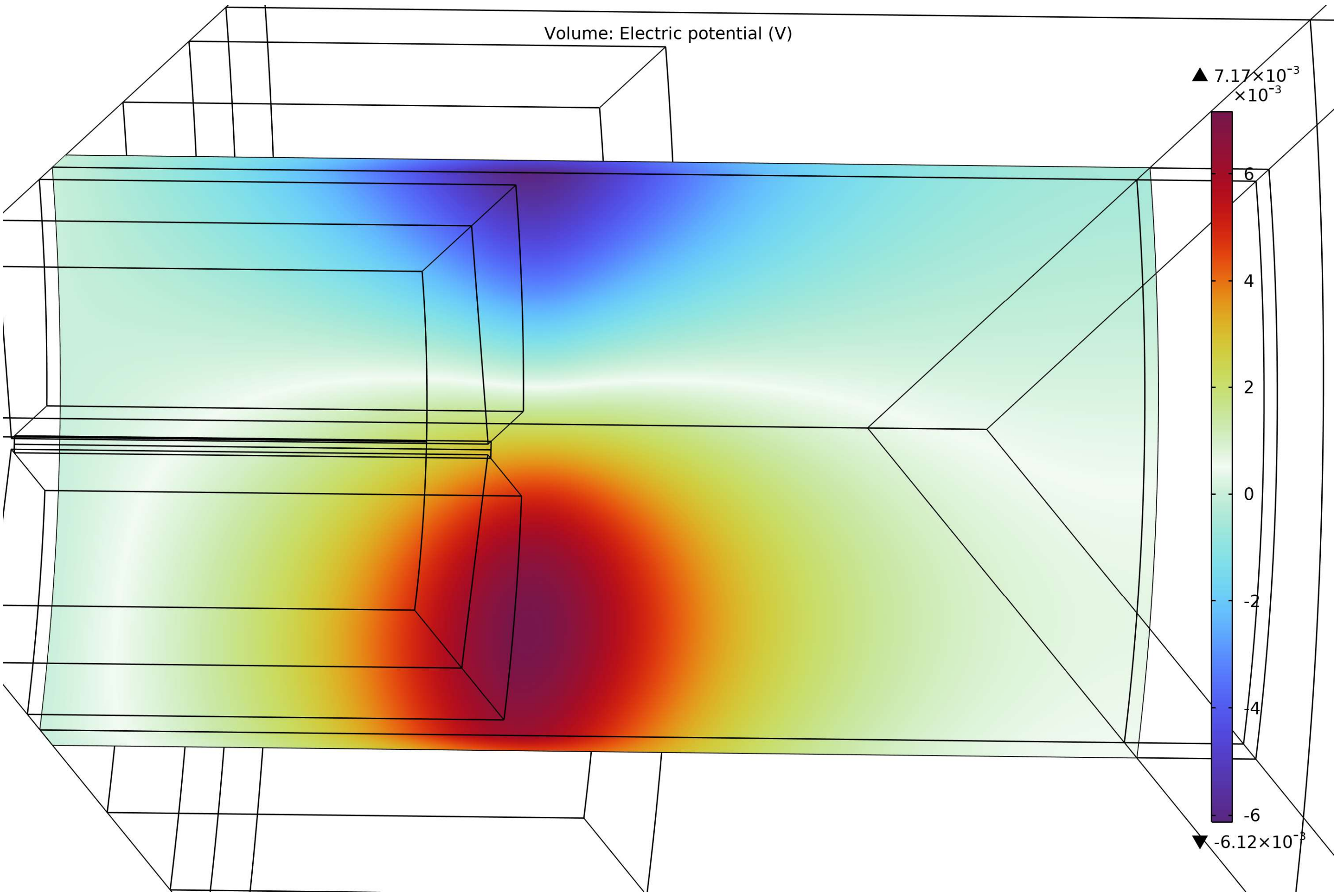


Eddy currents in canister

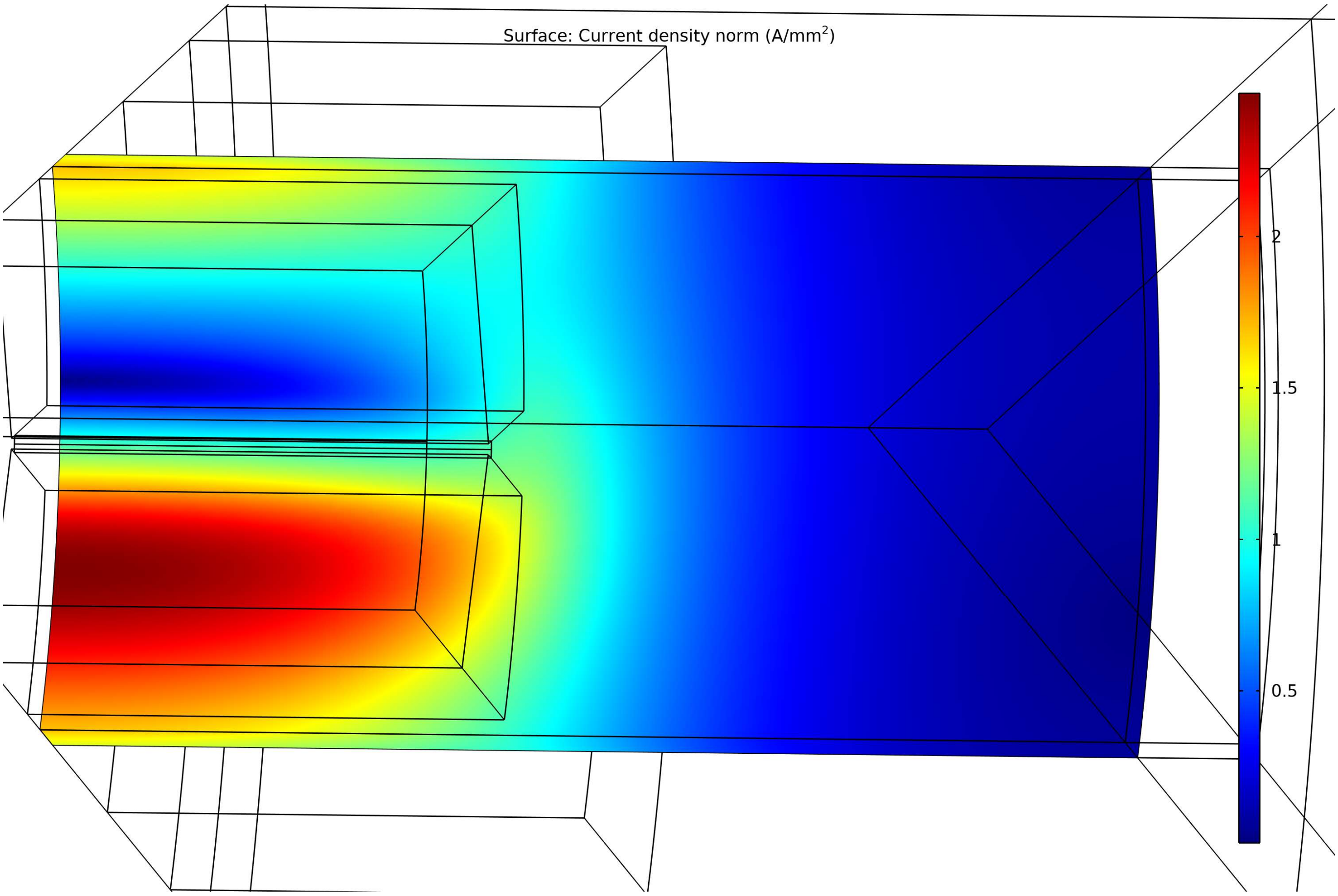
The radial component of the flux density in the canister can be seen in the figure below.



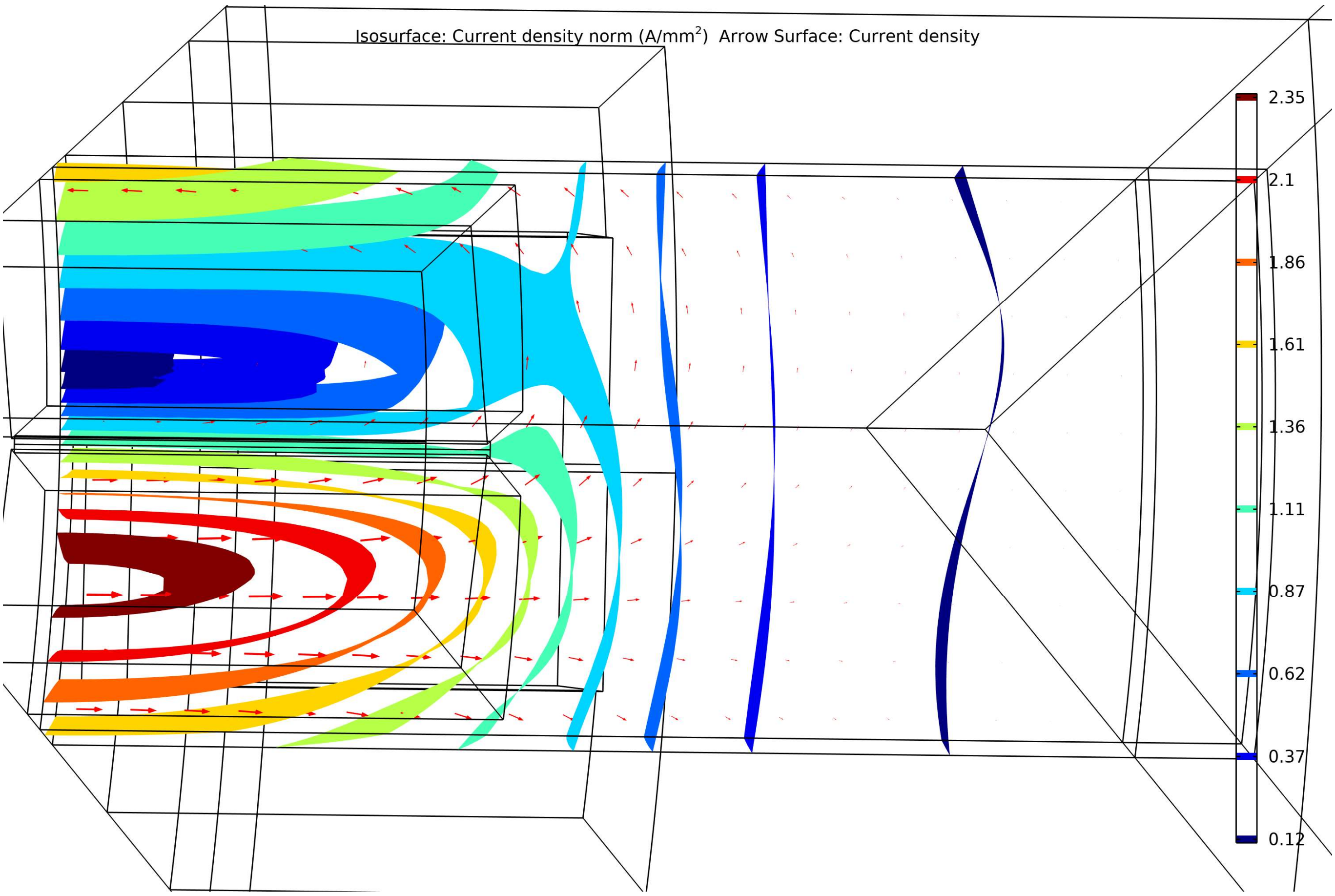
When the hubs rotate and the canister is standing still, a voltage is induced in the canister, see below.



This voltage can drive a current density (see below), that depends on the resistivity of the canister material.



In the next figure the flow of current is visualized with arrows.



Eddy current loss

The current that runs in the canister is also a function of how fast the hubs rotate (in this case 1000rpm) and the torque angle (in the simulation case 90°). In this case we get 38.3W.

In some cases, the loss in the canister is very high, which is a problem in many ways. It lowers the efficiency of the system and means that the system uses more power to do the same work. The eddy current loss also increase the temperature in the canister, which heat up both the sensitive magnets on the inner and outer hub, but also the media/fluid that the canister separates. If it i.e. is a pump for the food or medical industry, this could be unacceptable. In these cases TechnoFlex can make canisters in thin and strong materials like titanium and Hastelloy, or completely non-conducting materials like ceramic, PEEK and Borosilicate. Again this is decided in close collaboration with the costumer.

Measurements and testbench

The magnets used in the coupling all undergo quality control, depending on the necessary accuracy and tolerances.

We also have a dynamic test bench able to measure torque from 0.1-100Nm.

Balancing

If the speed of the coupling is high, sometimes it can be good to balance the coupling, to minimize vibrations. At TechnoFlex we have balancing equipment and can therefore deliver the couplings balanced both static and dynamic according to ISO 21940 -11:2016.

References

You can read more about torque couplings here.

Nr.	Description	Source
1	Article about use of couplings in wind turbines	https://www.comsol.com/story/download/507751/Sintex_CN2018.pdf
2	1 hour video about modelling of torque couplings	https://www.comsol.com/video/optimizing-magnetic-transmission-designs-with-comsol-oct-11-2018
3	IEEE Articles by author	https://ieeexplore.ieee.org/author/37275419700
4	Full CV of author	https://www.buusbendixen.dk/BuusMag/CV_FBB.pdf