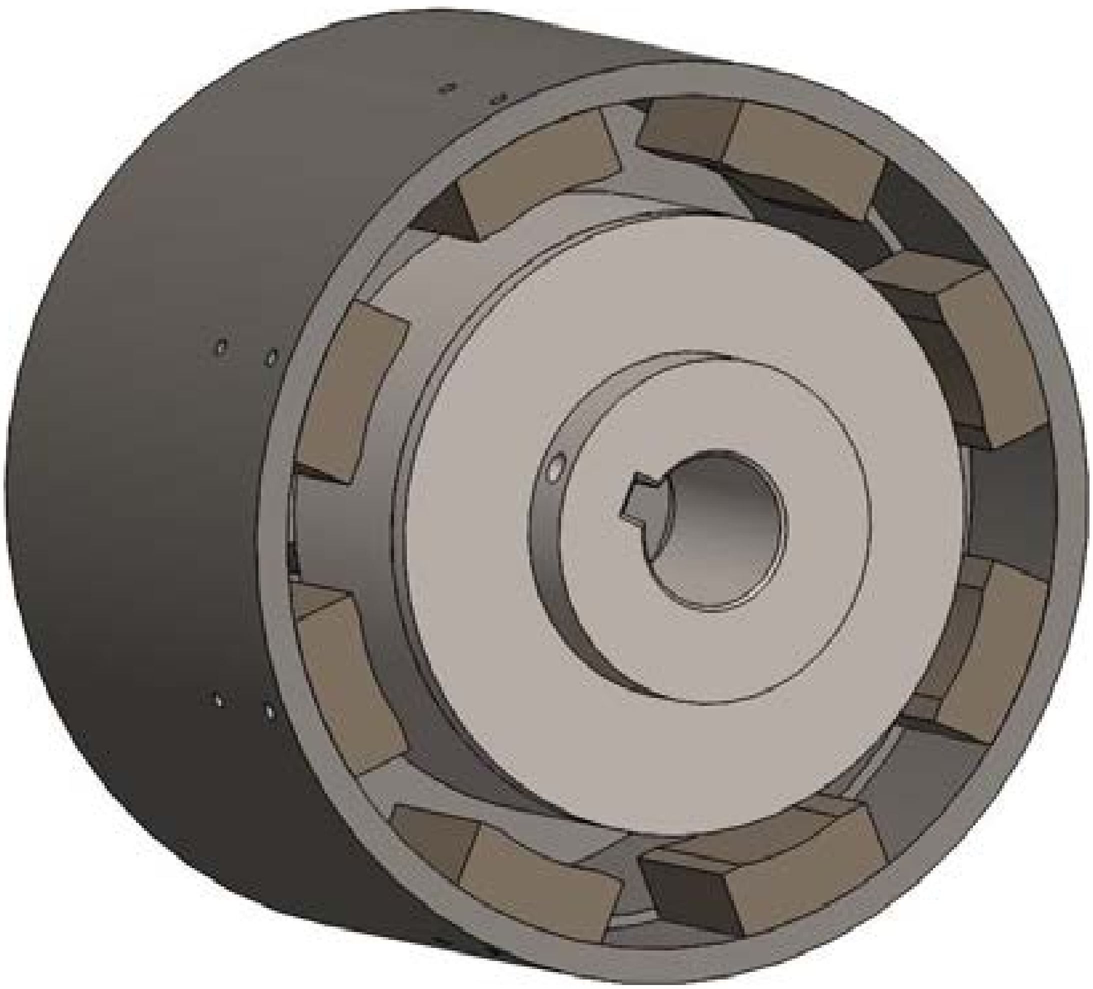
Magnetic Torque Coupling FEA Example



Title:	FEA Product Example Showcasing Common Options
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Description:	Example Finite Element Analysis report showcasing common options on a magnetic torque coupling.

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Table of Contents

Section 1: Design Intent & Purpose

The magnetic torque coupling detailed in this report is meant to transfer torque created by a motor, or any spinning device, to another object (mixer, impeller, propeller, etc.) without any form of physical contact. The torque creator is mounted to the outer coupling by means of the attached motor shaft mount (able to be replaced to accommodate most motor shafts without coupling modification). The torque recipient (the object requiring torque to rotate) is mounted to the inner coupling, either directly, or in this case to the inner couplings containment can.

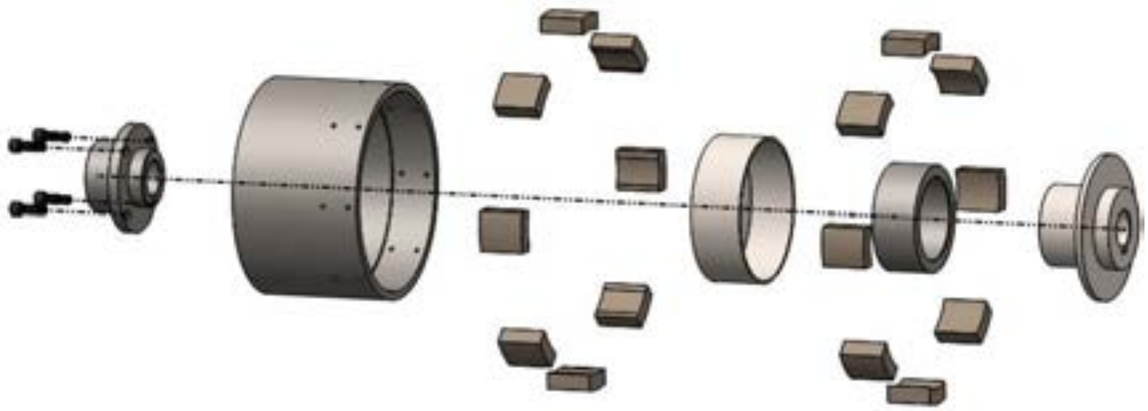
As the motor turns the outer coupling, the inner coupling will also turn due to the magnetic attraction and repulsion between the mounted permanent magnets. A non-magnetic (300 series stainless, titanium, etc.) containment can has been welded shut around the inner magnets to protect them from the environment (perhaps they were placed inside a tank with high temperature or caustic materials to turn a mixer). The gap between the couplings allows for the two halves of the coupling to exist in different environments without the need for seals while still transferring torque (seal-less pumps are a common application).

The desired parameters in this example application are 40 ft-lb of torque operating at 150°F. The theoretical motor driving this coupling has a maximum torque rating of 45 ft-lb. Before this torque is reached, the torque coupling must “break-free” and freely spin to prevent the motor from binding up and being damaged. This is accomplished in the application by designing the magnets with a certain power in mind. As the outer coupling spins the inner coupling will also turn in a 1:1 ratio. When the torque recipient binds up, or encounters resistance greater than the motor can power through, the outer coupling will push past the magnetic resistance of the inner coupling and spin freely at the max motor RPM, leaving the inner coupling stationary. Once the torque recipient has been cleared or untangled and is able to spin again, the motor can be stopped, allowing the two coupling to automatically re-align, and then slowly started again with no damage to the system.

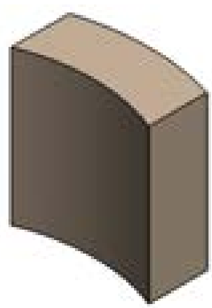
This process can repeat forever, without damaging the permanent magnetic couplings, given a few design considerations. If the couplings are not designed properly, the magnets will de-magnetize and the torque coupling will stop functioning, hence the need for a design analysis before production. Some important parameters are maximum desired torque, operating temperature, peak exposure temperature, and the application’s dimensional constraints.

Section 2: Coupling Parameters

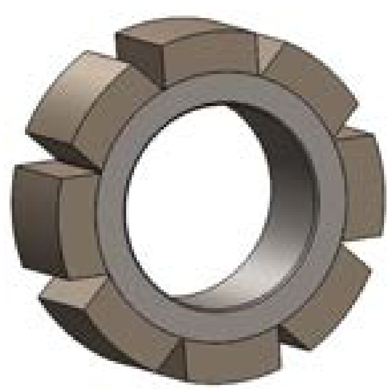
In this example analysis report, the exact dimensions and constraints of the coupling are not important, as it is operating in free space. Therefore, no measurements will be included for brevity and simplicity.



Full-Assembly Exploded View



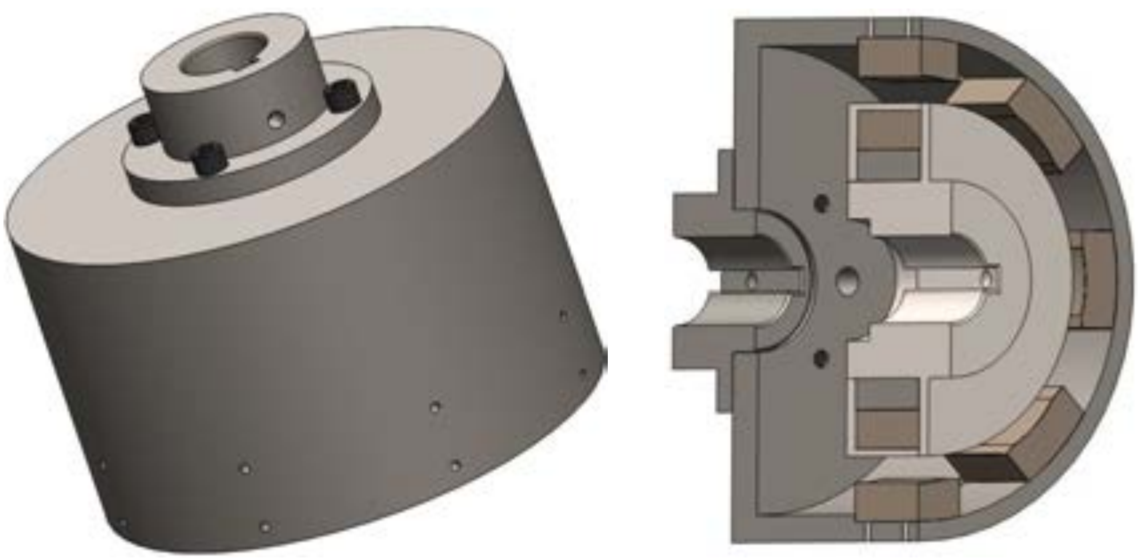
16 Alternating Pole NdFeB Magnets (8 on each coupling half)



Adhered Inner Coupling (Steel Inner with 8 Mounted Magnets)

Welded and Completely Sealed Containment Can (with Integrated Shaft Mount)

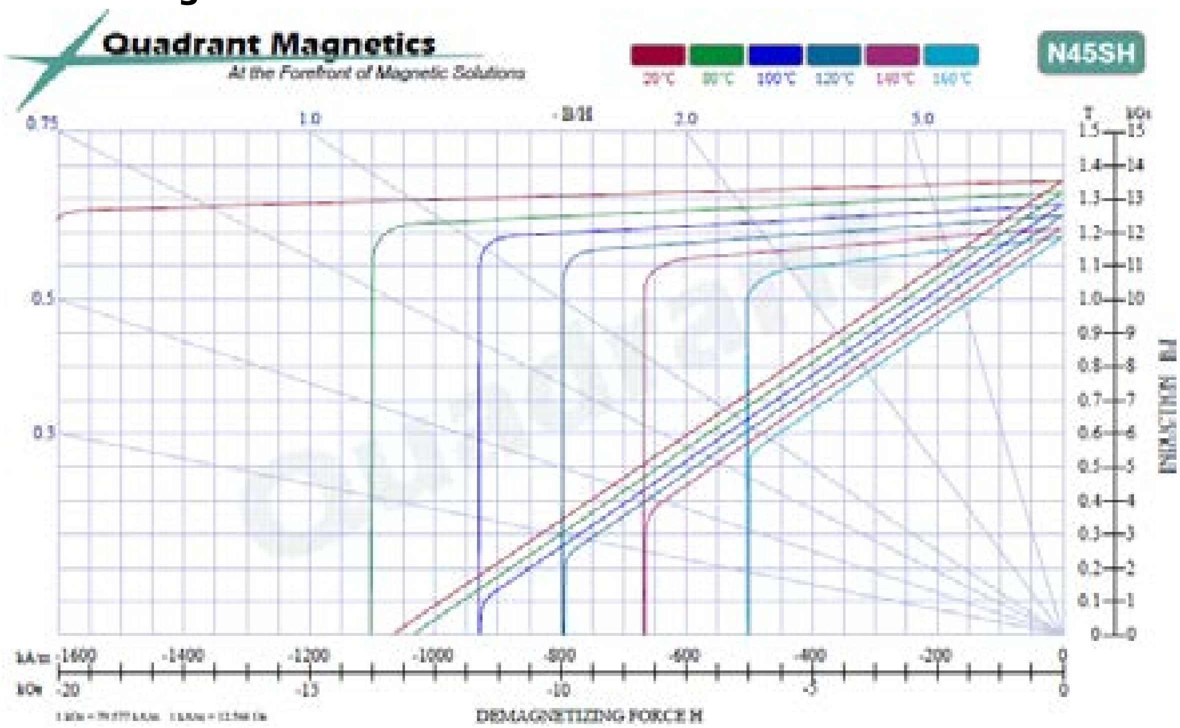
Adhered Outer Coupling (Steel Outer with 8 Mounted Magnets)



Motor Shaft Mount (Attached to Steel Outer)

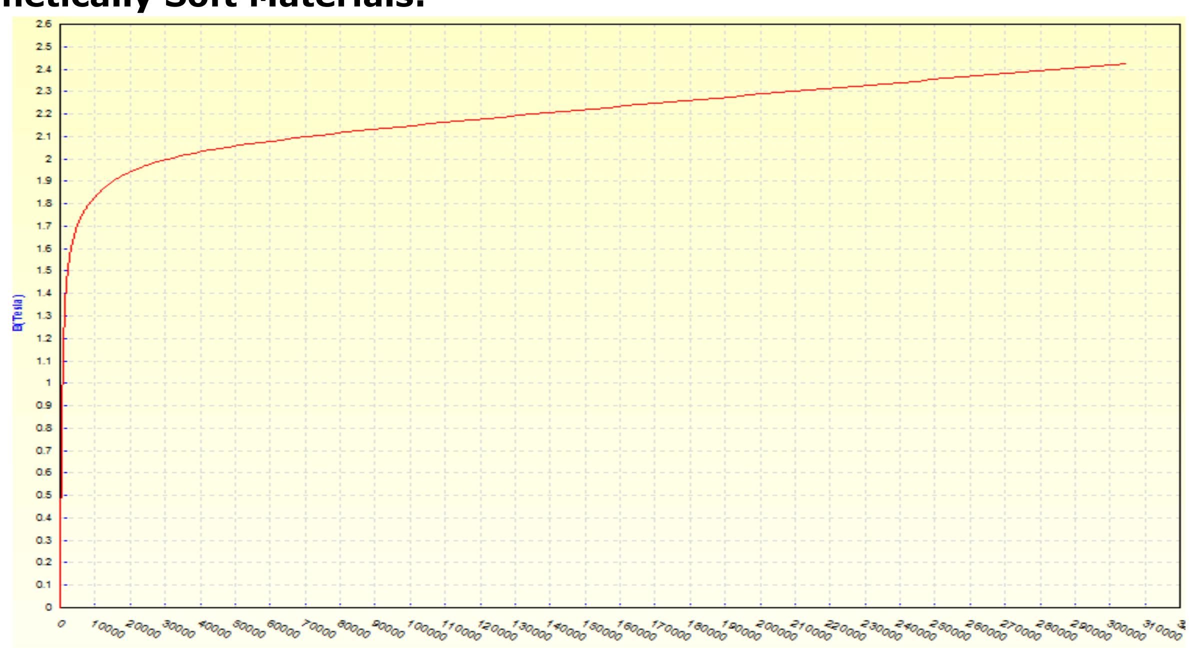
Section 3: Materials

Permanent Magnetic Materials:



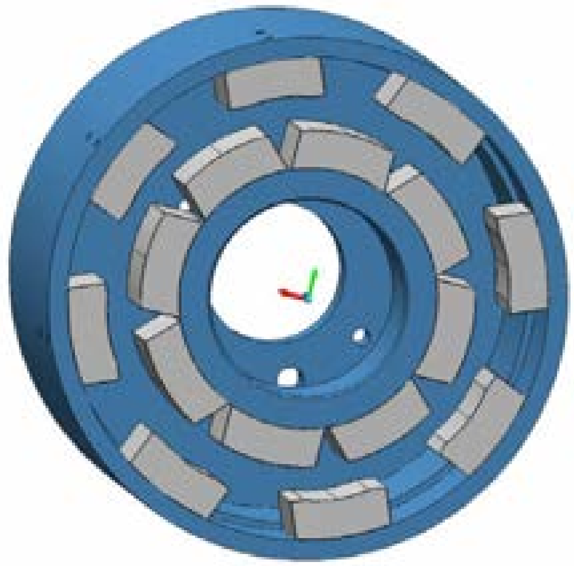
N45SH – High Coercivity/Temperature Neodymium Iron Boron with 45MGOe

Magnetically Soft Materials:

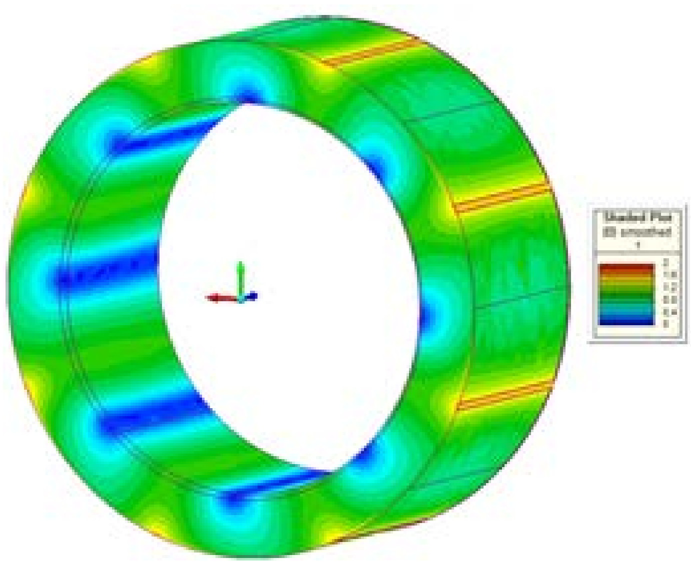


Generic Low-Carbon Steel (1010) – Curve drops off rapidly after 2 Tesla

Section 4: Steel Saturation Analysis



For the remainder of the analysis, the unnecessary (not relevant to the analysis) features of the model have been removed for simplicity and a better view. The motor shaft mount, while being steel and magnetic, is too far away from the magnets to have a real impact on the circuit. Only magnetic objects in the air gap between the magnets are going to have a large impact on this particular design. The containment can around the magnets is 300 series stainless steel, which is non-magnetic (has a permeability of nearly 1). It can be treated as virtual air for the purposes of this simulation.



Inner Steel Flux View (Limited to 2 Tesla)

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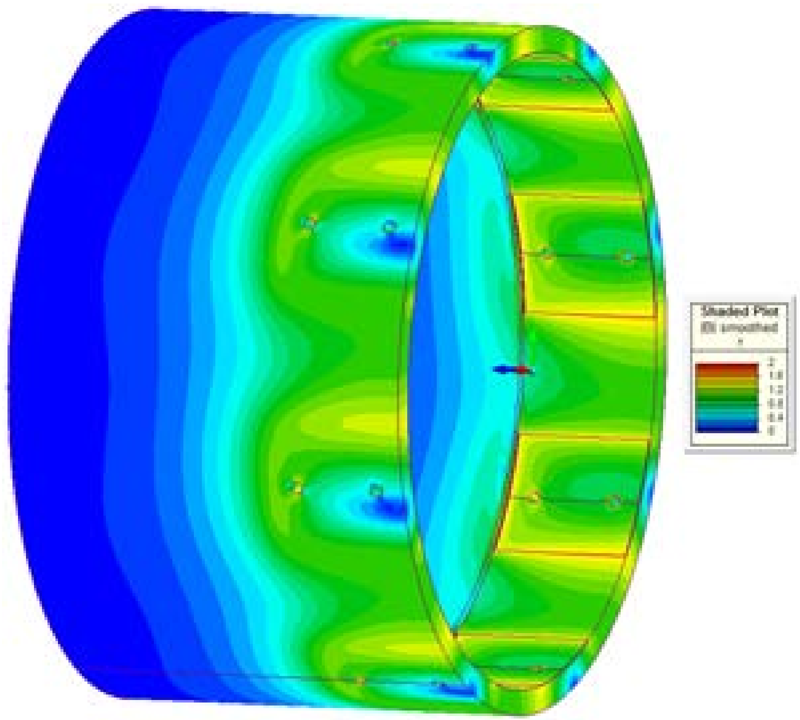


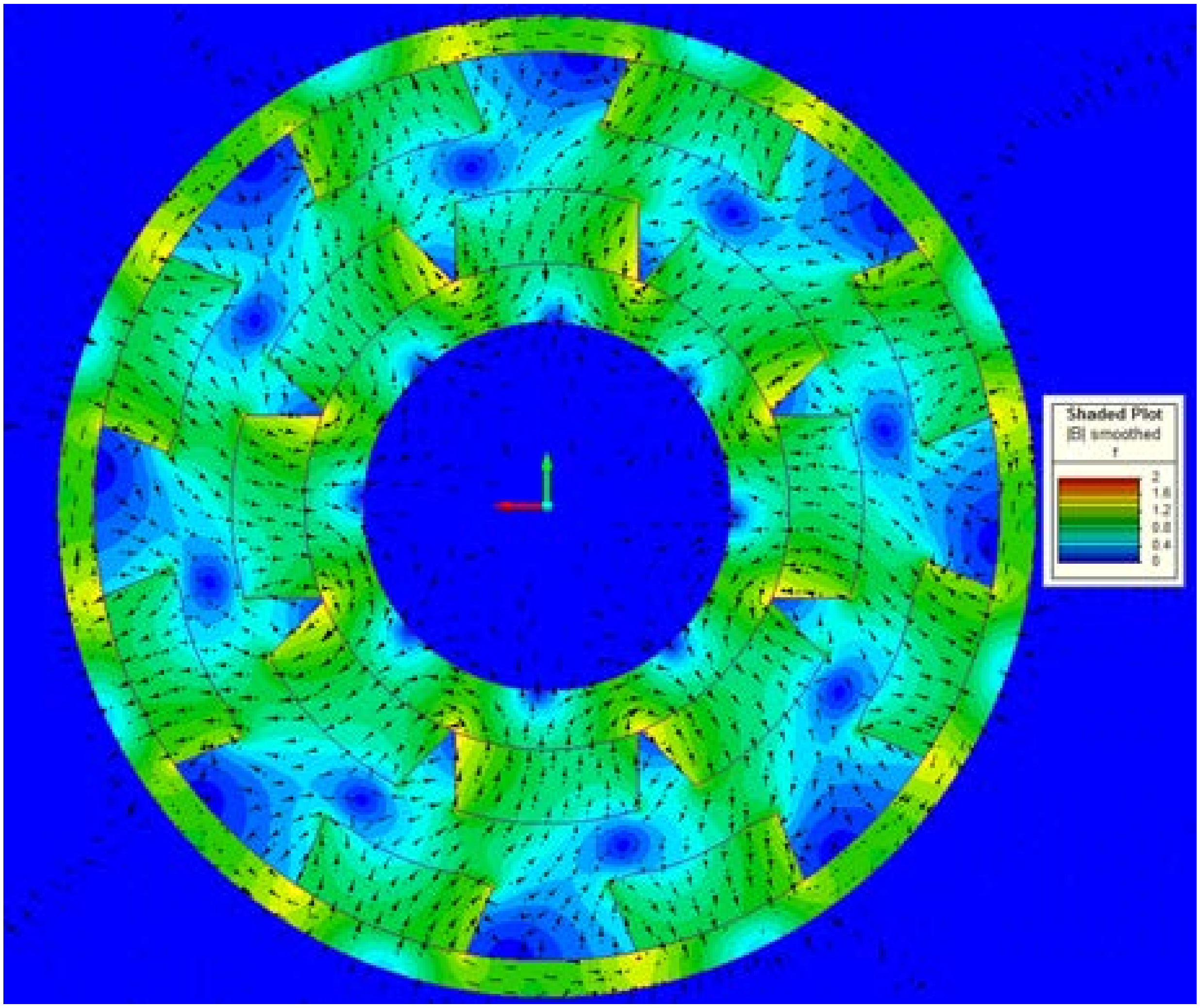
Outer Steel Flux View (Limited to 2 Tesla)

The steel in a magnetic circuit acts much like a wire in an electrical circuit. It allows flux to travel with less resistance. Much in the same fashion as a wire can be too small of a gauge for a certain amount of current, steel in a magnetic circuit can be too small or thin to properly carry the required flux. This creates resistance (reluctance) against the magnetic flow and limits the "power" of the circuit. The flux maps above have been designed to show red where steel saturation will start to be an issue. The above maps only show hints of red in the corners of the magnets. This can be safely ignored as an anomaly of 3D modelling. In the physical world there would be no perfectly sharp corners or perfect angle changes to cause a drastic increase in flux density.

The steel parts shown above are not in the saturation zone. They could be thinned slightly if their strength or size is not required for the application. Although this is not recommended as the areas of yellow above are nearing the saturation zone.

Conclusion: No concern of steel saturation.

Section 5: Peak Break-Free Torque Analysis at 70°F

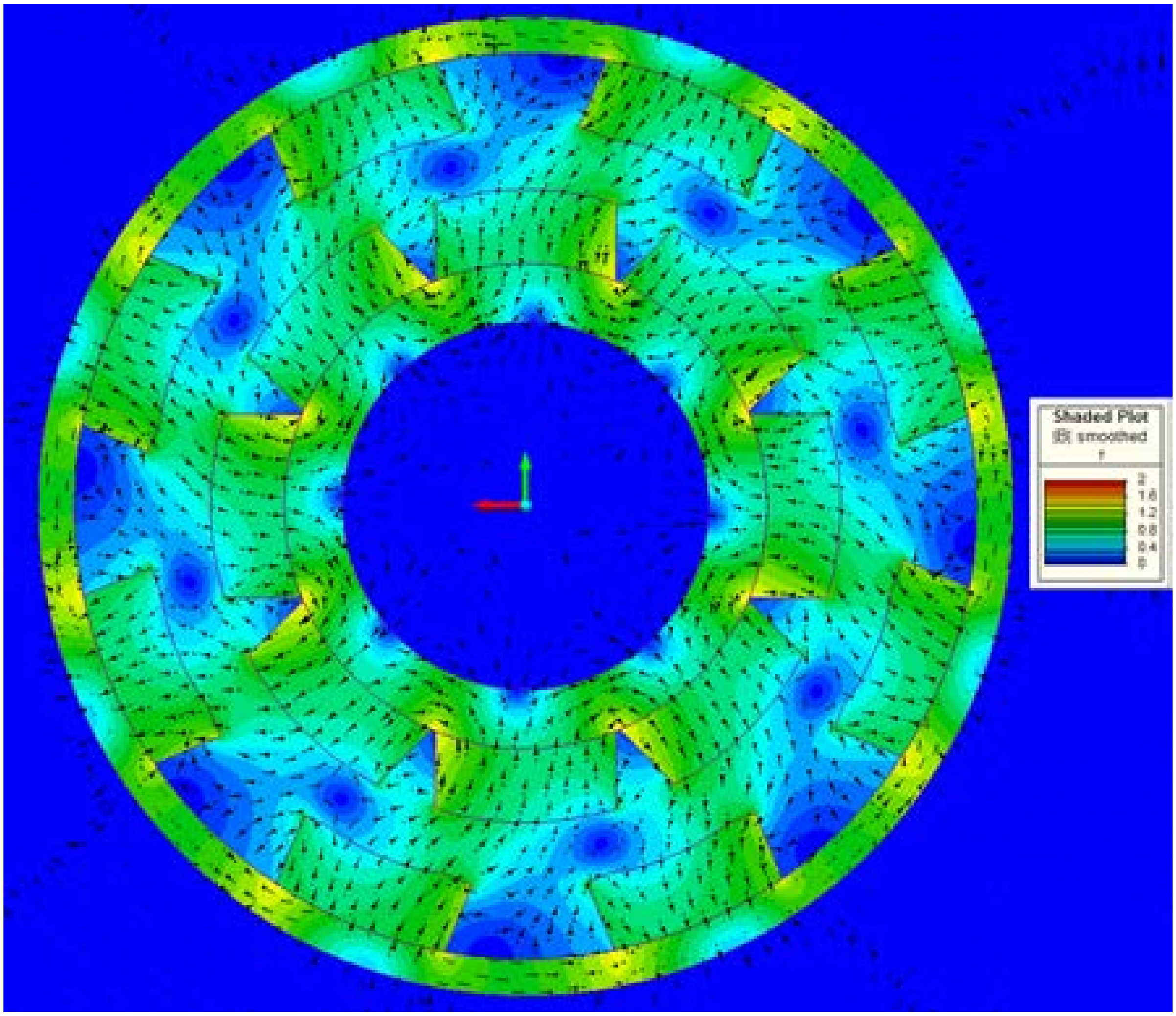


Flux map at drive angle offset of 22.5° at 70°F (limited to 2 Tesla)

The offset angle of half way between two magnets is typically the point of no return for a magnetic coupling. Once the magnets are this far misaligned it is almost certain that the couplings will spin free of each other. The goal is to find the "Break-Free" torque, so a 22.5° angle when the magnets are set at 45° will be used to measure the peak torque of the coupling before it breaks free from its other half. The final measurement is 40.52 ft-lb, which is only slightly above our goal and does not exceed the motor capability of 45 ft-lb. Applications should be underrated to consider a safety margin of at least 10%.

Maximum Torque: 40.52 ft-lb.

Section 6: Torque Analysis at 150°F Operating Temperature

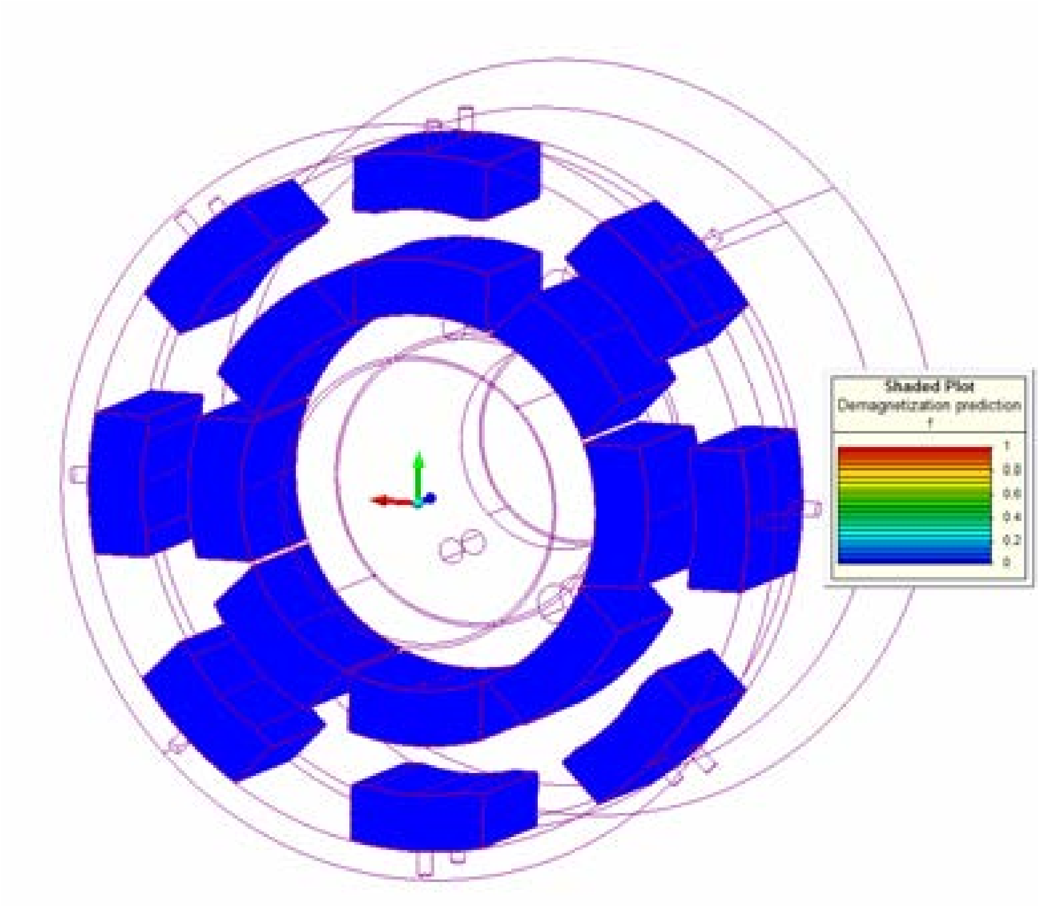


Flux map at drive angle offset of 22.5° at 150°F (limited to 2 Tesla)

At higher temperatures, permanent magnets perform differently than at room temperature. Refer to the material curves on page 6 for a reference. NdFeB magnets are particularly prone to power loss at higher temperatures. Often, the torque is check at an elevated temperature to ensure it still performs as required. The typical operating temperature in this example is 150°F. The magnets, which have been specifically chosen as a high temperature grade, still have an acceptable peak torque at the operating temperature.

Maximum Torque: 37.98 ft-lb.

Section 7: Demagnetization Analysis at 150°F



Demagnetization prediction at 150°F

At elevated temperatures, or in a poorly designed circuit, permanent magnets can demagnetize. They will then require re-magnetization before they are useful again. NdFeB (Neo) magnets are the most at risk magnetic material, however with a slightly different material mixture (typically adding dysprosium, which is expensive) the magnets can be created as high-coercivity/high-temperature grades. The N45SH grade used in this example was chosen for its high temperature properties. The demagnetization will typically be checked in a completely opposing angle for the magnets, in this case 45°. This is to simulate the worst environment for the magnets (when they break free). In this example there is no concern for demagnetization at 150°F. Some materials and circuits will not withstand this temperature without damage.

Conclusion: No demagnetization.

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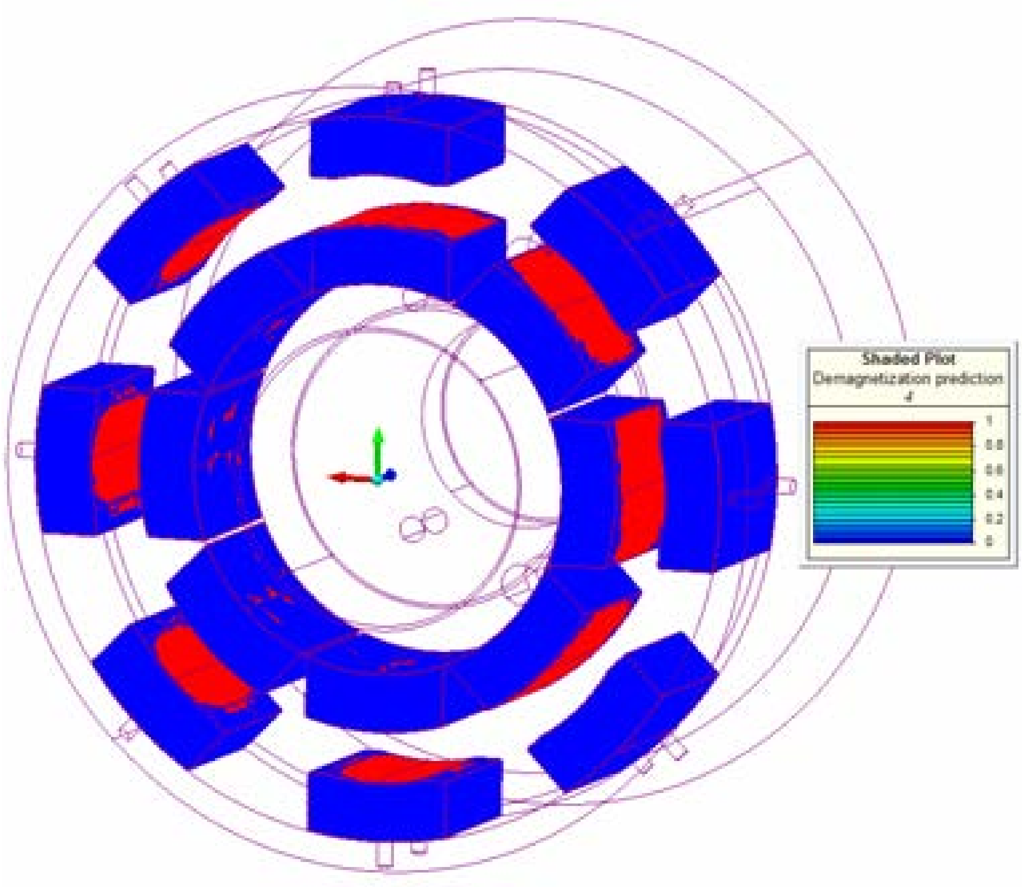
Section 8: Demagnetization Analysis at 300°F



Demagnetization prediction at 300°F

Although the material was chosen for high temperatures, 300°F is too hot for this circuit. Some damage will start to occur as early as 230°F. It can be seen above that a large portion of the magnet will start to demagnetize at this temperature, with the magnets in this position. N45SH was chosen as the magnetic material because of the design of this particular circuit and the operating temperature specification of 150°F. Operating outside those parameters can lead to failure.

Conclusion: Heavy damage at 300°F. This circuit is rated for 150°F.

Section 9: Design Suggestions, Considerations, & Review

Based on customer need, the design could be changed in several ways. If the torque requirement was lower than 40 ft-lb, the air gap between the couplings could be increased or the magnetic mass could be decreased. If the weight needs to decrease, some steel could be thinned. Typically the gap clearance between the coupling halves is specified and can't be decreased to gain more torque (to fit the containment can, if there is one, and all tolerance stack up).

If more torque is needed, a higher grade of magnet can be supplied, but usually at the cost of the temperature capabilities of the magnets. At an operating temperature of 150°F, it is unlikely the power of the magnets could be increased much. Therefore, the magnets (and whole coupling) must get bigger, the air gap between halves must get smaller, or the operating temperature must be decreased to accommodate such a change.

If a higher operating temperature is needed, the NdFeB magnets could be replaced with SmCo magnets. They have much more forgiving temperature characteristics, but at the cost of magnetic power. They are many grades weaker than NdFeB material (typically resulting in 20% or more loss of torque), but can survive above the 300°F range if designed properly.

These are some typical examples of change suggestions based on application need. If the application is as outlined in the design intent section on page 3, then this coupling would be adequately designed to make the most of cost and function. Many times an off the shelf coupling will not fit the requirements, in which case a new coupling will be designed by the customer or with the help of Quadrant Magnets through engineering service and FEA. FEA is often used as a design check in couplings that have seen failures or are being modified for a new environment or application.

The need for FEA service has hopefully been outlined in this example. Any magnetic circuit can be analyzed, but a magnetic torque coupling was a way to showcase many of the possible options for analysis and demonstrate their usefulness. To create the most efficient design, steel and magnetic mass need to be minimized, the proper magnetic material needs to be selected, and the fear of demagnetization or not meeting torque requirements must be eliminated.