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SYNCHRONOUS MAGNETIC TORQUE COUPLING DESIGN PROCESS

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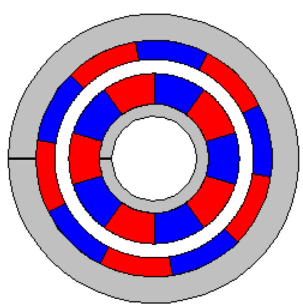
Magnetic torque couplings use magnetic field to transfer torque from one side (prime mover; driver) to another (load; follower). The technology is used in all market sectors, like medical, automotive, aviation, utility, energy, research labs, *etc*. The most common examples are called synchronous torque couplings; meaning the driver and the follower rotate at the same speed. Often a barrier component is found between the driver and the follower, to isolate the environments of the two sides (high pressure vs. low pressure; different media; hazardous vs. benign environments; vacuum vs. atmosphere; *etc*.); but that does not have to be the case. Compared to mechanical shaft couplings, magnetic couplings are not subjected to wear-and-tear, can withstand high tolerance of axial, radial, and angular misalignment between the prime mover and the load, and can transfer mechanical energy through a continuous barrier with no seals necessary, thus avoiding seal failures.

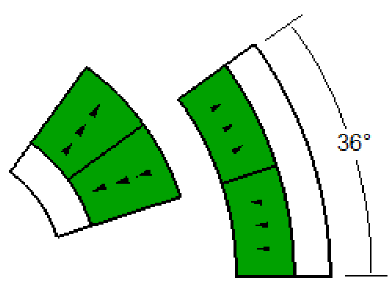
The designing of magnetic torque couplings used to be a trial-and-error process and highly empirical. With the abundance of finite element analysis packages nowadays, fluent users of numerous magnetic design programs can take up the task of designing a magnetic coupling with ease. This article outlines the general design process of synchronous magnetic torque couplings, using Integrated Engineering Software's (www.integratedsoft.com) Inducto™, Lorentz-EM™, and Faraday™ Boundary Element Analysis (BEA) packages. Specifically, the coaxial type of synchronous couplings is exemplified here; the face-to-face type of couplings is designed in a similar fashion but just not in 2D.

2D Design

The advantage of designing in 2D is obviously the short computation time and fast iterations, which enable rapid design optimizations. Inducto™-2D is the ideal program package for this purpose. In this case, a torque coupling is to be designed to meet the below requirements.

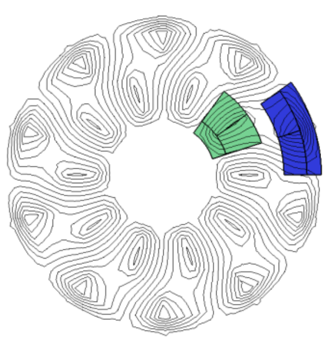
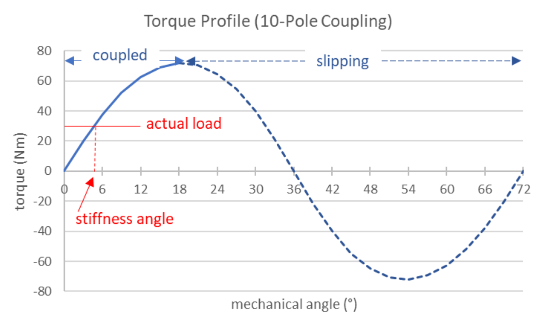
Outer diameter	110 mm
Length	50 mm
Barrier I.D.	73 mm
Barrier O.D.	83 mm
Op. temp.	< 150°C
Transmissible torque	58 Nm
Stiffness	< 12°

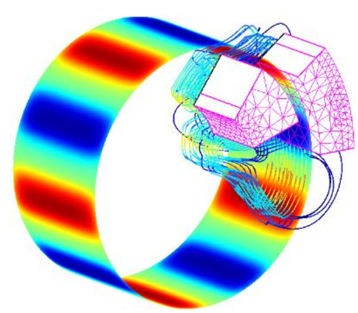




The design engineer sets up the model geometry in Inducto™-2D, taking advantage of the angular anti-periodicity, so only a 36°-slice is modeled for a 10-pole coupling. Be thoughtful of how magnet regions are represented in the model – magnets should be partitioned along the centerline, so two 18° sections each from two neighboring magnets make into the model as shown in the example. (The barrier is assumed to be nonmagnetic and not shown.) Permanent magnet orientation direction is usually straight across pointing out from or in toward the center for each magnet segment, as opposed to being truly radial, to be most economically and readily sourced. Rotate one side (driver or follower) of the coupling by 18° mechanical angle (90° electrical angle) with respect to the other side (follower or driver) for maximum transmissible torque. Segment lines on periodic boundaries are selected to be assigned anti-periodicity boundary condition. Solve the model using FEA or BEA and calculate torque (note the reported torque value is for the complete coupling assembly, not just for the 36° sector shown).
Make changes to the model – any of the diameters, magnet and backiron materials, operating temperature (affecting magnet Br and Hc properties), number of poles, *etc.* – to maximize torque (or minimize package size). Use parametric analysis as necessary to streamline the iterations. Parametric analysis is especially helpful to plot torque versus angular displacement (between the driver and the follower) profile, across 0 ~ 18° mechanical angle (0 ~ 90° electrical angle) range (for 10-pole coupling), to understand torque characteristics and find stiffness angle under a particular torque load.

The center shaft and especially the outer backiron are flux carriers and the key components in the magnetic circuit. If made of low-carbon steel, they magnetically saturate at around 1.8T. Size the backiron so that it operates slightly above saturation (~2.0T) to get the most bang for the buck.

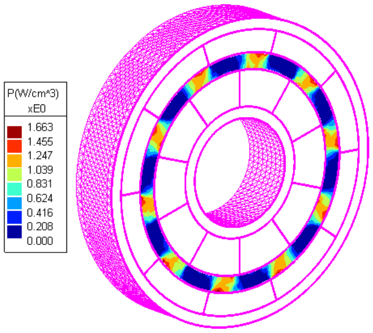





3D Design

Fringing effect (end effect) is not accounted for in 2D design. Use Lorentz-EM™ or Faraday™ for 3D analysis. Transfer the design parameters from the Inducto-2D™ model and set up the 3D model. Utilize not only angular periodicity but also symmetry boundary conditions as necessary to expedite the analysis. Solve the model and plot streamlines. It becomes evident that magnetic flux lines toward the ends of the coupling bend out into the air instead of traveling through the magnetic components – these fluxes do not contribute to torque generation. The maximum torque calculated from 3D model is 60 Nm instead of the 72 Nm from 2D model and is more realistic.

There are ways the barrier affects the coupling torque. Should the barrier be made of magnetic material, it exhibits a shunting effect, reducing the magnetic flux that travels from the driver to the follower and vice versa, thus reducing coupling torque. Or, if the barrier is electrically conductive, any relative movement between the barrier and the driver/follower system generates eddy current loss resulting in coupling torque loss. Eddy current loss is analyzed in Inducto™ 2D or 3D. With a Ti-6Al-4V titanium barrier and 500 rpm rotation speed, the eddy current loss in the barrier is calculated to be 21 W, which amounts to 0.4 Nm transmissible torque loss to this coupling. Power density due to eddy current loss in the barrier region is plotted as shown.



As demonstrated, Integrated Engineering Software's electromagnetic analysis packages are great tools for magnetic coupling designs.