This paper proposes improved analytical expressions for the interaction torque between permanent magnets applied to a magnetic bearing. Unlike the conventional analytical expressions these expressions are valid for any position, especially when surfaces of the different magnets are in the same plane. This property enables the design optimization of such bearings using fully analytical expressions.

Due to the demand for ever higher performance of high-performance vibration isolation (Fig. 1a), engineers increasingly turn to solutions that would have been considered too risky in the past. As a result vibration isolation and magnetic bearings based on permanent magnets (PMs) are increasingly considered (Fig. 1b-c). PM bearings have the distinct features such as clean, noiseless, vibration and maintenance free. Nevertheless, high costs due to control apparatus prevent their wide applications at present [1]. However, due to their inherently high control bandwidth and accuracy, they are frequently applied in high-performance static and dynamic planar bearing applications. As a result accurate modeling of the interaction behavior between the PMs, which are often cuboidal, is eminent.

The interaction force vector and the stiffness matrix are common design and control parameters for bearings or suspensions. However, the magnetic bearings are often contactless and can therefore not only translate but also rotate freely because there is no restricted degree of freedom (i.e. they are 6 dof). These rotations may be unstable, hence, require active compensation in order to provide a stabilized system in 6dof [2]. Torque creates such a rotation and for this reason it is important that not only forces but also the interaction torques between the PMs are accurately modeled.

Although numerical means are very interesting for evaluating the mechanical properties of the magnetic bearing, analytical expressions are a more elegant way due to their limited computational cost. Analytical surface charge modeling used in [3, 4] is applied to obtain the interaction force. Only in [5] analytical torque expressions have been derived using virtual work. Detailed research of the expressions from [3-5] shows that they are not defined when the side-surfaces of two PMs are in the same plane (Fig. 1d). Especially in magnetic bearings this PM alignment is very common, as is schematically illustrated in Fig. 1c-d. This makes the design of the bearing more difficult, also because most optimization routines cannot handle such undefined numbers, hence analytical expressions which are valid in those points are necessary.

Linear interpolation around the non-solving points is not difficult to implement, but it is a slower and less accurate method compared to a direct analytical calculation. Accuracy can be increased by taking more sample points, however at the cost of increased computational efforts. A fully analytical and computationally inexpensive solution is therefore considered more suitable. In Ref. [6] such analytical continuous solution was given for the force and stiffness expressions. This paper proposes novel and fully analytical expressions for the interaction torque between PMs which are valid for any position. The torque expressions are derived from the Lorentz force method, as opposed to the virtual work method in [5], and analytical expressions in the non-solving points are derived. Results are then compared to the Maxwell Stress method, which is less accurate, but does not exhibit non-solving points. With these adapted expressions it is possible to optimize planar bearing structures using fully analytical expressions without compromising the solution in non-solving points.

References: