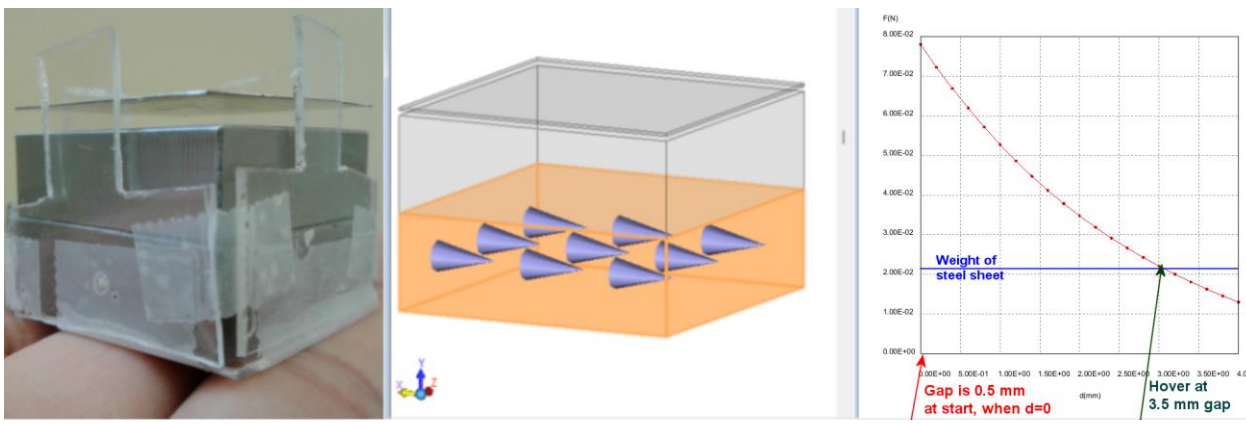
Steel Repulsion Zones around Permanent Magnet Assemblies

Dr. Doug Craigen, PhD (Team Leader, Testing and Benchmarking)
Integrated Engineering Software Inc.

Some recent benchmarking work on magnet forces has led to a new toy on my desktop, shown below. It consists of a 3x3x1 cm Nd magnet, a 3x3x1 cm block of steel, and a 3x3x0.03 cm steel sheet. The steel sheet hovers about 3.5 mm above the steel block. For my own amusement, from time to time I reach over and push the sheet into contact then watch it bounce back up.

The precisely manufactured steel and magnet are courtesy of Bo Zhang, Lead Magnetics Engineer at Dexter Magnetic Technologies. The crudely cut plexiglass held together by scotch tape is my quick construction of a structure enabling easy access to the sheet while preventing it from flying off sideways. Due to symmetry the horizontal forces balance, but as a saddle point. Disturb by a tiny amount in any horizontal direction and forces develop to pull it in that direction.



This project began when I noted a tiny force repelling a steel part away from all other steel and magnets in a test model for AMPERES™. I assumed this was wrong, an artifact of the nearly perfect cancellation of large forces meaning a very accurate solution was required. So, I adjusted the solver… it didn't go away. I tried a multitude of things to improve the calculation: BEM, FEM, Amperian force calculation, Maxwell Stress force calculation, Virtual Work force calculation, triangular elements, quadrilateral elements, and more. Nothing made it go away. Then we noted something similar in other models.

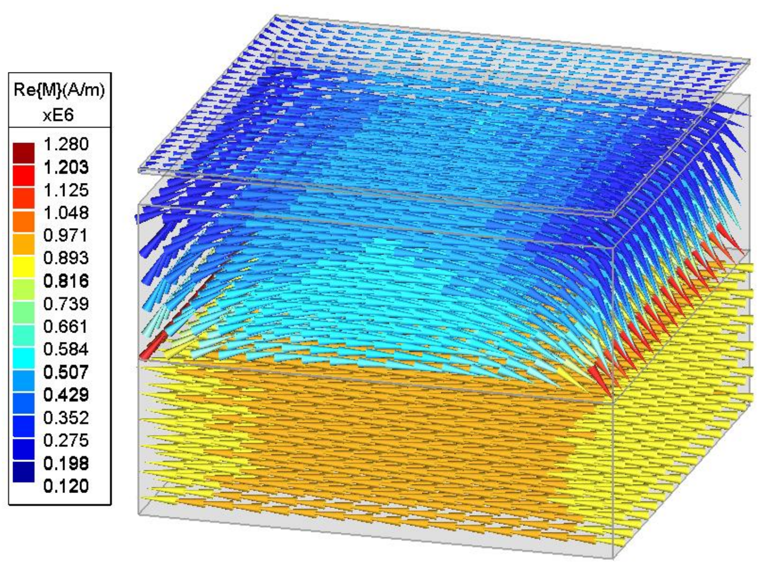
For sure the lowest energy configuration that such systems will tend toward is all the steel and magnets pulled together, but that does not preclude local areas of saddle point repulsion. So, is this real, or do I need to track down a small systematic force calculation problem over a wide range of AMPERES™ modeling? I decided to see if I could turn repulsion into a strong enough force to produce levitation and conceived of the model shown above. Levitation would solve the practical problem of measuring tiny forces in a saddle point situation. For this I turned to the Parametrics feature of INTEGRATED programs. I began with the magnet and steel block fixed and worked on parameters of the top steel. I found the net force on the piece to be only slightly dependent on its thickness. That is great for levitation because the thinner I make it the lighter it is. The question will be whether I can make it thin enough to levitate while being thick enough to be readily made. A quick Google search suggested 0.3 mm sheets would be at the thin end of available sheet metal. I modeled with 1010 steel for both the 1 cm thick plate and the 0.3 mm thick sheet. I made a parametric to study the force on the sheet versus height above the plate. Fortunately, the force only increases as the two get closer together and far exceeds the weight when in contact. That meant there would be a specific separation where the force equaled the weight. The parametric showed that was approximately 3.5 mm.

Although I am by training and at heart an experimental Physicist, I have no equipment for manufacturing or testing in my job. I have a computer, period. So, at a point like this I turn to our many good long-time associations with users. I sent Bo my model and asked generally if this is something observed around magnet structures or if I need to track a problem with AMPERES™. His reply surprised me, “we’ll find out”, he had sent the model specs to be built. Within days I got a photo of a levitating sheet, and they shipped it to me. Thanks! He also told me about an interesting similar device, a sheet fanner. These are not full levitation, they are devices which use a magnet to cause the edges of steel sheets to repel each other, separating them so the top is easier to remove.

On receiving the device, I was pleased not only by the levitation, but by the fact it is the predicted ~3.5 mm hovering distance. AMPERES™ came though very well on a simple looking but numerically challenging model. Besides the nearly perfect cancellation of contributions forcing a very accurate solution, the thin sheet presents a significant mesh challenge for a good solution, and I modeled with the B-H curve of 1010 steel, not just the permeability. The parametric feature was (as is often the case) key to getting a proposed design quickly.

I have not explored tolerances in this model, but I know that very similar looking models normally show no levitation. It very easily tips from the repulsion force exceeding the weight (levitation) to not (no levitation), and in fact attraction rather than repulsion is by far the usual sum of the forces. The device Dexter sent me is manufactured to high precision, which would be a significant factor in matching the AMPERES™ prediction so well.

For anybody wanting a framework to understand this kind of repulsion, I propose considering the magnetization of the parts. The two steel pieces magnetize parallel to each other and antiparallel to the magnet. That means they repel each other and attract to the steel. For the top sheet it is just a matter of whether the net effect of repelling from the steel plate and attracting to the magnet is going to be repulsion or attraction.



CONCLUSIONS

Although I now better understand the competing force dynamics in magnetic configurations, I have no simple principle for predicting whether net attraction or repulsion will occur. However, AMPERES™ can tell you for a proposed configuration. I've been able to find stronger repulsions in other situations, but they also tend to be more unstable configurations so it would take some work to make them into a nice demonstration. I have also created configurations of steel hovering over just a magnet (to be shown in detail later). I have not thoroughly explored the plate and magnet parameters because my basic goals were met simply by parametrizing the top plate height. However, some interesting spring type scenarios seem possible. That is, the sheet being repelled when too close and attracted when too far, hence behaving like an invisible spring. Certainly, the levitation could be observed with a weaker magnet and less of each material and a gap between the magnet and first steel volume. Any AMPERES™ users can do their own explorations.

For further explanation and to watch the device in action, including two hovering steel sheets, please see the YouTube video: Click Here

For more information about AMPERES™ see: https://www.integratedsoft.com/products/Amperes