TP IV-Report : Study of isotropic and anisotropic particles composed systems

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1 Introduction

Sealskin is used for the practice of cross-country skiing. In order to stick it to the ski one must use a special glue that is very sticky and hard to remove from the ski, and also it gets non-sticky if the glue is wet. In order to tackle this problem, a project has been submitted to the LQM laboratory in order to investigate a sealskin with nano-particle permanent magnets that will stick it to the skis.
The aim of this report is to compare the efficiency, in terms of magnetic field generated by the magnets, of isotropic and anisotropic nano-particles of NdFeB. To do so, one will simulate, with the help of Ansys' Maxwell3D mode, three composition of magnetic powder : 100% isotropic particles, 100% anisotropic particles and 50% isotropic and 50% anisotropic particles.

2 Permanent magnet and properties

The nano-particles are composed of NdFeB. NdFeB is a ferromagnet magnet and belongs to the class of permanent ferromagnets, in other words NdFeB generates its own persistent magnetic field, without needing to be in an external magnetic field.
To study the effect of permanent magnets on a bar made of steel, without any current, and determine the average of the magnitude of the magnetic field generated by NdFeB, one must solve with Maxwell's equations in the case of Magnetostatic :

$$\begin{cases} \vec{\nabla} \times \vec{H} = & 0 \\ \vec{\nabla} \cdot \vec{B} = & 0 \end{cases} \tag{1}$$

$\vec{B}$ [T] and $\vec{H}$ [A·m^{-1}] are respectively the magnetic induction field and the magnetic field. Moreover, $\vec{H}$ and $\vec{B}$ are linked by the following relation :

$$\vec{B} = \mu\vec{H} = \mu_0(\vec{H} + \vec{M}) \tag{2}$$

with μ [H·m^{-1}] the permeability, $\vec{M}$ [A·m^{-1}] the magnetisation and $\mu_0 = 4\pi 10^{-7}$ H·m^{-1} the relative permeability in the vacuum. One can rewrite 2 as :

$$\vec{B} = \mu_0(1+\chi)\vec{H} = \mu_0\mu_r\vec{H} = \mu\vec{H} \tag{3}$$

with the susceptibility $\chi = \frac{\partial M}{\partial H}$, $\mu_r = 1 + \chi$ the relative permeability of the magnet and $\mu = \mu_0\mu_r$.
However, the relation 3 is not linear in most the case, especially for ferromagnets in general, and permanent magnets in particular. In fact, a permanent magnet is characterised by its hysteresis curve and its magnetic momentum. The hysteresis curve, graph 1, will give information about the intrinsic coercive field H_{ci} and the remanence B_r.
H_{ci} corresponds to the magnetic field necessary to reduce the magnetisation of the magnet to zero, while B_r is the magnetisation that remains after the material is first saturated in a magnetic field H and then the field H is reduced to zero. Since the permeability μ depends strongly on H, at saturation, when $H = 0$, $\mu = \mu_0$, therefore $B_r = \mu_0 M_{sat}$. When B is vanishing, the coercive field writes $H_{ci} = -M_0$.

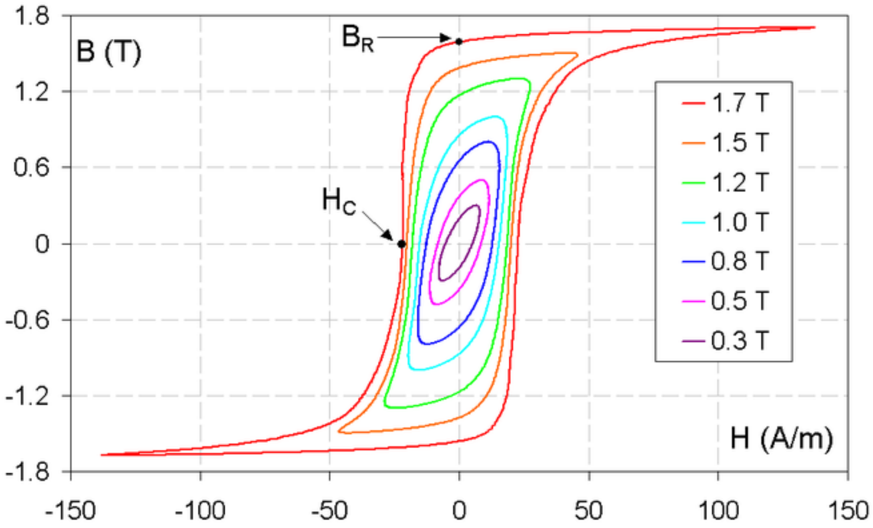

FIGURE 1 – Plot of hysteresis curves of a grain-oriented electrical steel, in order to illustrate what are the intrinsic coercitive field H_{ci} and the remanence B_r. From Wikipedia

The knowledge of the remanence B_r and the coercive field H_{ci} of a permanent magnet enable one to compute its magnetic permeabilty μ, solve Maxwell's equations in the case of magnetostatics and find the magnetic induction field generated by NdFeB particles on a steel bar.
To do so, one can use Ansys's Maxwell3D mode in magnetostatics.

3 Simulations and results

3.1 Meshing.

The discretization of the geometry of the problem will permit to obtain a set of equations algebraically solvable. In order to obtain the most accurate results for the magnetic induction field's magnitude on the steel bar, in a minimum of time, one must choose carefully its meshing.
Ansys' Maxwell 3D program has been chosen in order to solve the problem. Maxwell 3D uses the Finite Element Method to solve Maxwell's equations. Since the simulations are done under Magneto-static mode, Maxwell 3D initially builds discrete blocks, tetrahedra, that are automatically refined in order to achieve the required level of accuracy in field computation. The maximum lengths of the tetrahedra blocks can be fixed beforehand, thus one can require more or less precision for the meshing of the simulation.

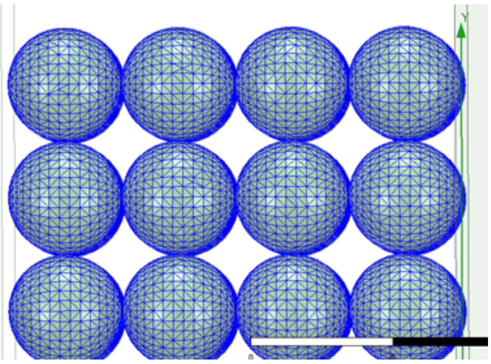

FIGURE 2 – Meshing of the isotropic particles.

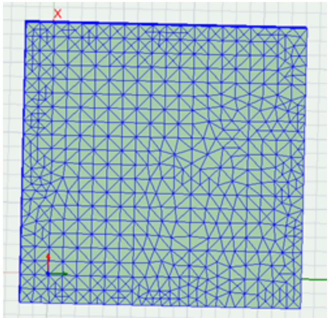

FIGURE 3 – Meshing of the anisotropic particles.

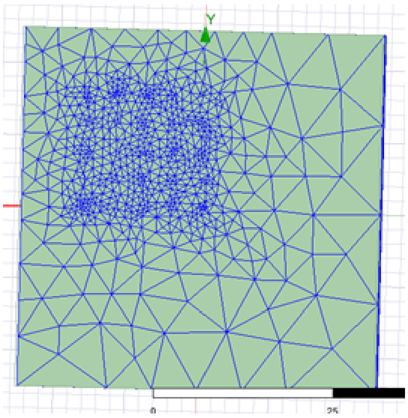

FIGURE 4 – Meshing of the ski, viewed from the face where the magnets are.

The plots 2, 3 and 4 display, respectively, the meshing used for the isotropic and anisotropic particles and the ski.

3.2 Configuration.

All the simulations have a steel 1010 bar, modelling the ski, and four layers of 25 nanoparticles each, placed under the bar, at its centre. Three simulations have been done, each one having a different composition from the others. The first one is composed of only isotropic particles, modelled by spheres, the second one is composed of only anisotropic particles, modelled by cubes and the third one simulates a mix of isotropic and anisotropic particles, at a proportion of 50%-50%.

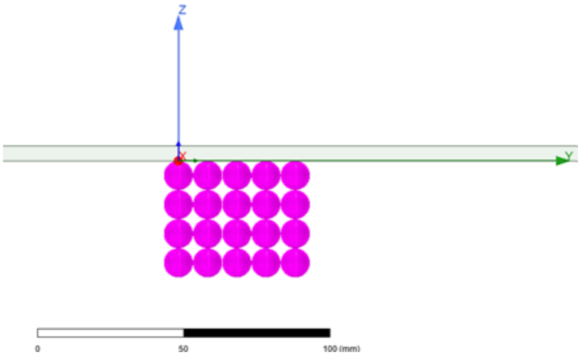

FIGURE 5 – Configuration with only isotropic particles.

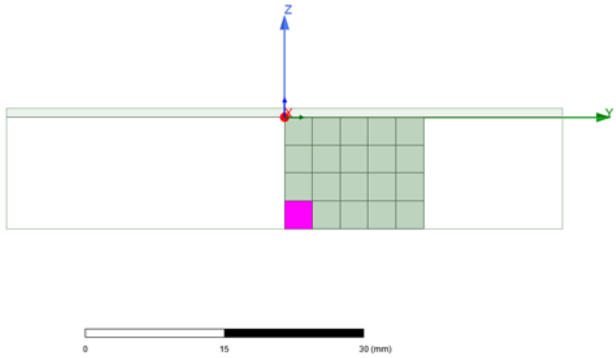

FIGURE 6 – Configuration with only anisotropic particles.

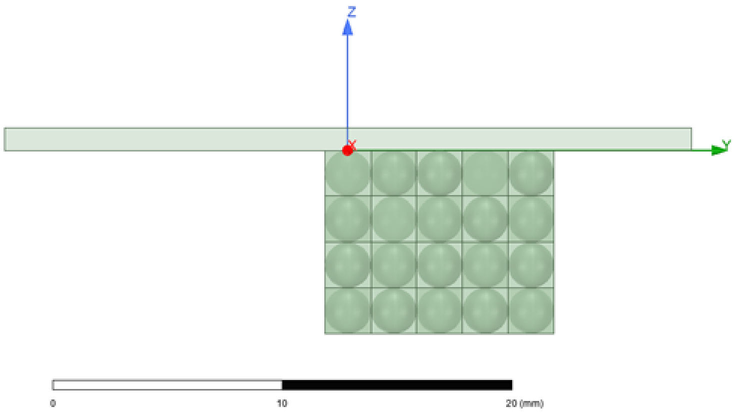

FIGURE 7 – Configuration with 50% isotropic particles and 50% anisotropic particles in alternation.

The pictures shown above display the configuration and the composition in terms of particles for the different simulations.
The following chart lists the different values of the relevant parameters used to simulate the problem.

	Isotropic	Anisotropic		Ski
Radius/Length [mm]	2	4	Length [mm]	50
Intrinsic coercivity H_{ci} [kOe]	9.4	13.7	Width [mm]	50
Residual Induction B_r [kG]	7.6	12.9	Thickness [mm]	10

(4)

It is worth noting that the simulation is run on a portion of ski and not its entirety, otherwise it will take too much time for an equivalent result. Also, since particles have their characteristic length of the order of the nanometre and the length of the ski is of the order of the centimetre and one would like to make a comparison between the magnetic field generated by the three kinds of configurations, one will set the radius/length of the particles up the order of the millimetre. Indeed, one would like to conduct a qualitative study, not a quantitative one, and determine the order of difference in terms of magnetic induction field's magnitude for the three simulations. The following assumptions have been made :

— the particles are in contact with one another and with the ski.

— The magnetic particles have their magnetization oriented along the axis $\hat{\mathbf{z}}$, positively.

3.3 Results.

The following images display the magnetic induction field generated by the magnet particles for each simulation.

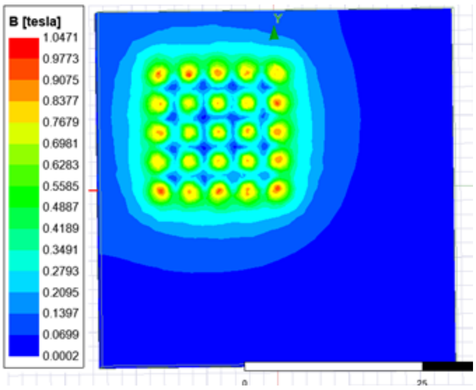

FIGURE 8 – Magnitude of the magnetic induction field $\vec{B}$ for a configuration with only isotropic particles.

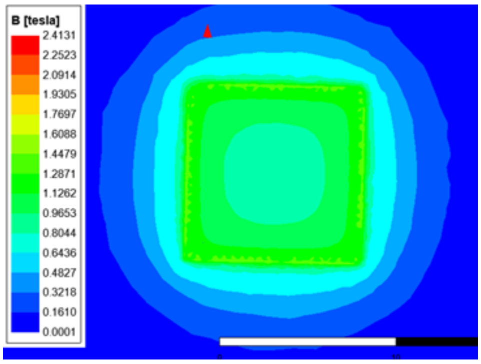

FIGURE 9 – Magnitude of the magnetic induction field $\vec{B}$ for a configuration with only anisotropic particles.

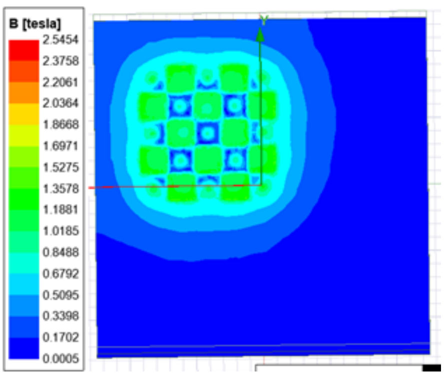

FIGURE 10 – Magnitude of the magnetic induction field $\vec{B}$ for a configuration with 50% isotropic particles and 50% anisotropic particles.

At first glance, one could think that the anisotropic particles configuration exert a greater hold over the ski than the mixed particles configuration and the isotropic particles configuration.
One can calculate the average value of the magnitude of $\vec{B}$, $\langle||\vec{B}||\rangle$, over the surface of the ski in order to check. The following chart reports the value of $\langle||\vec{B}||\rangle$ for

different composition of the magnetic powder :

	100% Isotropic particles	100% Anisotropic particles	50% Isotropic particles 50% Anisotropic particles
$\langle \|\|\vec{B}\|\| \rangle [T]$	0.076	0.211	0.155

(5)

Following the results given by the chart 5, one can conclude that $\langle ||\vec{B}|| \rangle_{Aniso} \approx 2.77 \langle ||\vec{B}|| \rangle_{Iso}$ and $\langle ||\vec{B}|| \rangle_{Aniso} \approx 1.36 \langle ||\vec{B}|| \rangle_{50\% Iso - 50\% Aniso}$. The average of the magnetic induction field's magnitude is significantly higher when using only anisotripic particles rather than only isotropic particles or a mix of the two types of particles.

4 Conclusion

After having simulating, with Ansys' Maxwell3D mode, three different systems composed of only isotropic particles, only anisotropic particles and a 50%-50% mix of isotropic and anisotropic particles in order to find the average magnitude of the magnetic induction field $\langle ||\vec{B}|| \rangle_{Aniso}$ on the ski, one has found that it is almost three times and one and a half times higher, respectively, in the case where the sealskin is composed of only anisotropic than in the cases of only isotropic particles and 50%-50% particles mix. Therefore one should use anisotropic nano-particles of NdFeB for the conception of the sealskin.