Magnetic levitation sliding systems

Medium slider magnetic field evaluation

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1 Motivation

This study was carried out to analyze the behavior of the Medium magnetic levitation sliding system produced by IronBox Srl with respect to the packing instructions for air transport of magnetic materials and the guidelines on limits of exposure to static magnetic fields in conformity with the standard UN 2807, Class 9. According to the International Civil Aviation Organization (ICAO) Technical Instructions (TI) [1], the article is not restricted as a magnetized material (UN 2807, Class 9) if the amplitude of the maximum field observed at a distance of 2.1 m is less than $H_\ell = 0.159$ A/m. This limit, in air, can be expressed in terms of magnetic flux density, as:

$$B_\ell = \mu_0 H_\ell \approx 200\,\text{nT},$$

where $\mu_0 = 4\pi \cdot 10^{-7}\ H/m$ is the vacuum magnetic permeability.

Concerning the limit of exposure to static magnetic fields, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) established it to 400 mT for the general public exposure of any part of the body [2].

The analysis carried out with the methodology described in the following Sections, using the information about the device provided by IronBox Srl, revealed the compliance of the slider with both these limits.

2 Methodology

Given the difficulties to measure very low values of the magnetic flux density, due to the interference of the environment, the uncertainties related to the probe resolution and so on, in this report a hybrid methodology was used. It is based on the development of a numerical model of the device under evaluation, validated with experimental measurements in the near-field region. Then, the magnetic field at larger distances was evaluated by the simulation performed with the numerical model. The numerical analysis is based on 3D-Finite Element (FE) Models obtained by using two different codes (i.e., Simcenter MagNet [3] and EFFE [4]). As for the validation, experimental measurements were performed at different positions using two probes with different ranges. In particular, simulation results at distances of 20 cm and 40 cm were compared with measurements performed with the *AlphaLab DC Milligauss Meter Model MGM*. Instead, simulation values for distances lower than 10 cm were validated by measuring the magnetic field with the *Lakeshore F71 Teslameter* with a three-axis field probe.

In order to measure the magnetic flux density in the near-field region, the device was placed on a moving platform (refer to Figure 1), able to precisely control the position in the space, move along the three axes and rotate about the vertical axis. The amplitude of the magnetic

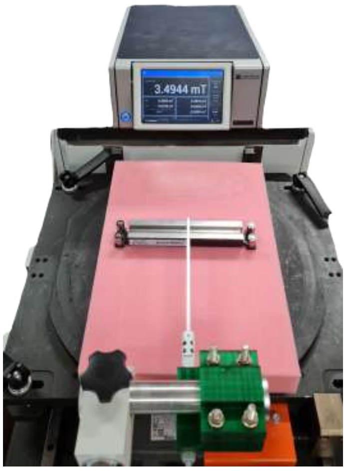


Figure 1: Experimental setup used to measure the magnetic field.

flux density produced by the slider was measured using the *Lakeshore* field probe fixed to a support. The relative position between the slider and the probe was varied in a reduced volume using the moving platform, and the magnetic flux density was measured by changing the slider position. The effect of the iron rail on the magnetic field was also considered by performing the same analysis in both conditions (i.e., without and with the rail in the slider). The *AlphaLab* probe, instead, was used to evaluate the field in the far-field region, reducing the interference with the environment.

3 Results

The device under investigation is shown in Figure 2. The overall dimensions of the slider are 199x45x41.2 mm, while the rail section diameter is 12 mm.

Figure 2: IronBox Medium slider system.

The magnetic field behavior was investigated as a function of the distance from the slider. The following analyses were carried out considering the system of coordinates visible in Figure 3. The Medium slider behavior was analyzed using two different FE software (i.e., Simcenter MagNet and EFFE). Their results were validated by comparing them with measurements of magnetic flux density near the slider, as described in the previous Section. The validated models were then used to investigate the magnetic field behavior 2.1 m away from the slider.

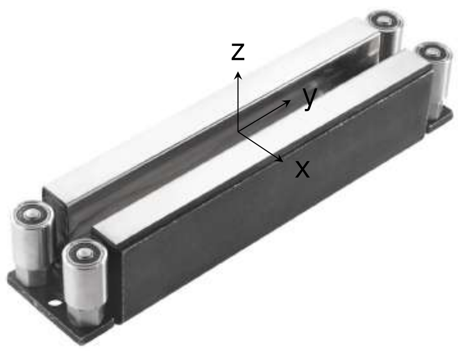
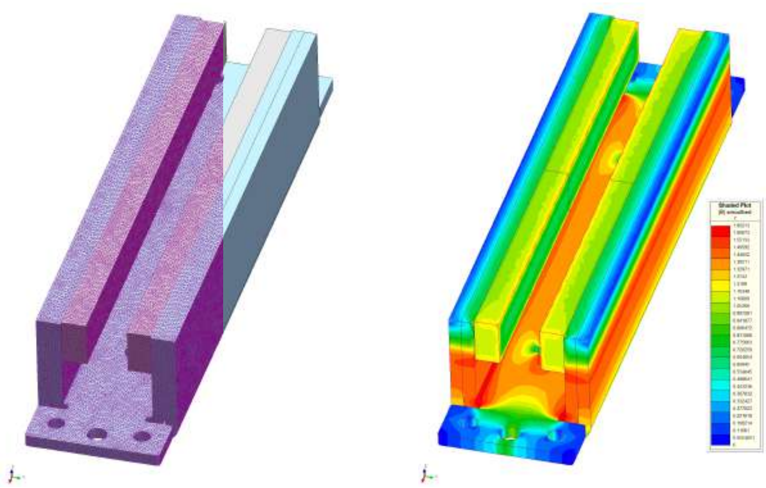


Figure 3: System of coordinates.

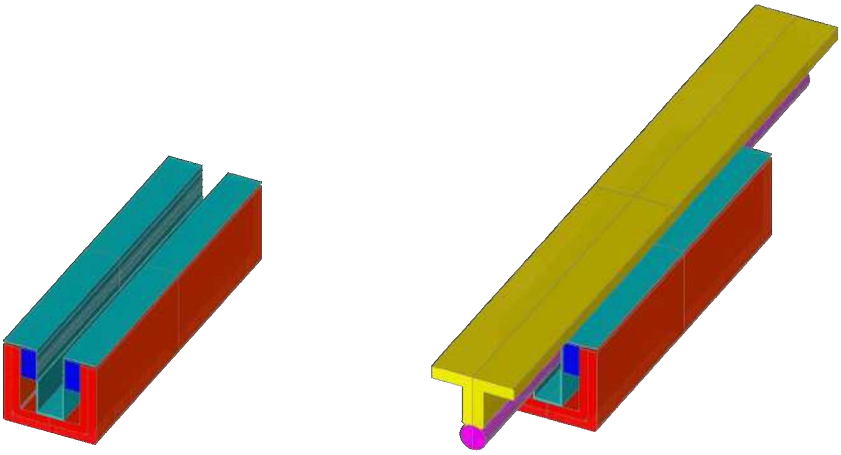
Figure 4 reports the FE model used to derive the magnetic field near the slider with Simcenter MagNet, together with the solution mesh through which the magnetic flux density distribution in the slider was derived.



(a) (b)

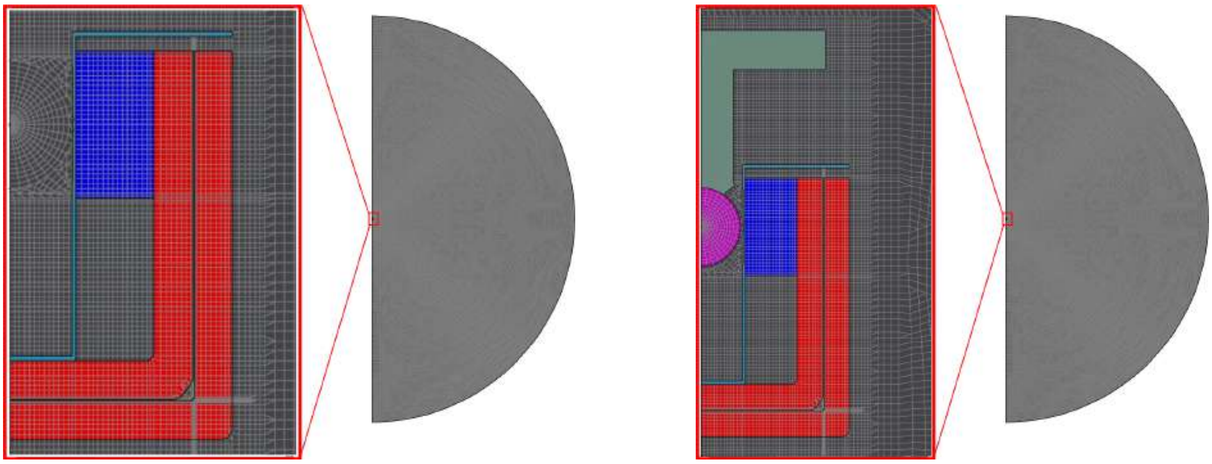
Figure 4: Full-3D FE model of the Medium slider in Simcenter MagNet with detail of the mesh and magnetic flux density map.

The 3D FE model, mesh and magnetic flux density obtained with the EFFE code are shown in Figures 5, 6, 7, 8, and 9.
Even if both the FE models show good consistency with respect to experimental data in the near-field region, the reliability of measurements in the far-field one was limited. Due to the small resolution of the far-field probe, that is several times less the amplitude of the Earth field, measurements may be affected by interference. For this reason, the magnetic flux density at large distances from the slider was obtained using the EFFE software.



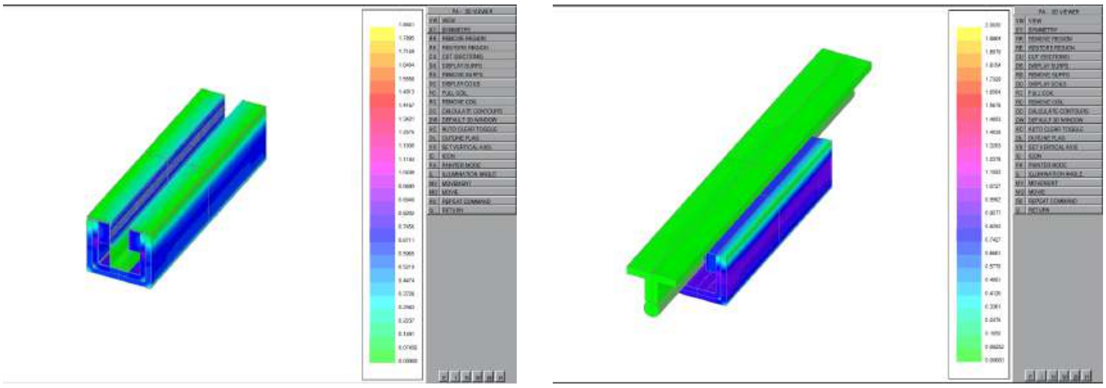
(a) (b)

Figure 5: Full-3D FE models of the Medium slider in EFFE: configurations without (a) and with (b) the iron rail.



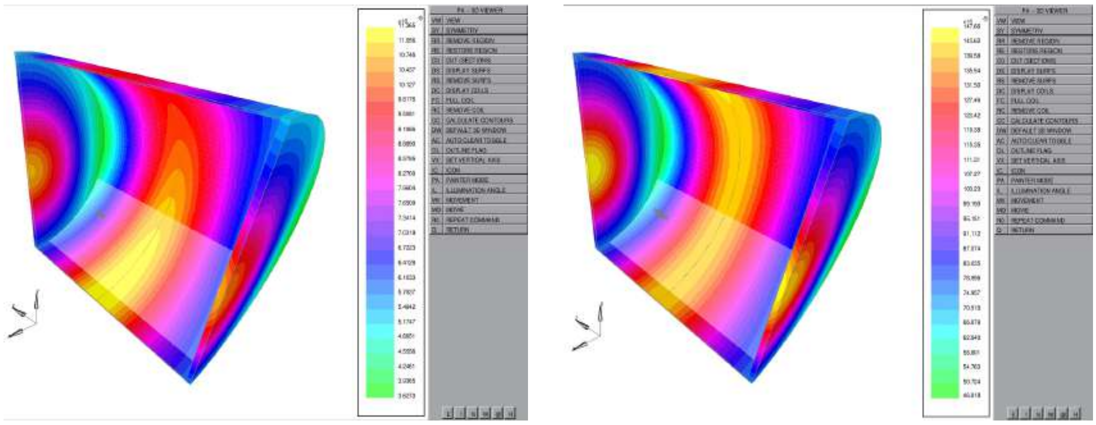
(a) (b)

Figure 6: Details of the mesh of the Medium slider FE models in EFFE: configurations without (a) and with (b) the iron rail.



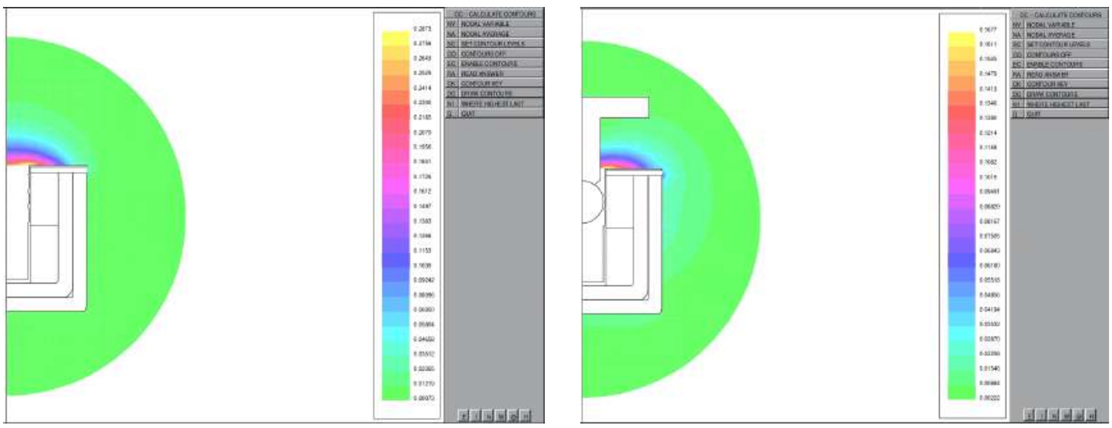
(a) (b)

Figure 7: FE models in EFFE: magnetic flux density maps (without (a) and with (b) the iron rail).



(a) (b)

Figure 8: FE models in EFFE: magnetic flux density maps (without (a) and with (b) the iron rail) on the surface of a cylinder having a radius of 2.1 m and a height of 4.2 m.



(a) (b)

Figure 9: FE models in EFFE: magnetic flux density maps near the slider (without (a) and with (b) the iron rail).

3.1 Near-field region

The magnetic induction produced by the slider assumes its maximum value near the system. In particular, both without and with the iron rail, the maximum value occurs on the top of the slider, in correspondence with the boundary of the magnet on the opposite part with respect to the ferromagnetic support (ref. Figure 9). The slider compliance with the limits established by the ICNIRP can be verified by deriving the magnetic flux density amplitude near the system. Figure 10 reports the behavior of the magnetic induction amplitude with respect to the y-axis direction (see Figure 3), both without and with the iron rail, in correspondence with the point of maximum field on the x-z plane. Simulation results were compared with measured data, highlighting acceptable errors in both conditions, also considering the uncertainties related to the probe position. The maximum value of the magnetic flux density resulted in about 280 mT, obtained without the iron rail.

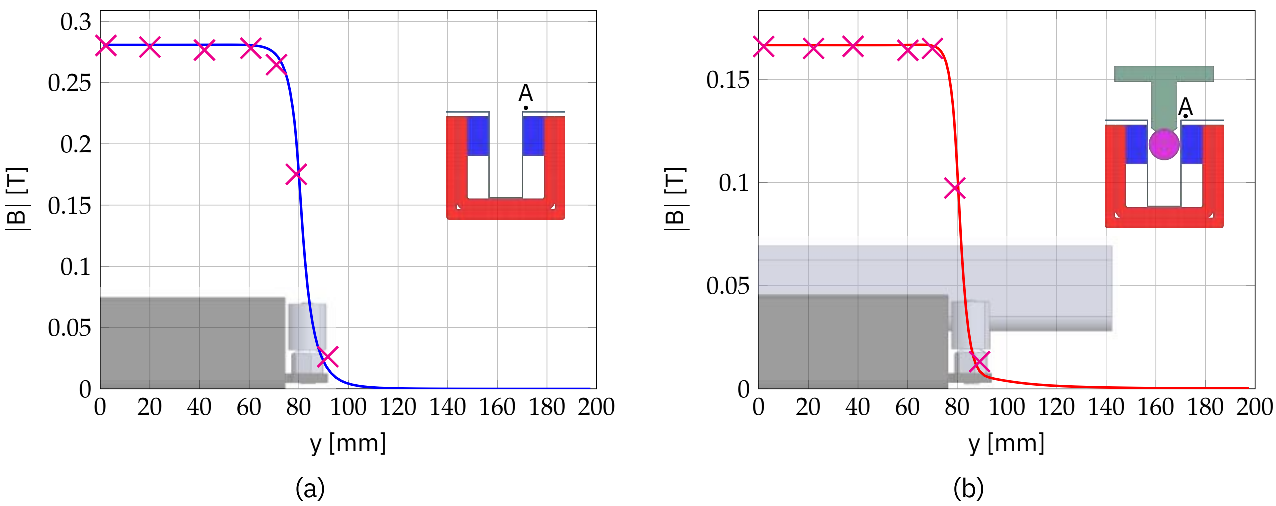


Figure 10: Amplitude of the magnetic flux density as a function of the displacement along the y-axis without (a) and with (b) the iron rail inserted. Values refer to points in correspondence with the top of the slider in the point of maximum field (see point **A**) with y ranging from 0 cm to 20 cm. The magenta crosses highlight experimentally obtained data, with acceptable errors in both conditions, also considering the uncertainties related to the probe position.

The near-field behavior was derived also with respect to the x-axis direction. Figure 11 reports it for x sweeping from 0 mm (i.e., the center of the slider) to 25 mm, in correspondence with the top of the slider and at its center along the y-axis direction (i.e., y=0 referring to the coordinate system in Figure 3). Once again, the behavior was investigated without and with the iron rail, highlighting a smaller field at the same distance when the iron rail was inserted. Simulation results were compared with measured data, resulting in acceptable errors both without and with the iron rail.

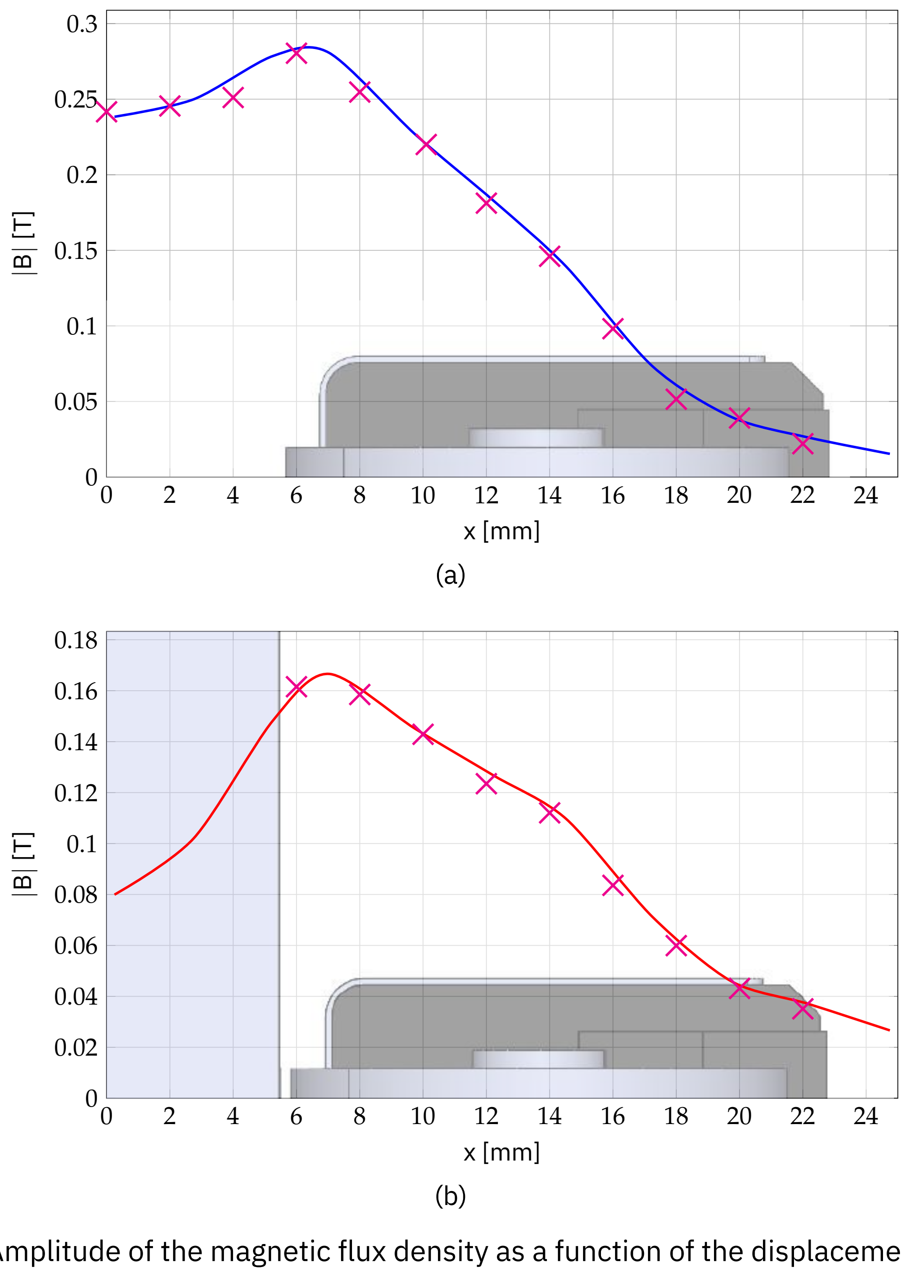


Figure 11: Amplitude of the magnetic flux density as a function of the displacement along the x-axis without (a) and with (b) the iron rail inserted. Values correspond to points in contact with the upper part of the slider with x ranging from 0 mm to 25 mm. The magenta crosses highlight experimentally obtained data.

3.2 Far-field region

The magnetic field behavior far from the slider was investigated to verify the compliance with the ICAO TI guidelines, deriving the amplitude of the magnetic induction produced by the slider at various distances.

3.2.1 Behavior with respect to the x-axis and z-axis directions

Figure 12 reports the simulated behavior of the magnetic flux density amplitude on various circumferences (i.e., radii: 5 cm, 10 cm, 20 cm, 40 cm, and 2.1 m), centered in the middle of the slider. It is worth noticing that the iron rail amplifies the magnetic flux density produced by the slider. This behavior may be accounted for the material saturation, due to the decrease of the magnetic circuit reluctance in presence of the rail. Simulation results without and with the iron rail were compared with the measured values, highlighting small errors in both cases. To improve readability, not all the experimental measurements are depicted in the following figures.

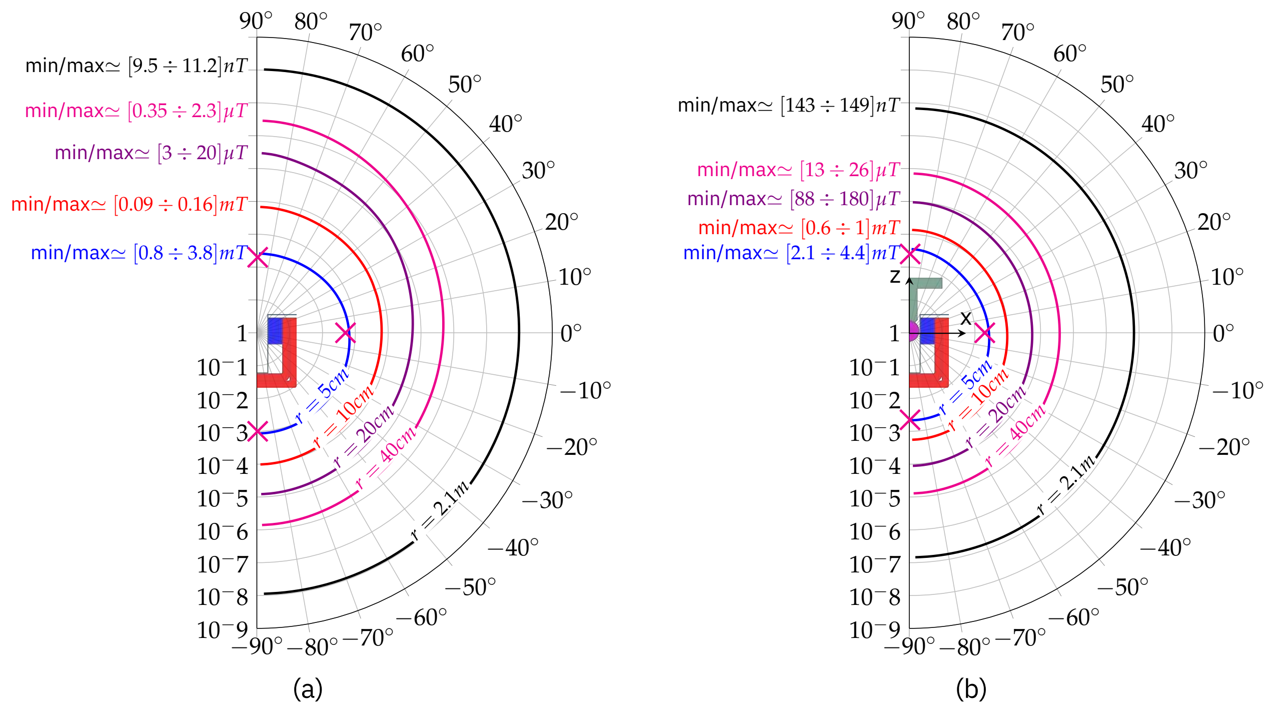
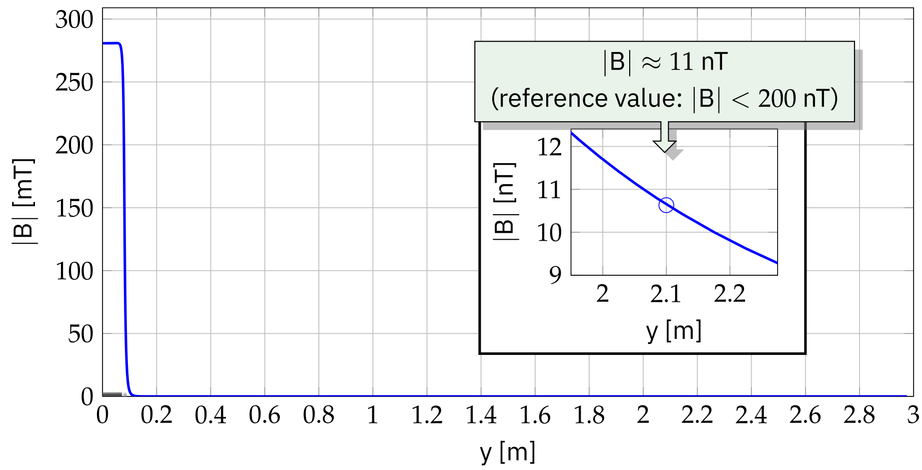


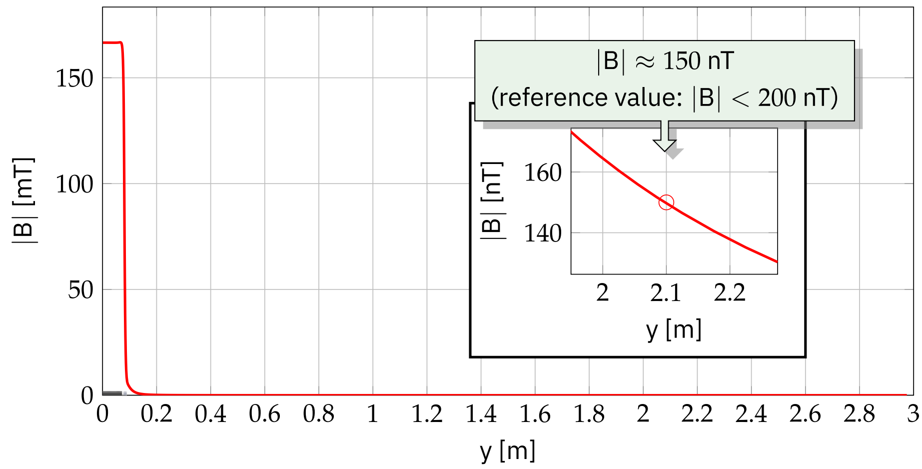
Figure 12: Amplitude of the magnetic flux density on various circumferences (i.e., radii: 5 cm, 10 cm, 20 cm, 40 cm, and 2.1 m), centered in the middle of the slider, as a function of the angle position without (a) and with (b) the iron rail. Values of magnetic field are plotted in logarithmic scale. The magenta crosses highlight experimentally obtained data.

3.2.2 Behavior with respect to the y-axis direction

The behavior of the magnetic flux density amplitude with respect to the distance along the y-direction (referring to the system of coordinates in Figure 3) was investigated in correspondence with the maximum value of B in the near field (point A visible in Figure 10). The magnetic flux density amplitude at y-direction distances from the middle of the slider in the range [0;3] m are reported in Figure 13. The simulation results for y distances below 15 cm were compared with measured values. The comparison was performed without and with the iron rail, highlighting small errors in both conditions. The simulated values of the magnetic flux density amplitude at a distance of 2.1 m (see also Figure 8) resulted in about 11 nT without the iron rail and 150 nT with the iron rail inserted in the slider. Both values are below the reference one set by the ICAO TI.



(a)



(b)

Figure 13: Amplitude of the magnetic flux density as a function of the displacement along the y-axis without (a) and with (b) the iron rail inserted. Values correspond to points of the maximum value of B in the near field (point A visible in Figure 10).

4 Conclusions

This preliminary study aimed to analyze the behavior of the magnetic slider with respect to the air transport regulation of magnetic materials and the guidelines on limits of exposure to static magnetic fields. According to the ICAO guidelines, the article is not restricted as a magnetized material if the amplitude of the maximum field observed at a distance of 2.1 m is less than 0.159 A/m (i.e., the maximum magnetic flux density is less than 200 nT). As for the exposure to static magnetic fields, the ICNIRP directives set the limit to 400 mT.

A hybrid methodology was used to investigate the magnetic flux density produced by the IronBox Medium slider device, without or with the iron rail. Measured data were used to verify the consistency of FE models, which were then used to analyze the magnetic flux density behavior until a distance of 2.1 m.

According to our analysis, carried out with the methodology described, the investigation shows that the slider produces a magnetic flux density of about 11 nT at a distance of 2.1 m when the iron rail is not inserted. This value grows to about 150 nT if the iron rail is present. In both configurations, the magnetic flux density at 2.1 m is lower than the limit of 200 nT.

Concerning the near-field results, simulated and measured data highlighted a maximum value of magnetic flux density of about 280 mT without the iron rail and about 165 mT with the iron rail inserted. Both values are smaller than the limit of 400 mT.

However, further in-depth analyses may be performed in order to confirm these results by means other models (e.g., [5, 6, 7, 8]).

References

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