Influence of lightning at a magnetic anchor point

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Release management

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Introduction
Scaffold anchor points can be used in an outdoor installation. This means that lightning could strike. The question is how the magnet will respond to this. This document will determine what the expected impact is in a worst case scenario to be determined.

Description of the situation
A scaffold is always used next to a metal object, like a tank. Due to safety, this object is always connected to the local electrical ground using a PE ground connection with sufficiently low impedance.
The scaffold is also connected to the ground with its own ground connection. This is standard procedure. There are no known problems with this installation. If lightning strikes, everything will remain intact.
The anchor magnets are not deliberately electrically connected to the object or the scaffold. If a coating has been applied to the object, the electrical impedance between the scaffolding pipe and the object will be relatively high: several ohms are not unlikely. The coating can also be of such a nature and quality to produce an insulating layer. This will have a stress resistance level that cannot be higher than a few kV/mm (observe the field increase due to points and imperfections).
If the magnetic anchor point is located on a unmachined object, the electrical connection between the object and the magnet will be relatively good.
A secured bolt connection that connects two bare metal strips has an electrical impedance of at least a few μΩ.
The connection of a magnet and an object will therefore have an impedance ranging from several μΩ to insulator values with an overvoltage of several kV/mm.

Drawing:

Object Scaffold Anchor points in red

Ground point Ground point

Figure 1: Scaffold with anchor points secured to an object

In a situation where lightning strikes the scaffold, (a part of) the current could run to the object through a magnet.

Characterization of the lightning
We assume the idea of a standardized lightning pulse of 1 μs rise time and 250 μs end time (e-power). This means a frequency content of at least 4 kHz.
Lightning current size with very good conductivity: 40 kA.
Lightning voltages are typically around 5 MV.
With these rise times, no conduction will occur through the full material. The current will be limited to the surface. This is called penetration depth. With faster phenomena (higher frequencies) the penetration depth is smaller. The penetration depth is determined using:

$$d = 1/\sqrt{(\pi.\mu_0.\mu_r.\sigma.f)}$$

where:
d - penetration depth in m
μ_0 - absolute permeability in H/m
μ_r. - relative permeability
σ - conductivity (= 1/resistivity) in S/m
f - frequency in Hz
For carbon steel and 4 kHz the penetration depth is approximately 0.1 mm.

Elaboration

Lightning can strike at two principally different locations:

point A – the object
point B – the scaffold

Electrically, there is a parallel circuit from the resistance of the object parallel to the resistance of the scaffold. First, the DC resistance is determined. Then the HF impedance. This is determined first for the object and then for the scaffold. Phase shifts are not taken into account.

Resistance and impedance of object

For example, take a steel tank of 7 mm thick steel, 35 m high and 30 meters in diameter. Essentially, this is a short tube with a large diameter.

The resistivity of carbon steel is: 0.18 10^{-6} Ω.m (DC value). For the lightning strike a penetration depth of 0.1 m should be taken into account.

This tank will have a DC resistance of approximately 5.10^{-6} Ω. With a DC current of 40 kA, when the full diameter is used, a voltage of $U = IxR = 40.10^{3}.5.10^{-6} = 200$ mV is generated.

However, for a lightning pulse, only the outer 0.1 mm contributes to the conductivity (outer wall and inner wall 0.1 mm each). Furthermore, not the entire tank outline contributes to the impact, which only takes place at one point. It is estimated that the time needed for the voltage wave to get from the top of the tank edge downwards also implies expansion in width.

On a flat surface it looks as below.

Figure 2: Results tank wall with lightning strike course

The HF behavior provides an impedance of 35 times higher than the DC resistance. Since a part of the tank wall participates, the resistance is increased by the ratio of the surfaces: 3290/1225 = 2.7 times as high. The DC resistance will increase by a total of 35 x 2.7 = 94.5 times from 5 10^{-6} to 472.5 10^{-6} Ω. The voltage will also increase by 94.5. This results in a maximum of 18.9 V between the top and the bottom of the tank. This will not lead to any problems.

Resistance and impedance of scaffold

The electrical impedance consists of four scaffolding pipes in parallel with a height of 35 meters. A scaffolding pipe of 4 meters weighs 19.1 kg. With an sg of $7.8x10^{3}$ kg/m^{3} the steel diameter of the scaffolding pipe is $0.6x10^{-3}$ m^{2} = $0.6x10^{3}$ mm^{2}. This results in a wall thickness of 3 mm.

The electrical resistance at a height of 35 meters will then be approximately 10 m Ω (DC value) per pipe. Four pipes in parallel have a DC resistance of 2.5 m Ω. When a current of 40 kA runs through, a voltage of 100 V is generated.

For a lightning current that only passes through the outer 0.1 mm (outside and inside of tube) the impedance increases 15 times: 37.5 mΩ. This also generates a 15-fold voltage: 1500 V. Again, this will not yet lead to any problems.

Power distribution due to lightning

It is important to determine how much the current can increase through an anchor point in a worst case scenario in case of a lightning strike in B. The worst case scenario will occur when one of the upper anchor points is electrically and correctly connected with the object and all the other anchor points are not. This is a highly unlikely situation. A voltage difference between the scaffold and the object of 1500 – 18.9 V will result in a breakdown from the magnet sole to the object at more than one magnet. This is, however, in case of a very worst case. The electrical diagram in that situation will be as below:

Impact

Robject = 472.5 µΩ
Rscaffold = 37.5 mΩ

Earth

Figure 3: Electrical display of scaffold with one conductive anchor point to an object

Electrically, the ratio of the currents at an impact in B will be the inverse ratio of the resistors. This means that the ratio of current through the object and current through the scaffold will be 79:1. Almost the entire lightning current that strikes in B will go to the object through the anchor point.

This current will run across the outside of the anchor point and will be distributed over the outer surface. The associated magnetic field will also remain on the outside of the magnet. Roughly, after each penetration depth a factor e (natural log base) will provide attenuation of the magnetic field. For a characteristic distance of 10 mm between the current path and the magnet a factor of approximately e^{10} = 22,000 attenuation will occur.
To demagnetize Neodymium a field of approximately 1MA/m is required. When the permanent magnets are at a distance of 1 cm from the current path of the lightning and solid steel is located between them, the current on the outside will have to generate a field that is 22,000 times larger.
According to Maxwell $H = I/(2.\pi.d)$, where d is the distance between the current path and the magnet.
A lightning current concentrated on one line creates a field at a distance of 1 cm from:
H = 40 kA/(2x3.14x0.01) = 640 kA/m= 0.64 MA/m. This is a factor of 34000 too small to be able to demagnetize. The behavior of the steel is completely neglected here.
In practice, the current will not follow one line, but will be distributed across the magnet surface. This leads to lower current densities and consequently also lower fields at the location of the permanent magnets in the magnet.

Conclusion

Even in a worst case scenario where one anchor point would feed the entire lightning current of 40 kA, no demagnetization of the Neodymium magnets in the anchor point is to be expected.