300 kHz AC Dipole Model with MnZn Ferrite

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The Mu2e AC Dipole magnet should have 12 mm gap, the peak field 160 Gauss, and length 3 m. Because magnet will work in the continuous mode operation at 300 kHz, there will be high power losses in the ferrite core. It is proposed to build the 0.5 m long magnet model to investigate and confirm the magnet performance and the concept. The 3 m long magnet will be assembled from 0.5 m long identical sections. Besides left and right conductors will be powered from separated resonant circuits of power supply. It will substantially reduce the peak voltage to the ground.

Magnetic Design

It was chosen the H-type magnet configuration shown in Fig. 1. The results of field calculation is shown in Fig. 2 – Fig. 3.

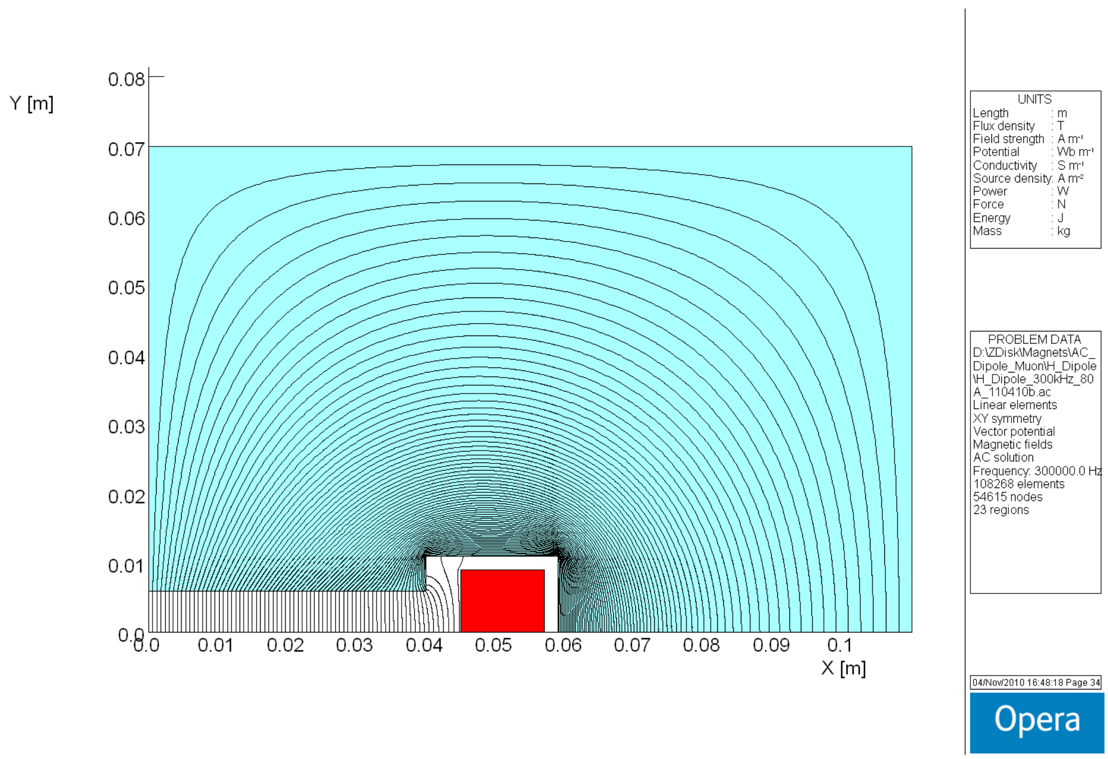

Fig. 1. Magnetic flux lines.

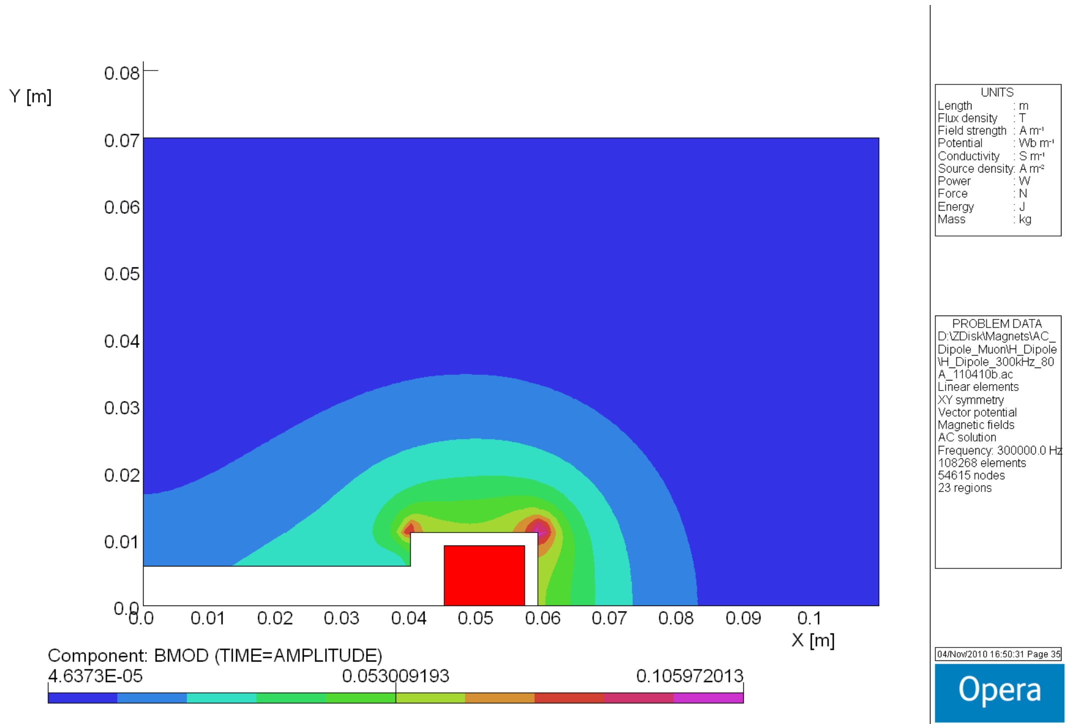

Fig. 2. Flux density in the ferrite core.

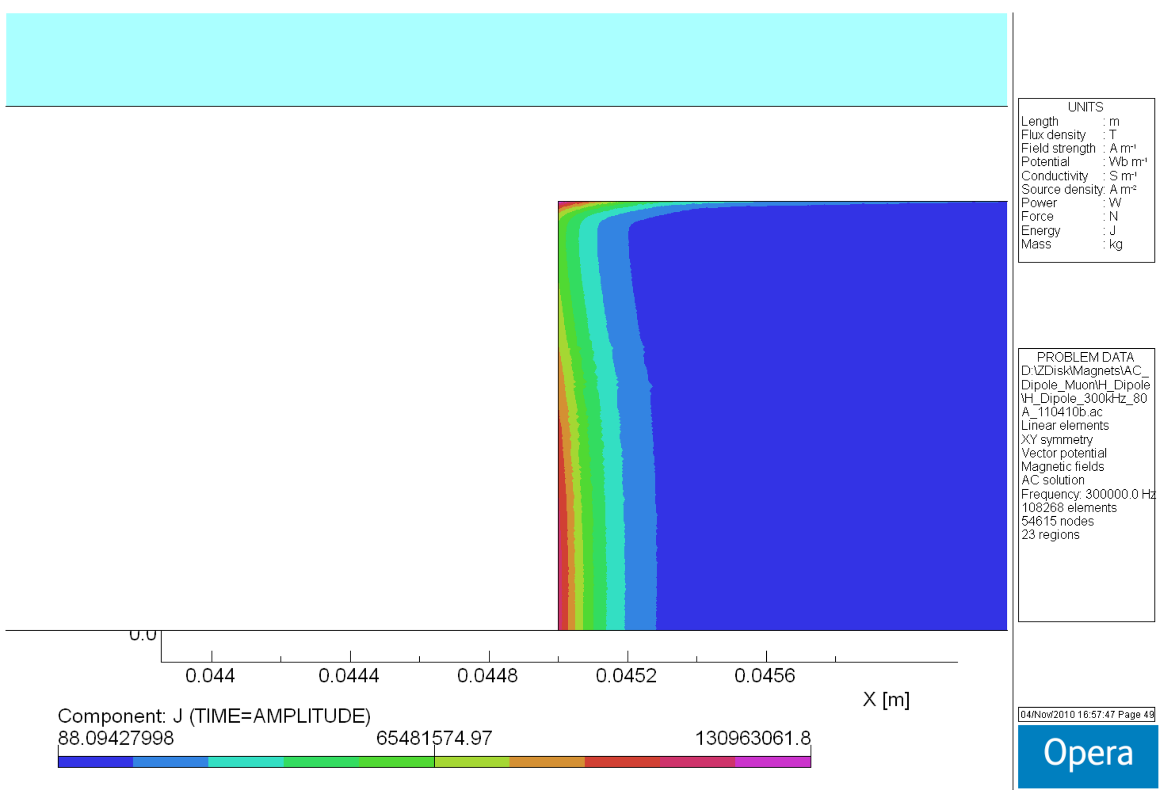

Fig. 3. Current density distribution. The skin depth is only 0.13 mm.

During 2009-2010 there were investigated several NiZn and MnZn ferrite plates having thickness 5 mm and 10 mm. Initial results were published in [1]. The NiZn ferrite has very high resistivity but large hysteresis losses. The MnZn ferrite was optimized by manufactures to reduce total losses in high frequency devices. The test results showed the advantage of MnZn ferrite material which had lower total losses defined by hysteresis and eddy current effects. The measured of ferrite MN60LL properties is shown in Fig. 4.

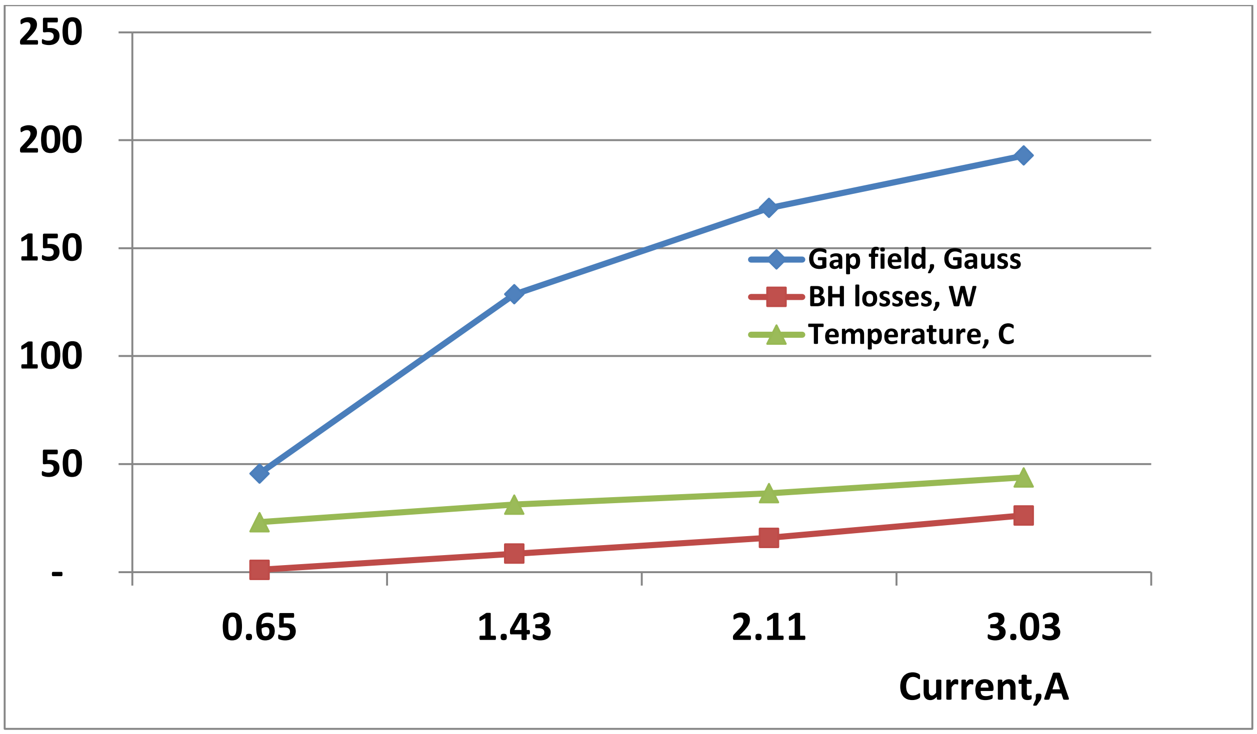

Fig. 4. Measurement results for 2x5 mm ferrite plates assembly at 300 kHz.

Nevertheless, the value of these losses is large because the magnet works continuously at 300 kHz frequency. It causes the ferrite temperature rise and the proportional material performance reduction. Ferrite plates should be as thin as possible. The two 5 mm MnZn plates have two times lower losses (~16 W) than the single 10 mm plate. The discussion with vendor will be useful if the plate thickness could be further reduced to 3-4 mm for the shown in Fig. 6 dimensions.

Magnet model concept

The magnet model has 0.5 m lengths and cross-section shown in Fig. 5. The magnet excited by two single turn coils wound around yoke backlegs as shown in Fig. 5. The copper conductor has dimensions 12 mm x 18 mm with the hole ø 8 mm. It should be noted, that the skin depth at 300 kHz frequency is only 0.13 mm and all current concentrated close the the magnet gap area (See Fig. 3). The conductor losses could be reduced by using Litz cable wound around a cooling pipe. The magnet cooled by the water flowing through the conductor hole. The special attention should be paid on the ferrite area cooling (close to the conductor) where generated the peak power losses. If this area will be overheated the ferrite properties may obtain irreversible degradation. So, the thickness of conductor electrical ground insulation should be optimized for a better thermal conductivity.

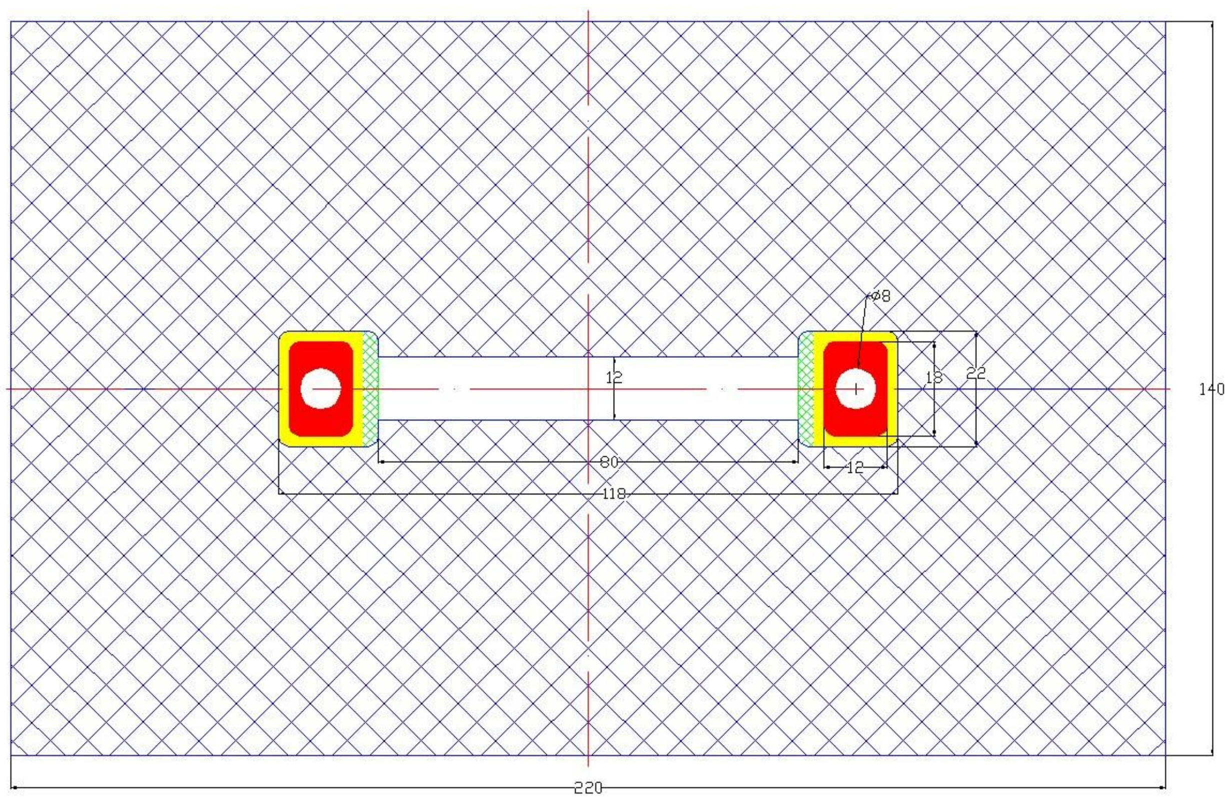

Fig. 5 Dipole magnet cross-section.

The magnet splitted in the middle plane and the half-cores have the length 500 mm. Plates are electrically insulated by an enamel insulation or by a thin kapton layer. The ferrite plate dimension shown in Fig. 6.

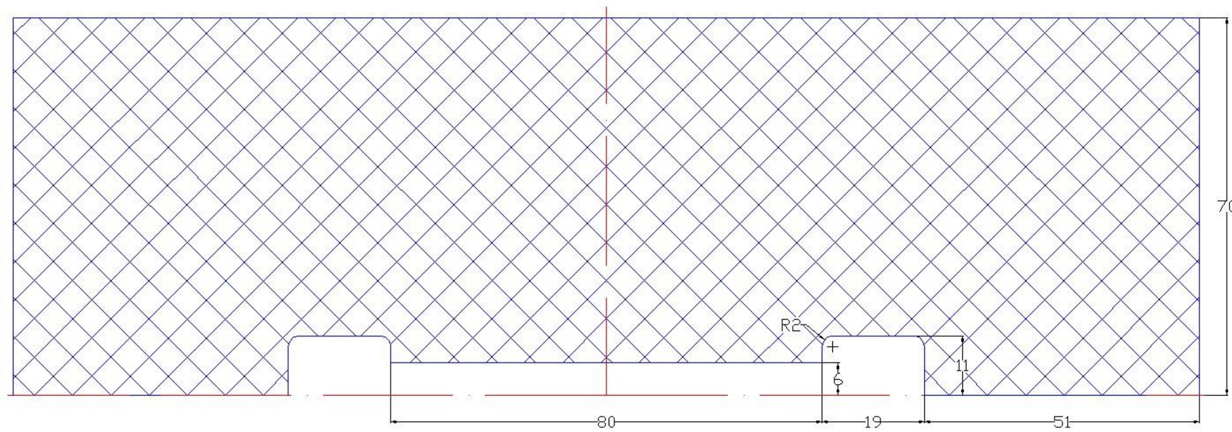

Fig. 6. Ferrite plate cross-section.

For the long 3 m magnet the hollow copper conductor will go all the way through the magnet. The thin copper or Litz cables leads will connect the main conductor to power supply resonant sections. The dipole magnet parameters presented in Table 1.

Table 1

Parameter	Units	0.5 m magnet	3 m magnet
The peak field	T	0.016	0.016
Current sine wave frequency	kHz	300	300
Peak current	A	160	160
Inductance	μH	4.8	29
Inductive voltage	kV	1.5	6 x 1.5
Number of sections		1	6
Number of turns		1	1
Ferrite type		MN60LL	MN60LL
Ferrite plate thickness (max)	mm	5	5
Ferrite losses	kW	1.2	7.2
Conductor losses	kW	0.15	0.9
Total losses	kW	1.5	9.0