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Research on Spatial Distribution in Power Frequency Magnetic Field Immunity Test

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Abstract. At present, the automation level in the power frequency magnetic field immunity test is relatively low. The placement and rotation of the tested equipment are manually done, which has health implications on lab technicians caused by long-term exposure to magnetic fields. This paper uses finite element simulation software to study the spatial distribution of the power frequency magnetic field. We started by building a simulation model of the power frequency magnetic field, then set up the air region, copper coil material, and magnetic field parameters. As a result of the simulation, we obtained the magnetic flux density model and the magnetic field arrow diagram. We then deduced the safe operation distance of test by referencing GB 8702-2014 and the simulation result. The simulation model's and algorithm's effectiveness are then verified by real-world measurement results of the spatial distribution of power frequency magnetic field.

Keywords. Power frequency magnetic field immunity test, spatial distribution, finite element simulation, safe operation distance

1. Introduction

An electric field and a magnetic field constitute an electromagnetic field together. Due to different features of a magnetic field and an electric field, they cause different biological health issues. According to prior researches, a magnetic field is far more harmful to the health of a living being than an electric field. A power frequency magnetic field is generated by the power-frequency currents in a conductor. The waveform of a test magnetic field is a power-frequency sine wave. The test magnetic field is imposed on the subject equipment by the immersion method.

During the power frequency magnetic field immunity test, the test equipment and the magnetic field coil are placed and rotated manually. Specific test equipment requires high strength of magnetic field and long staying period, e.g. electricity meter. According to OIML R46-1/-2:2012 [1], measure the error changes in the two load current conditions of $10I_{tr}$ and I_{max} upon a power factor of 1.0 and a continued magnetic field of 0.5mT; impose the magnetic field in 3 mutually-vertical directions of the meter upon a continued

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magnetic field of 0.5mT and a test period of 3s without load currents. The continued magnetic field is 1.25mT with 20x theoretical starting time. Therefore, the test period of a single electricity meter may be 1h or so. The impacts on the physical health of the test personnel can't be ignored due to long-term short-distance direct contact with the magnetic field. In the current standards, however, there is no specific requirement on the distance between the test personnel and the test equipment. Therefore, it is particularly important to research on the spatial distribution of the magnetic field during an immunity test of power frequency magnetic field and analyze and infer the safe operation distance of a test.

2. Status-Quo of Research at Home and Abroad

2.1. Status-Quo of Research

There are primarily two methods for the research on spatial distribution in a power-frequency magnetic field test. First, directly place the magnetic field probe on a test bed for measurement. If it is disabled due to difficulty in field measurement, an equivalent model will be established for the measurement. Second, perform modeling and simulation of the research subject, conclude on the necessity for research and finally make a comparison with the real experiment data to justify modeling.

Yu Hongwen, et al researched on the phase shift in the same frequency under a power-frequency magnetic field and proposed on immunity devices [2] in response to the latest standards on electricity meter. Due to complexity and diversity of the test subjects, there are limited researches on the power frequency magnetic field test of an electronic and electric product. The available researches on the power frequency magnetic field test of an electronic and electric product are primarily concentrated on the test equipment, the calibration method and the biological effects of power-frequency magnetic field. For instance, Zhao Shizhen et al researched on the design of coil upon electromagnetic compatibility, including the features and structure of a coil, as a reference for further research on power-frequency magnetic field tests [3]. Huang Wenguang et al used existing power-frequency magnetic field equipment to research on the basic principles, magnetic induction calculation and prior cases [4]. Han Bao et al analyzed the impacts of converter and coil in power-frequency magnetic field test equipment on the test results [5].

2.2. Research Work in the Thesis

Simulation software COMSOL Multiphysics is adopted to establish the spatial distribution model of magnetic field. The GSH250A power-frequency magnetic field test equipment of SIPAI from ZJIM is adopted as the reference. Simulation software is used for modeling and simulation of the spatial distribution of power-frequency magnetic field test. The equipment coil has an inner diameter of 150cm, an outer diameter of 164cm and a width of 7cm. the inner diameters of two parallel coils are 70cm from each other and their outer diameters are 84cm away from each other. The equipment is 200cm high. As the spatial distribution plan, the center of coil is taken as the origin and five planes are chosen at an interval of 0.4m (as Figure 1 shows). Twenty points at an interval of 0.375m are chosen on each plane (as Figure 1 shows) and a total of 100 points are chosen to establish the spatial distribution model. The magnetic field strength data of a spatial position are obtained through simulation. Then a teslameter is used for practical measurement of the magnetic field data at 100 spatial points in the same position to verify the correctness of the simulated data. Finally, the safe operating distance during a power-frequency magnetic field test is concluded according to the electromagnetic environment control limits of the latest GB 8702-2014 [6].

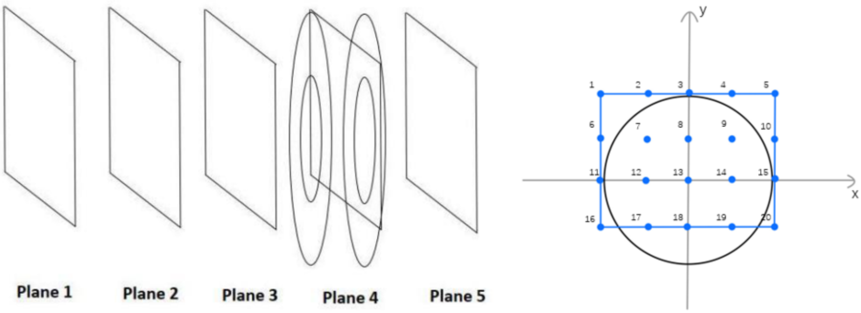

figure 1. Schematic diagram of spatial distribution test plan and measuring points within plane.

3. Simulation of Spatial Distribution in a Power-Frequency Magnetic Field Test

COMSOL Multiphysics is simulation software of physical fields based on finite element mathematical method. It includes using partial differential methods to research on and simulate physical fields.

The spatial distribution simulation of the power-frequency magnetic field test has Maxwell equation as the core; first, a 3D spatial module is established; choose electromagnetic field module in field volume and add it; choose the frequency domain via the solver and then analyze it. The steps are as follows:

- Establish the required geometric structure which basically comprises the external cubic structure and two parallel circular coils. First, obtain the basic coil structure through the establishment of a plane geometric circle and then set the parameters and tensile changes and z-ordinate parameters to obtain two parallel circles. Then produce the external cubic structure and make it transparent (as Figure 2 shows).
- Perform material operations, produce the air domain and the copper coil material and set their parameters.
- Set the structural magnetic field, choose even multi-coil wires, set AC input and define the AC input face. The figure shows the AC input face wherein physic field control network is adopted for the grid and the size of cell is set (as Figure 3 shows).
- The magnetic flux density mode and magnetic field arrow chart are acquired through calculation (as Figure 4 shows).

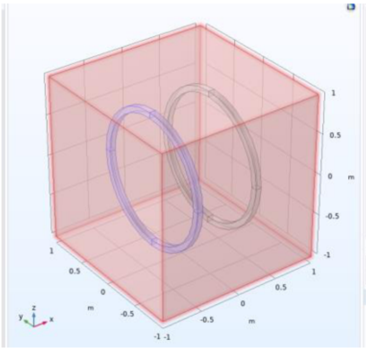

Figure 2. Establish the Structure Diagram.

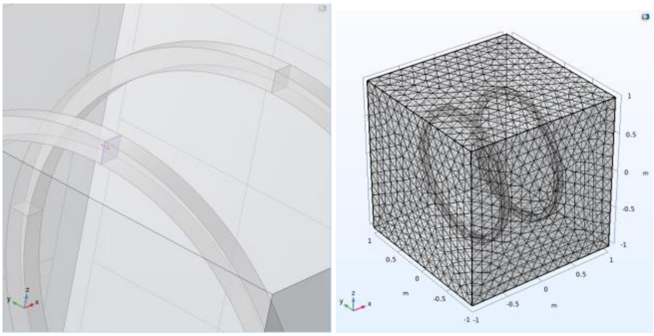

Figure 3. AC Input Face Diagram (left) Grid Section Diagram (right).

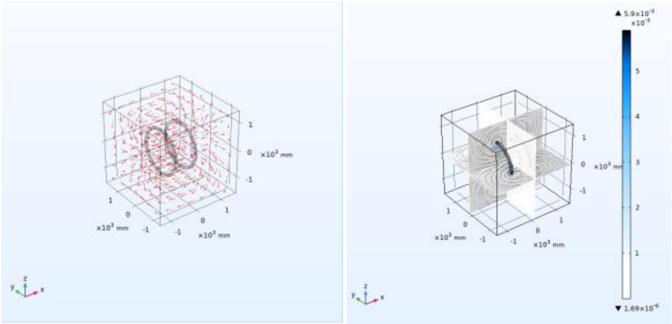

Figure 4. Magnetic field arrow chart (left) and magnetic flux density mode diagram (right).

3.1. Simulation Results

Use COMSOL Multiphysics to calculate and obtain the image of the magnetic flux density mode of the simulation results, as the figure shows. The lines in Figure 5 indicate magnetic induction lines. Darker color indicates greater strength of magnetic induction. The circle in the diagram is the Helmholtz coil. The magnetic induction lines excited by the coil demonstrate a plurality of closed curves on three planes. The density of magnetic induction lines indicates the strength of the magnetic field. The figure shows that the magnetic induction lines around the Helmholtz coil are dense while those farther away from the Helmholtz coil have a lower density.

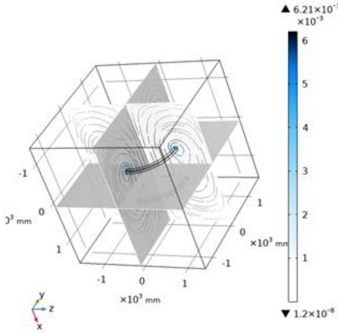

Figure 5. Image of Magnetic Flux Density Mode of Simulation Results.

The accuracy of the model can be verified according to the convergence diagram. As Figure 6 shows, convergence is concluded if the error is 0.0001<0.01 upon the third iteration. Therefore, the simulation model satisfies the requirement.

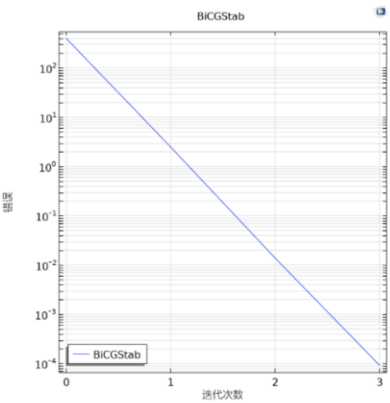

Figure 6. Convergence Diagram of Simulation Model.

Perform parametric scanning of the fixed points. Change the scanning step width successively to obtain the data of simulated magnetic flux density mode at a total of 100 points on 5 planes.

	Plane (mT)	1 Plane2 (mT)	Plane3 (mT)	Plane4 (mT)	Plane5 (mT)
1	0.053	0.003	0.064	0.029	0.021
2	0.329	0.082	0.328	0.064	0.03
3	0.033	0.085	0.373	0.071	0.035
4	0.34	0.079	0.351	0.069	0.041
5	0.059	0.004	0.049	0.038	0.023
6	0.255	0.052	0.258	0.067	0.037
7	0.137	0.131	0.142	0.088	0.042
8	0.128	0.136	0.135	0.085	0.048
9	0.142	0.123	0.146	0.081	0.049
10	0.23	0.052	0.238	0.055	0.036
11	0.244	0.063	0.259	0.072	0.038
12	0.138	0.129	0.131	0.083	0.044
13	0.131	0.131	0.125	0.088	0.047
14	0.133	0.128	0.133	0.09	0.041
15	0.434	0.059	0.425	0.061	0.033
16	0.209	0.042	0.207	0.058	0.04
17	0.161	0.152	0.155	0.082	0.051
18	0.14	0.118	0.146	0.085	0.051
19	0.17	0.116	0.163	0.085	0.053
20	0.205	0.039	0.206	0.055	0.038

4. Measurement of Spatial Distribution of Power-Frequency Magnetic Field

The power-frequency magnetic field test device used for the measurement comprise external equipment and induction coils. External equipment supplies the required AC currents and the Helmholtz coil generates the magnetic fields and thus form the complete test equipment (as Figure 7 shows). AC currents in 50Hz and 1.1A are used for the test primarily to generate the magnetic induction strength of 0.125mT in line with the simulation software.

Figure 7. Power-frequency Magnetic Field Experimental Equipment(left) and Teslameter and Standard Probe(right).

In order to verify the correctness of the simulated model of spatial distribution of power-frequency magnetic field test, a teslameter is adopted to measure the magnetic field data at 100 points on 5 planes; and the simulation data are analyzed through comparison. The real-time magnetic field data are read by the 8053 electromagnetic radiation teslameter of Narda; EHP-50C standard magnetic field probe is adopted (as Figure 7 shows) which is connected to the teslameter via an optical fiber. The measurements of the teslameter are magnetic induction strength data in mT.

The measurement is performed in a lab of 20°C. For the purpose of this measurement, the spaces around the test equipment are divided into 5 planes (as Figure 1 shows) at an interval of 0.4m. Choose 4 points along one column on the same plane and a total of 5 columns and 20 points are defined, with an interval of 0.375m between two points. As such, a regular rectangle (as Figure 1 shows) is constituted. Totally 100 points are measured on 5 planes, thus constituting a regular cube.

Real measurements at 100 points on 5 planes

	Plane1 (mT)	Plane2 (mT)	Plane3 (mT)	Plane4 (mT)	Plane5 (mT)
1	0.049	0.006	0.05	0.032	0.018
2	0.32	0.071	0.318	0.058	0.025
3	0.03	0.092	0.344	0.062	0.027
4	0.335	0.071	0.334	0.06	0.025
5	0.052	0.008	0.052	0.033	0.018
6	0.25	0.042	0.249	0.053	0.024
7	0.131	0.12	0.133	0.078	0.033
8	0.125	0.124	0.126	0.075	0.036
9	0.14	0.123	0.139	0.077	0.035
10	0.228	0.04	0.229	0.055	0.025
11	0.24	0.059	0.24	0.06	0.026
12	0.12	0.123	0.119	0.077	0.036
13	0.113	0.12	0.114	0.074	0.038
14	0.12	0.122	0.121	0.076	0.037
15	0.416	0.053	0.417	0.061	0.026
16	0.194	0.032	0.193	0.049	0.022
17	0.145	0.141	0.144	0.073	0.031
18	0.132	0.103	0.133	0.073	0.034
19	0.151	0.108	0.152	0.072	0.032
20	0.196	0.033	0.195	0.048	0.023

5. Analysis of Errors and Results of Simulated and Measured Data

Produce a thermodynamic chart of the simulated and measured data. The horizontal ordinate is the serial number of planes and the longitudinal ordinate is the serial number of measuring points.

According to Figure 8 thermodynamic chart of simulation results: Point 15 of Plane 1 and Plane 3 is highly different from other points around in color primarily because Plane 1 and Plane 3 are the two planes closest to the Helmholtz coil and have similar data and thus are symmetric to each other. Compared with other points, Point 15 is closer to the coil and therefore has sharp color changes. As the figure shows, it gets brighter from Plane 2 to Plane 3, indicating data increase; it gets darker from Plane 3 to Plane 5, indicating data decrease. It means that the magnetic induction strength is lower when it is farther away from the Helmholtz coil. Thermodynamic chart of the measurements also has the same rule, which proves that the simulated spatial distribution rule of the magnetic field conforms to the de-facto measurement.

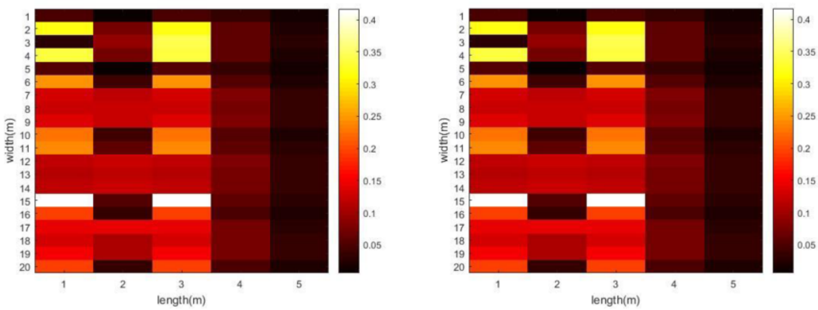

Figure 8. Thermodynamic Chart of Simulation Results(left)and measurements(right).

Take simulation and measurement methods as the independent variable and the obtained magnetic field data are the dependent variable for independent sample *t* test, Levene variance and other homogeneity test of the data of 200 points. If the Levene variance significance *P* >0.05, the two groups of data may be deemed to have the same variance, indicating that the two methods are not significantly different; calculation shows that the *P* value of the two groups of data is 0.879 (see Table 1) and therefore the variances of the two independent samples can be taken to be homogeneous. Therefore, when variance homogeneity is satisfied and it is assumed the significance is higher than 0.05 in equal variance, mean value and other homogeneity *t* tests, it can be concluded that the two groups of data are not significantly different from each other in variance. As the significance is 0.473 which is higher than 0.05 based on the simulated and the measured data, it is thus believed that the two groups of data are not different from each other with a significance level of 0.05. It shows that the simulation model and the simulation algorithm are effective.

Table 1. Levene Variance Homogeneity Test and Mean Value Homogeneity t- test.

	F	Significance	2-tailed significance	Average value difference
Assume equalvariance	0.017	0.879	0.473	-0.0093
Unassume equal variance	/	/	0.473	-0.0093

6. Analysis of the Safe Operating Distance

GB 8702-2014[6] electromagnetic environment control limits specify the range of public exposure to an electromagnetic environment and the environment for the use of this standard. 50Hz AC current is adopted for the test and therefore the limit is 0.025kHz~1.2kHz. See formulae (1) for the formula to calculate the magnetic induction strength, which shall be lower than 0.1mT. A comparison of the simulation result and the de-facto measurement shows that the magnetic field of Plane 5 (0.8m from the Helmholtz coil) is basically lower than 0.1mT. Therefore, under the test of 0.125mT, it is safer to perform the test with a vertical distance of higher than 0.8m from the Helmholtz coil in order to ensure the health and safety of the test personnel.

$$B = 5 / f = 5000 / 50 = 100\mu T = 0.1mT \qquad (1)$$

7. Conclusion

Software simulation is adopted in this paper, the spatial distribution of power frequency magnetic test is simulated with COMSOL Multiphysics software. Then, the validity of the simulation model and algorithm is verified by field measurement of power frequency magnetic field test spatial distribution data with a Tesla meter. Finally, according to the standard, the safe operating distance for tester is analyzed and deduced. In various laboratories, for different manufacturers, different sizes of power frequency magnetic field test equipment, and different levels of magnetic flux density it provides a method and idea to study the spatial distribution of magnetic field and analyze the safe operation distance of test personnel.

List of nomenclatures.

Terms	Definitions
GB	Chinese national standard
immersion method	Placed in the center of an inductive coil
$10I_{tr}$, I_{max}	Input value of load current tested by electric energy meter
ZJIM	Zhejiang Institute of Metrology
Helmholtz coil	In loop flows a current, generating a magnetic field of defined constancy in its plane and in the enclosed volume
Thermodynamic Chart	It is a statistical chart that displays data by shading color blocks
Levene Variance Homogeneity Test	In statistics, it is called homogeneity (equality) test of variance
Mean Value Homogeneity t- test	Compare whether there is difference in the overall mean of two different samples

References

[1] International organization of legal metrology. international recommendation. OIML R 46-1/-2Edition 2012(E) Active electrical energy meters-Part 1: Metrological and technical requirements, Part 2: Metrological controls and performance tests [s]: International.

[2] Yu HW, Zhao DY, Ke J. Research and development of standard device for the power frequency magnetic immunity with same frequency and phase shift of the smart meter. Metrology & Mesurement Technique. 2018; 45(01):5-7+10.
[3] Zhao SZ, Wu ZW, Ma X. Design and verification of Helmholtz coil in EMC test. Shanghai Measurement and Testing. 2012; 39(03):7-11.
[4] Huang WG. Analysis of power frequency magnetic field measurement system and design of induction coil. Medical Equipment. 2010; 23(11):13-15.
[5] Han B, Liu WG, Zhang H. Research on calibration of power frequency magnetic field immunity test device. Electronic Measurement Technology. 2013; 36(08):108-110.
[6] State Administration for Market Regulation of the People's Republic of China, Standardization Administration of China. GB 8702—2014 Electromagnetic Environment Control Limits[s] Beijing: Standardization Administration of China,2014