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Magnetic structure design of strong magnetic field NMR logging tool

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Abstract

The eccentric NMR logging tool plays an important role in petroleum exploration, but the magnetic field intensity limits its application in special well conditions. In order to improve the magnetic field strength of eccentric NMR logging tool in special well conditions, a magnet structure of strong magnetic field NMR logging tool is proposed in this paper. After analyzing and summarizing the magnets of typical NMR logging tools, the new magnet structure is modeled, simulated and optimized by ANSYS software. The simulation results show that when samarium cobalt material is used, the magnetic field strength of the magnet can reach 1.2 T, which is higher than that of the same type of instruments, and its Curie temperature (850 ℃) is high, which is suitable for underground working environment. When the shape of the magnet is cylindrical, the vector distribution of magnetic induction intensity is regular and the magnetic induction intensity is relatively strong. When the distance between magnets is 500 mm, the magnetic field intensity is maximum. Therefore, the magnet structure of the new eccentric NMR logging tool can obtain an axial uniform magnetic field of more than 0.8 T, while keeping the relative size small, thus enhancing the detection performance.

Keywords

Eccentric NMR logging tool, magnet, magnetic density.

1. Introduction

With the increasing demand for oil in China, the task and difficulty of oil exploration are increasing year by year. The Guiding Opinions on Energy Work in 2021 issued by the National Energy Administration of China [1] puts forward the strategy of "promoting oil and gas storage and production, ensuring the investment in exploration and development, and strengthening the basic geological survey and exploration of oil and gas in key basins and sea areas". With the support of national policies, the exploration and development of China's oil and gas industry will be further promoted. In the process of petroleum exploration, logging technology has a decisive influence on the petroleum industry [2]. Compared with other logging methods, NMR logging range is clear and controllable [3], which can not only measure formation permeability and total porosity, but also describe the static and dynamic conditions of oil, gas and water [4-6]. And the signal measured by NMR logging directly comes from the pore fluid in the formation in the resonance area, so the measurement results are not affected by rocks, skeletons and minerals [7,8]. Nuclear magnetic resonance logging (NMR) is the only way to distinguish the confined fluid from the movable fluid in the formation [9]. Under the current situation of energy shortage, the research and development and application of NMR logging instruments have become an important symbol to measure the level of logging technology in a country.

Nuclear magnetic resonance logging instrument consists of probe, spectrometer electronic circuit, energy storage sub, pusher and surface data analysis and processing software. Probe is the core of nuclear magnetic resonance logging instrument, which consists of magnet and antenna [10]. Its function is to polarize and excite protons in formation pore fluid and receive

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NMR signals. The structure of the probe determines the key performance of the instrument, such as measurement mode, resonance area and signal strength. According to the measurement method, nuclear magnetic resonance logging can be divided into two types: center type and eccentric type. Compared with the center type, the eccentric NMR logging tool has the characteristics of strong adaptability to borehole environment, short echo interval and fast velocity measurement, and can be used in complex environments such as highly deviated wells, near-horizontal wells or horizontal wells, so the eccentric NMR logging tool is more in line with the development trend of logging tools. At present, most of the existing nuclear magnetic resonance permanent magnets are made of nonmetallic materials. Because the magnetic field strength of nonmetallic permanent magnets is relatively weak, it is generally necessary to increase the size of nuclear magnetic resonance permanent magnets in order to make them reach the axial uniform magnetic field that meets the preset length requirements, which leads to the increase of the volume of nuclear magnetic resonance logging tool.

In this paper, the electromagnetic field finite element method is used to simulate and analyze the magnetic field distribution of a typical eccentric NMR logging tool probe, and a new type of eccentric NMR logging tool magnet structure is designed from three aspects: magnet material, magnet shape and magnet size. While obtaining an axially uniform magnetic field that meets the preset length requirement, the size of the nuclear magnetic resonance permanent magnet is reduced or not increased, and the detection performance of the probe is improved.

2. Typical NMR logging tool analysis

2.1. CMR logging tool magnet simulation analysis

One of the typical representatives of the eccentric logging tool is the CMR logging tool [11], which uses a combination of three magnets, and the magnets have the same polarization direction and the polarization direction is perpendicular to the well axis. The three magnets are placed in parallel inside the probe, forming a uniform magnetic field area with a diameter of about 3 cm at a distance of about 2.5 cm from the borehole wall. Flip the magnetization direction of the adjusting magnet in the middle to adjust the magnetic field in the detection area. The antenna structure adopts a semi-coaxial structure. In order to increase the efficiency of the antenna, a soft ferrite material is designed in the antenna. This design scheme makes the structure of the probe very complex and requires high manufacturing process of the instrument. In order to form a uniform magnetic field in the wellbore environment, the probe magnet structure has been adjusted many times, and in order to form a radio frequency field that matches the static magnetic field, the structure is finally formed after many trials and modifications. Due to the uniform magnetic field, the instrument has only one detection frequency. Under the downhole condition, the working temperature of the tool can reach 175℃, and the magnetism of the permanent magnet will decrease in the high temperature environment. That is to say, when the tool works in the bottom hole condition, the intensity of the magnetic field generated by it will change, and within the detection area, the change of the magnetic field intensity will bring about the drift of the Larmor frequency.

Use ANSYS software to conduct simulation analysis, establish a two-dimensional model structure of the CMR nuclear magnetic resonance logging tool and assign the permanent magnet property as samarium cobalt material; set the magnetization direction to X Component, set the boundary condition of the air domain edge to Vector Potential, and set the value of is 0; after the model check is completed, the simulation analysis is performed to obtain the magnetic field line distribution and the magnetic induction intensity vector distribution (radial) of the CMR magnet, as shown in Figure 1 and Figure 2.

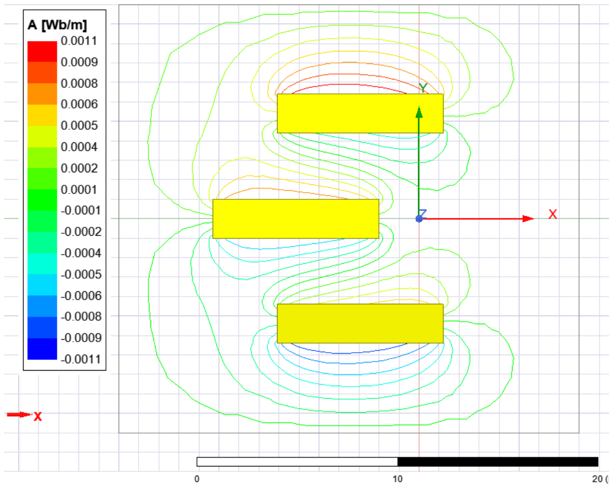

Fig. 1 Distribution of magnetic induction line of CMR magnet

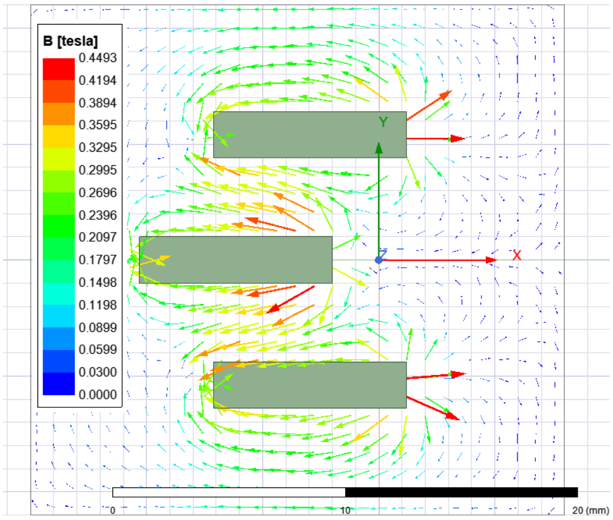

Fig. 2 Magnetic induction intensity vector distribution of CMR magnet in the formation

The magnetic field strength of the CMR instrument reaches 0.4 T. CMR adopts the measurement method of sticking to the wellbore. The wellbore drilling fluid has no effect on the measurement signal, and there is no need to add dopants into the wellbore, which not only improves the quality of the logging data, but also reduces the logging cost. However, the radial detection depth of the instrument is relatively shallow, and the detection area is small, resulting in weak signal strength and low signal-to-noise ratio of the instrument. This improves the data signal-to-noise ratio, but also reduces the longitudinal resolution of the instrument.

2.2. MR scanner logging tool magnet simulation analysis

MR Scanner is a typical structure of eccentric logging tool [12], and its probe structure is shown in Figure 3. The inside of the probe of the instrument is mainly composed of a multi-antenna structure. Among them, the maximum detection depth of the main antenna is 0.1 m, which mainly evaluates the fluid. The other two high-resolution antennas have a detection depth of about 0.32 m, and their role is to provide lithological parameters.

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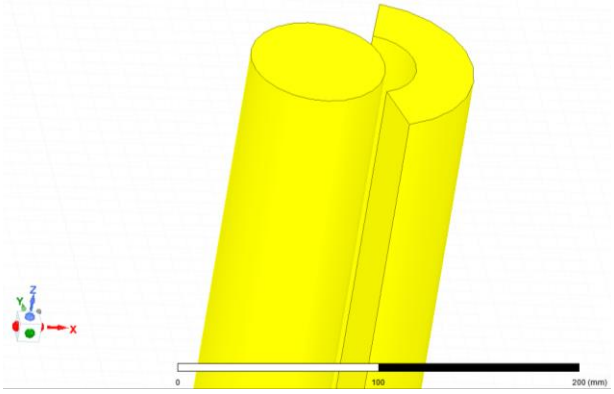

Fig. 3 structural diagram of MR scanner nuclear magnetic logging tool

Since the cross-sectional structure of the MR Scanner probe is the same at each position on the Z axis, a two-dimensional simulation model as shown in Figure 4 is established for calculation.

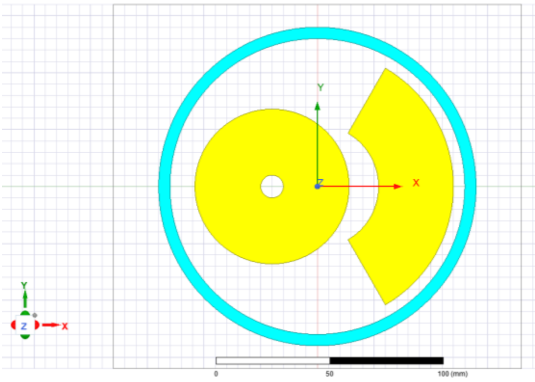

Fig. 4 2D simulation model of MR Scanner probe magnet

MR Scanner magnet is made of samarium cobalt material, and its relative permeability is 1.03 H/m and remanence is 1.1 t. The relative permeability of formation medium is 1 H/m .. The magnetic induction line distribution and magnetic induction intensity vector distribution of MR Scanner magnet are obtained through finite element calculation, as shown in Figure 5 and Figure 6.

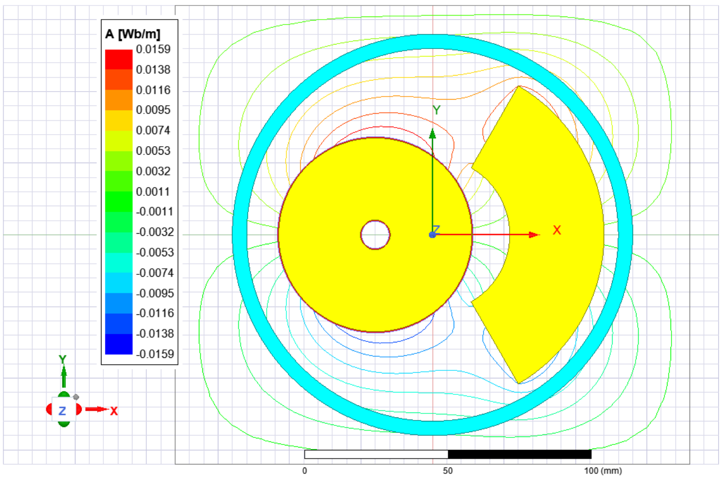

Fig. 5 Distribution of magnetic field lines of MR Scanner magnet

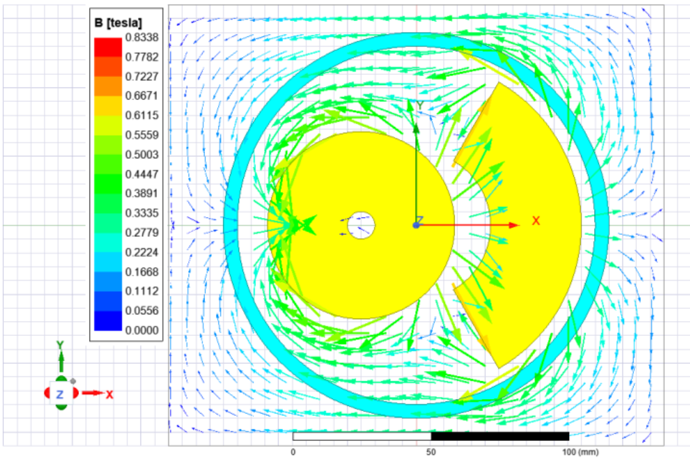

Fig. 6 magnetic induction vector distribution of MR scanner magnet

The magnetic field intensity of MR Scanner instrument reaches 0.8 T . The MR Scanner instrument has three frequencies for measuring different volumes to form concentric arcs around the antenna. Because of the eccentric working mode and sensor design, it can have four detection depths, ranging from 1.5 inches to 4 inches, and the bow spring is used to hold the antenna close to the borehole wall. The design of the instrument ensures that it can be transmitted in casing and controlled in large borehole and deviated well.

3. Magnetic structure design of strong magnetic NMR logging tool

Through the analysis of a typical NMR logging tool, it can be seen that the radio frequency signal emitted by the antenna is perpendicular to the magnetic field generated by the permanent magnet. If the permanent magnets are made of metal materials, the radio frequency signals will be seriously interfered, so the existing permanent magnets for nuclear magnetic resonance are mostly made of nonmetal materials. However, because the magnetic field strength of non-metallic permanent magnets is relatively weak, it is generally necessary to increase the size of nuclear magnetic resonance permanent magnets in order to make them reach the axial uniform magnetic field required by the preset length, which leads to the increase of the volume of nuclear magnetic resonance logging tool. Therefore, a strong magnetic field type NMR logging tool magnet structure is designed to increase the magnetic field strength without increasing the volume of NMR logging tool.

3.1. Optimum design of magnets

The magnet structure of strong magnetic field NMR logging tool is divided into main permanent magnet and auxiliary permanent magnet. Commonly used magnet material parameters are shown in Table 1 [13]. The main permanent magnet is made of ferrite material, and an auxiliary permanent magnet is arranged on both sides of the main permanent magnet, and its three-dimensional model is shown in Figure 7.

Table 1 Material parameters of magnet

Material	Remanence (T)	Curie point(℃)	Coercive force(kA/m)	Temperature coefficient
NdFeB	1.2	380	970	-0.4%/K
SmCo	1.1	850	840	-0.03%/K
Ferrite Bead	0.44	450	300	-0.2%/K

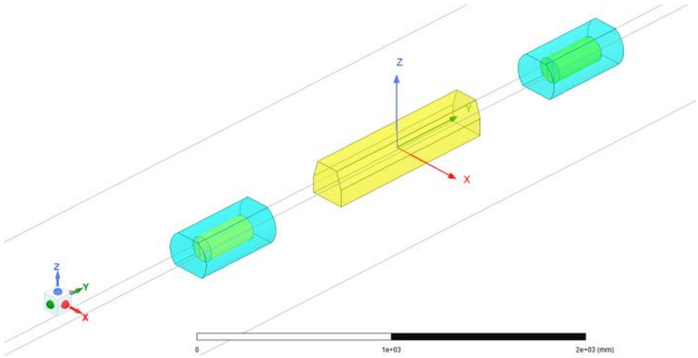

Fig. 7 Three-dimensional model of permanent magnet

After finite element calculation, in order to make the results more reasonable and accurate, YZ surface is taken as the analysis surface of simulation results, and its magnetic induction vector distribution is shown in Figure 8.

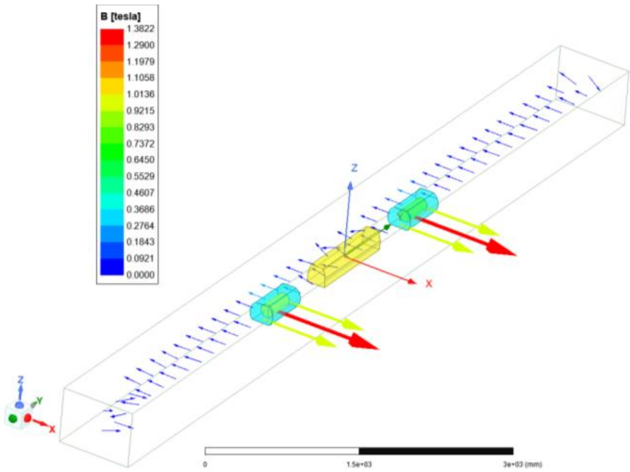

Fig. 8 Vector distribution of magnetic induction intensity of permanent magnet (NdFeB material)

Under the condition that the other conditions remain unchanged, the structural material of the cylindrical magnet is changed from NdFeB to SmCo for simulation analysis. Among them, the coercivity of the samarium cobalt material is 820 KA/m. The magnetic field directions of the main permanent magnet and the auxiliary permanent magnet are the same, and the magnetization direction is set as the X axis, and a three-dimensional model is established.

After the finite element calculation, in order to make the results more reasonable and accurate, the YZ plane is used as the simulation result analysis plane, and the magnetic induction intensity vector distribution is shown in Figure 9.

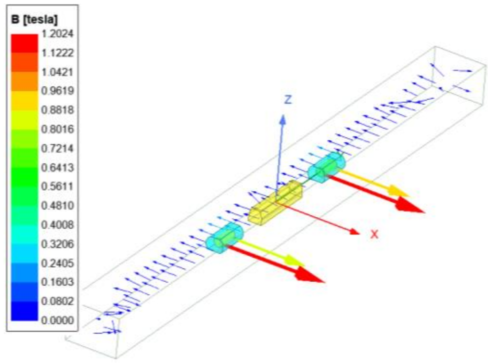

Fig. 9 Vector distribution of magnetic induction intensity of permanent magnet (SmCo material)

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According to the simulation results in Figure 8 and Figure 9, the magnetic properties of NdFeB material are better than that of samarium cobalt material, but the Curie temperature (380℃) of NdFeB material is much lower than that of samarium cobalt material (850℃), and the magnetic properties of NdFeB material will be greatly attenuated in the underground high-temperature environment, and the temperature coefficient of NdFeB material is -0.4 %/K, samarium. Therefore, samarium cobalt will be selected as the structural material of the secondary permanent magnet.

3.2. Optimal design of magnet shape

According to the foregoing, the structure of strong magnetic field type NMR permanent magnet is determined as follows: the upper top surface of the main permanent magnet and the auxiliary permanent magnet are N poles, and the lower bottom surface is S poles; The auxiliary permanent magnet is made of samarium cobalt material, and the magnetic field direction of the main permanent magnet and the auxiliary permanent magnet is the same, and the magnetization direction is set as the X axis.

Samarium-cobalt is a brittle magnetic material, which will break when subjected to strong mechanical stress or impact. Therefore, when designing the secondary permanent magnet structure, the cylindrical magnet structure is designed to avoid sharp structure as much as possible. The cylindrical magnet structure and prismatic magnet structure are calculated by finite element method respectively, and the XY plane is taken as the simulation result analysis surface. The magnetic induction vector distribution results are shown in Figures 10 and 11.

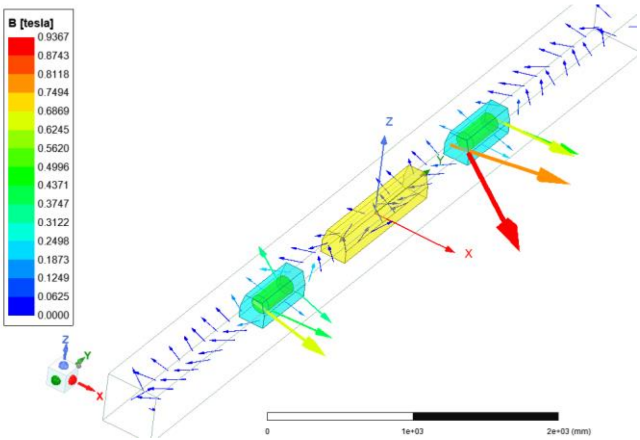

Fig. 10 Vector distribution of magnetic induction intensity of permanent magnet (straight hexagonal prism structure)

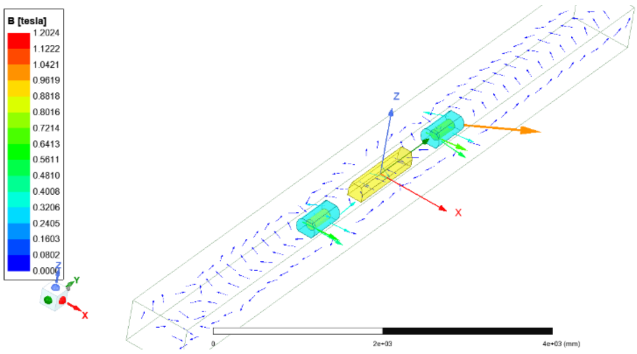

Fig. 11 Vector distribution of magnetic induction intensity of permanent magnet (cylindrical structure)

It can be seen from the results of Figure 10 and Figure 11 that when the secondary permanent magnet has a relatively large number of sharp structures, its magnetic induction vector distribution is relatively disordered and its magnetic induction is relatively weak, so the cylindrical structure is more suitable for the strong magnetic field type NMR logging permanent magnet.

3.3. Optimal design of magnet distance

The axial length of the probe magnet of MRIL-P logging tool is 191 cm [14], and the length of the main permanent magnet and the length of the auxiliary permanent magnet with strong magnetic field type NMR permanent magnet are 1000 mm and 500 mm, respectively. From the design goal, it can be seen that the overall length of NMR permanent magnet needs to be between 2500 mm and 3000 mm to reduce or not increase the size of NMR permanent magnet while obtaining the axial uniform magnetic field that meets the preset length requirements.

The following auxiliary permanent magnets and main permanent magnets are provided with magnetic fields with the same direction. By adjusting the distance between the auxiliary permanent magnets and the main permanent magnets, an axial uniform magnetic field meeting the requirements is obtained, and a comparative analysis is carried out.

When the total length is 3000 mm, that is, the distance between the auxiliary permanent magnet and the main permanent magnet is 500 mm, a two-dimensional simulation model is established. After finite element calculation, the vector distribution results of magnetic induction intensity are shown in Figure 12.

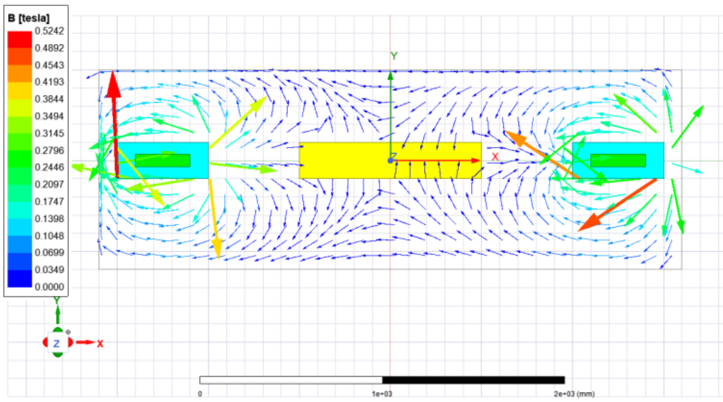

Fig. 12 Vector distribution of magnetic induction intensity of permanent magnet (500 mm)

When the total length is 2800 mm, that is, the distance between the auxiliary permanent magnet and the main permanent magnet is 400 mm, a two-dimensional simulation model is established. After finite element calculation, the vector distribution results of magnetic induction intensity are shown in Figure 13.

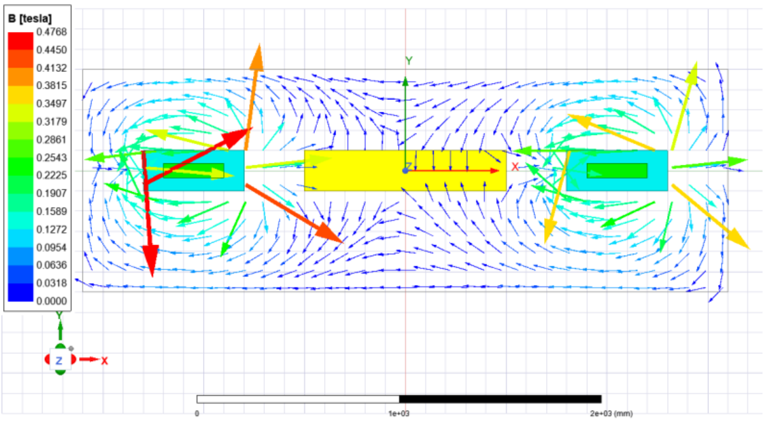

Fig. 13 Vector distribution of magnetic induction intensity of permanent magnet (400 mm)

When the total length is 2500 mm, that is, the distance between the secondary permanent magnet and the main permanent magnet is 250 mm, a two-dimensional simulation model is established. After finite element calculation, the vector distribution results of magnetic induction intensity are shown in Figure 14.

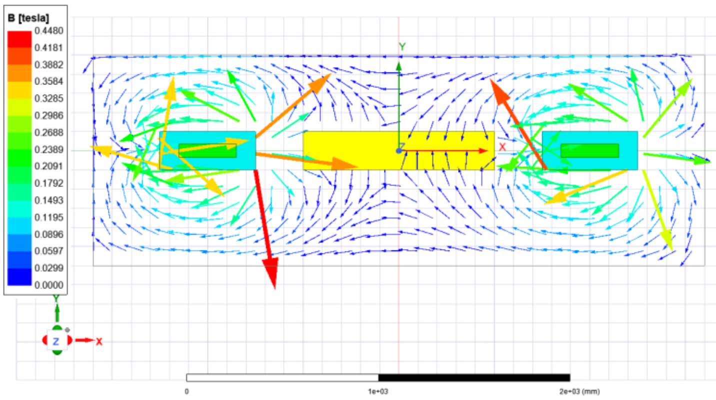

Fig. 14 Vector distribution of magnetic induction intensity of permanent magnet (250 mm)

The simulation results show that when only the distance between the main permanent magnet and the auxiliary permanent magnet is changed, the farther the distance between the main permanent magnet and the auxiliary permanent magnet is, the greater the magnetic induction intensity is. When the distance between the main permanent magnet and the auxiliary permanent magnet is 500 mm, the magnetic induction intensity reaches the maximum value, so 500 mm is chosen as the best condition.

To sum up, the permanent magnet of the probe of the ferromagnetic NMR logging tool is made of ferrite material, and the upper section is a straight quadrangle prism composed of an isosceles right-angled trapezoid, and the lower section is a rectangular straight quadrangle prism; The secondary permanent magnet adopts the cylindrical structure of samarium cobalt material; When the distance between the main permanent magnet and the auxiliary permanent magnet is 500 mm, the magnetic field intensity is maximum.

4. Conclusion

Nuclear magnetic resonance logging tool works in underground high temperature and high pressure environment, and its structure is strictly limited by borehole size. In order to meet the logging requirements, through the analysis and summary of CMR and MR scanner magnets, the magnet structure of strong magnetic field type NMR logging tool is designed on the basis of typical logging tools, and the magnetic field strength is increased without increasing its size.The simulation results show that: (1) The magnetic field of samarium cobalt permanent magnet can reach 1.2 T, and its Curie temperature (850℃) is good, so it is suitable for underground high-temperature working environment, and it is the preferred material of eccentric NMR logging tool. (2) When the permanent magnet has a relatively large number of sharp structures, its magnetic induction intensity vector distribution is relatively disordered, and its magnetic induction intensity is 1.2 T lower than that of the cylindrical structure, so the eccentric permanent magnet for NMR logging is more suitable for the cylindrical structure. (3) Referring to the axial length of the probe magnet of MRIL-P logging tool, on the premise that the total length of the probe does not exceed 3000 mm, the magnetic field intensity will be maximum when the distance between the main permanent magnet and the auxiliary permanent magnet is 500 mm

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