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Magnet Design and Simulation of Nuclear Magnetic Resonance Logging Probe for Drilling Ship

Shixin Zhang, Zhijie Zhang, and Wenyi Sun

Binzhou Vocational and Technical University, Binzhou 256600, China

Abstract

Nuclear magnetic resonance (NMR) logging probe is the core component of drilling ship logging tool, and the performance of magnet directly determines the accuracy of logging data. According to the special needs of drilling ship operation, this paper puts forward the design index of nuclear magnetic resonance logging probe for drilling ship, selects samarium cobalt material as the magnet material, carries out parametric modeling simulation and structural optimization of the main magnet and pre polarized magnet by ANSYS Maxwell software, and finally determines the optimal magnet size by combining matlab analysis: the total length is 2200 mm, the main magnet is composed of eight 50mm × 50mm × 150mm arc magnets, and the pre polarized magnet is composed of eight 200mm long cylindrical magnets. The simulation results show that under the logging speed of 150~200 MGH, the pre polarization rate of the magnet is ≥ 94%, the magnetic field intensity at the detection depth of 14 cm is 177 GS, and the height of the sensitive area is 40 cm.

Keywords

Drilling Vessel; Nuclear Magnetic Resonance Logging Probe; Magnet Design; Samarium Cobalt Magnet; Finite Element Simulation.

1. Introduction

The nuclear magnetic resonance (NMR) logging probe is the core component of the nuclear magnetic resonance (NMR) logging tool for drilling ships[1], and is the fundamental source of all logging information. The NMR logging probe is mainly composed of magnet and antenna. The magnet is the cornerstone of the NMR logging tool, producing a stable and powerful static magnetic field, providing a solid foundation for subsequent measurement and ensuring the accuracy of data. In this paper, the design index of nuclear magnetic resonance logging probe for drilling ship is put forward. According to the design goal, the preset structure of nuclear magnetic resonance logging probe magnet for drilling ship is proposed. The finite element software ANSYS is used to model and optimize the structure of the probe magnet, and the magnet structure meeting the detection requirements is studied.

2. Overall Design Scheme of Nuclear Magnetic Resonance Logging Probe for Drilling Ship

2.1. Probe Magnet Design

Nuclear magnetic resonance logging is a dynamic measurement scheme. The nuclear magnetic resonance logging tool completes the logging process in the process of lifting or lowering. The lifting and lowering speed of the instrument affects the quality of the observed NMR signal. In the design of NMR logging probe, logging speed is one of the key issues to be considered[2]. The logging speed of early nuclear magnetic resonance logging tools is slow. In order to improve the logging speed, the design method of adding pre polarized magnets at both ends of the main

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magnet is often used, so that when the logging tool is observing a sensitive area, the next sensitive area to be measured can be polarized in advance, so as to improve the logging speed[3]. The magnet of nuclear magnetic resonance logging probe for drilling ship is composed of main magnet and pre polarized magnet at both ends. The synergy of these two parts is helpful to improve the quality and accuracy of logging data.

2.2. Probe Magnet Material Selection.

The parameters of commonly used permanent magnet magnetic materials are shown in Table 1.

Table 1. magnetic material parameters of common permanent magnets

material	Remanence intensity (T)	Coercivity (Oe)	Magnetic product energy (MGOe)	temperature coefficient (%/℃)	market price ($/Kg)
samarium cobalt	1.16	10500	30	-0.035	102
NdFeBNeodymium	1.29	12300	40	-0.12	83
nickel cobalt	1.25	640	5.5	-0.02	32
Ferrite	0.39	3200	3.5	-0.2	5

In the case of the same volume, the higher the remanence intensity, the greater the coercivity, and the higher the magnetic energy product, the greater the magnetic field intensity[4,5]. In the design of the magnet for the nuclear magnetic resonance logging probe used in the drilling ship, it is required that the magnet can produce a magnetic field with high magnetic field strength. Samarium cobalt and neodymium iron boron magnets can produce a strong magnetic field. At present, the maximum operating temperature of NdFeB magnets on the market is 80 ℃, while SmCo magnets can withstand temperatures as high as 350 ℃. When the temperature exceeds 180 ℃, the stability and chemical stability of SmCo magnets are significantly better than NdFeB magnets, and are more suitable for the work of offshore oil and gas fields in high temperature environment. Therefore, the cobalt magnet is selected as the probe magnet material.

2.3. Probe Design Index.

According to the scientific problems and engineering application requirements, the parameters of nuclear magnetic resonance logging probe for drilling ship are determined. See Table 2 for details.

Table 2. design objectives of nuclear magnetic resonance logging probe for drilling ship

index	characteristic
operation mode Magnetic field type	Eccentricity measurement Gradient magnetic field
Magnet material Detection depth	samarium cobalt ≥14 cm
Magnet structure Vertical resolution	Combined type 40 cm(point measurement)
Operating frequency range Special environment	500 kHz~1 MHz(750 kHz) High temperature resistance, high pressure, underground operation

3. Design of Main Magnet for NMR Logging Probe

3.1. Structure Design of Probe Main Magnet.

The main magnet is one of the key components of the probe magnet of NMR logging tool, which directly determines the detection characteristics of the probe and the accuracy of the measurement results. In this section, the structure of the main magnet of the nuclear magnetic resonance logging probe for the drilling ship is preliminarily designed. As shown in Fig. 1, it is the main magnet structure of the designed NMR logging probe.

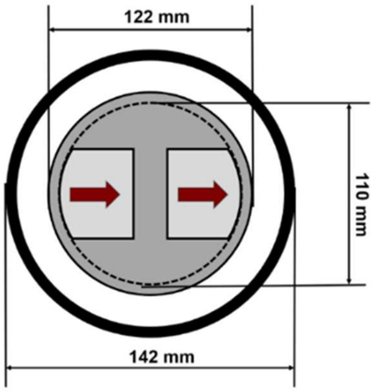

Fig. 1 Structure and size of main magnet

The magnet structure is composed of two arc magnets with the same size and shape. The design idea of arc magnet is to avoid structural damage caused by collision of the sharp structure of magnet during transportation. Two arc-shaped main magnets generate a measuring magnetic field, and their arc surfaces are distributed on a circle with the same diameter of 110 mm. According to the relative position of the two arc magnets, a magnet framework with a diameter of 122 mm was designed. The outermost part of the probe magnet was made of a shell material with a diameter of 142 mm, and the probe coil was installed inside the shell. The dimensions of the two arc magnets are obtained by parametric modeling and simulation analysis using ANSYSMaxwell software.

3.2. Structure Optimization of Probe Main Magnet

Keep the arc radius of the two arc magnets unchanged, which is 55 mm as described above. Keep the materials of the two arc magnets unchanged, which is the above samarium cobalt material. The relative permeability and coercivity parameters of the samarium cobalt material are shown in Table 1. two design parameters h and W are selected. H is the width of a single arc magnet and W is the length of a single arc magnet. The two design parameters h and W are associated with the position control size of the two arc magnets, that is, the shape and size of the two arc magnets can be driven by the parameters h and W. through the adjustment of the parameters h and W, the geometry of the two arc magnets can be changed without changing their relative positions.

Atotal of 121 groups of data were obtained through parametric optimization, of which 21 groups met the above restrictions. Considering the high price of samarium cobalt materials, 21 sets of data were screened from the perspective of reducing the use of materials. H × w can be approximated as the area of arc magnet, and the structure scheme with the least material consumption can be found. Analyze 21 groups of data, as shown in Fig. 2.

The results in Fig. 2 show that when h=50 mm and w=50 mm, the material consumption of the magnet is the most economical, the magnetic field intensity generated by the magnet is about 178 GS, and the magnetic field uniformity is about 91%, which has a high magnetic field uniformity and meets the design requirements. Therefore, the size of the main magnet is set to be 50 mm high and 50 mm wide.

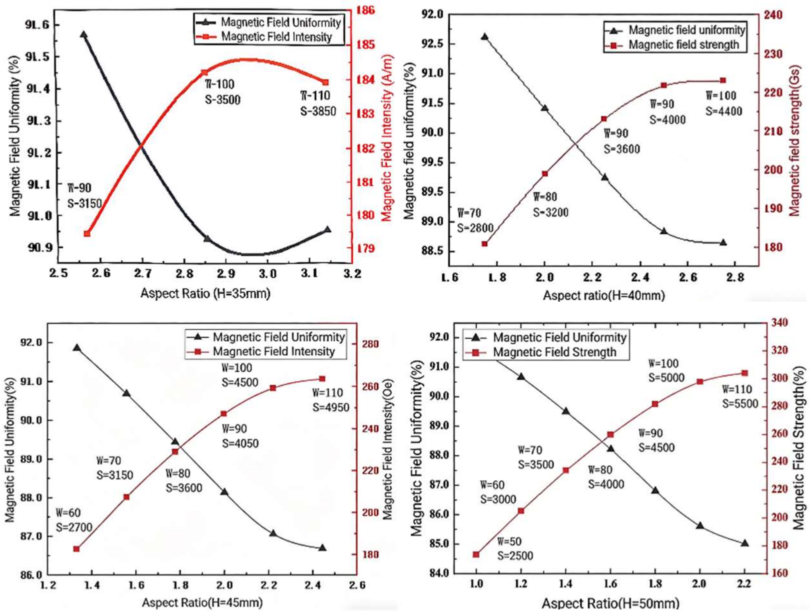

Fig. 2 optimization results of main magnet

4. Design of Pre Polarized Magnet for NMR Logging Probe

4.1. Structure Design of Probe Pre Polarized Magnet

When designing the probe pre polarized magnet, the key problem is how to effectively pre polarize the sample under the premise of ensuring the magnetic field strength, so as to improve the logging speed. In this section, the structure of the pre polarized magnet of the probe is preliminarily designed, as shown in Fig. 3, which is the size and structure diagram of the pre polarized magnet of the designed NMR logging probe.

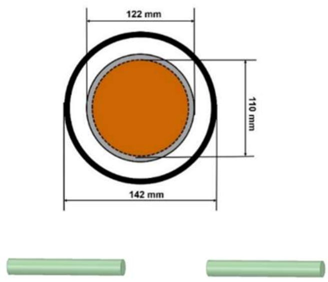

Fig. 3 Schematic diagram of the structure of the prepolarized magnet

The structure of the pre polarized magnet is composed of two solid cylindrical magnets with the same size and shape. The two cylindrical magnets generate the pre polarized magnetic field, and their cross section is a circle with a diameter of 110 mm.In order to facilitate the assembly of the magnet, a magnet framework withpositioning holes and slots was designed. Its diameter was 122 mm, and the black ring with an external diameter of 142 mm was used as the probe shell material.

4.2. Structure Optimization of Probe Pre Polarized Magnet

How to effectively polarize the sample under the condition of ensuring the magnetic field strength and improve the logging speed as much as possible is the key problem in the design of the probe pre polarized magnet. This section will determine the relationship between the pre polarization efficiency and the magnetization length according to the nuclear magnetic

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resonance characteristics of oil, gas and water three-phase, and more accurately define the length range of the pre polarized magnet. Generally speaking, the length of the pre polarized magnet is less than 1000 mm[6]. Most of the longitudinal relaxation time of the fluid in the formation is in the range of 0.001 s~5 s, so the relaxation time is selected as 5 s[7], and the relationship between the polarizability and the magnetization length at different logging speeds is obtained by MATLAB programming.

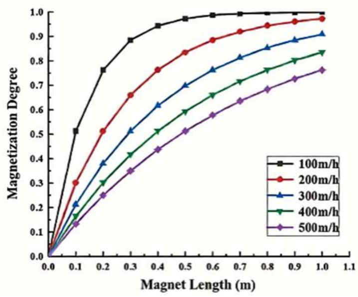

Fig. 4 Relationship between magnet length and polarizability

It can be seen from Fig. 4 that the higher the logging speed, the longer the magnet length required to reach the target polarization degree. When the magnet length remains unchanged, the higher the logging speed, the lower the formation fluid polarizability, and the more severe the distortion of logging data. On the basis of controlling the length of the pre polarized magnet, in order to make the pre polarized efficiency of the pre polarized magnet reach 94% and make the logging speed as large as possible. The logging speed should be kept between 150 m/h and 200 m/h.

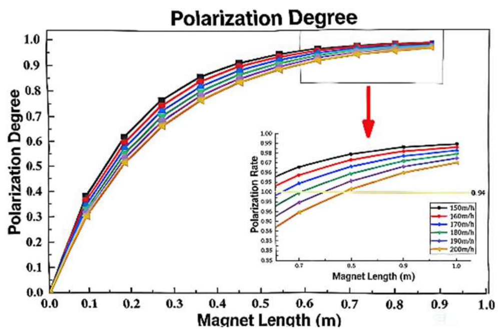

Fig. 5 Determination of the length of the pre polarized magnet

It can be seen from Fig.5 that when the oil and gas relaxation time is selected as 5 s and the length of the pre polarized magnet is set as 800 mm, the polarizability of the pre polarized magnet to the formation is greater than 94% at the logging speed of 150 m/h-200 m/h, meeting the design goal. Therefore, the length of the pre polarized magnet is 800 mm. In order to facilitate handling, assembly and transportation in practical application, the pre polarized magnet of nuclear magnetic resonance logging probe for drilling ship is bonded by 8 cylindrical magnets with a length of 200 mm.

5. Numerical Simulation Experiment on Magnet of Nuclear Magnetic Resonance Logging Probe for Drilling Ship

The magnet of nuclear magnetic resonance logging probe for drilling ship is composed of pre polarized magnet and main magnet, and the magnet material is samarium cobalt material. The total length of the probe magnet is 2200 mm. The pre polarized magnet is composed of eight cylindrical magnets with a radius of 55 mm and a length of 200 mm. The main magnet is composed of eight arc magnets with a length of 150 mm, width and height of 50 mm. ANSYS Maxwell 3D was used to model and calculate the magnet structure of the designed probe magnet, and the magnetic field intensity within the range of 0~20 cm from the shell was collected in four detection directions, as shown in Fig.6.

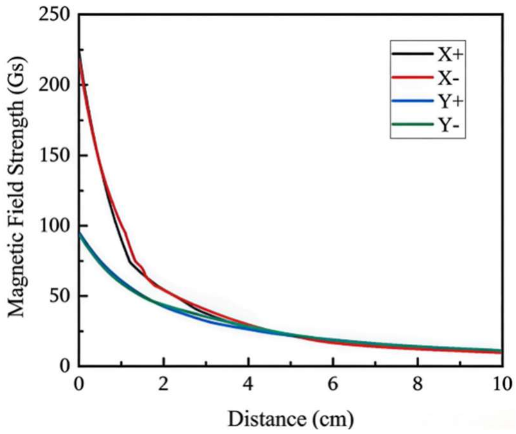

Fig. 6 Magnetic field distribution in four directions of probe magnet

It can be seen from Fig.6 that the addition of the pre polarized magnet compensates the magnetic field strength in the y-axis direction, making the magnetic field strength in each detection direction tend to be consistent, and the difference of magnetic field strength in each detection direction becomes smaller. This unique design helps to reduce the impact of seawater interference on the measurement in the drilling ship operating environment and improve the adaptability of the probe to the drilling ship operating environment. Starting from the probe shell, collect the magnetic field intensity generated by the probe magnet in the direction of the main detection area on the middle cross section of the probe magnet, as shown in Fig.7. When the detection depth is 14 cm, the magnetic field intensity can reach 177 GS, and the probe magnet can meet the design requirements of the NMR logging probe as a whole.

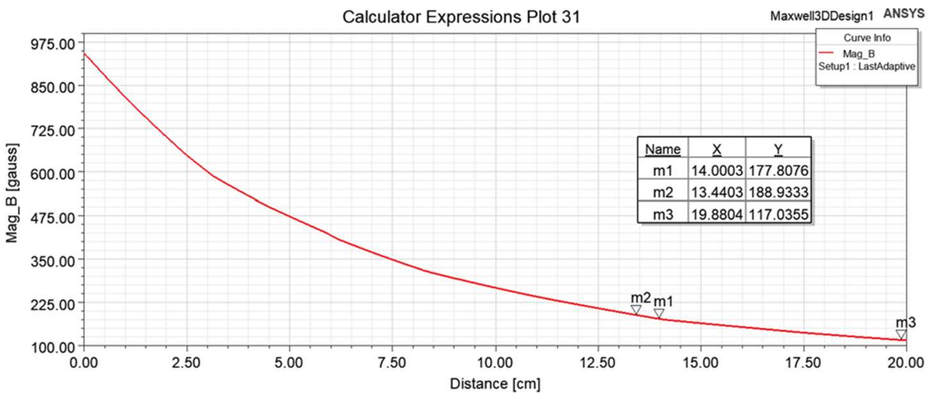

Fig. 7 Variation of magnetic field intensity in the positive direction of Y axis

As shown in Fig.8, it is the magnetic field generated by the main magnet at 14 cm in the radial direction. It can be seen from the figure that there is a relatively stable peak area in the magnetic field generated by the total magnet in the radial direction. The radial position corresponding to the peak area is the target detection area, and the height of the detection area is about 40 cm.

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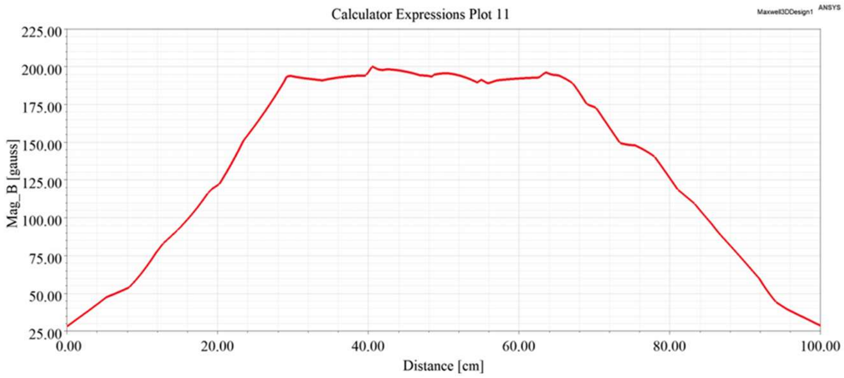

Fig. 8 Axial magnetic field distribution of probe magnet

6. Conclusion

The total length of the magnet of the nuclear magnetic resonance logging probe designed in this paper is 2200 mm, the magnet material of the probe is cobalt coated magnet, the total length of the main magnet is 600 mm, which is bonded by eight arc magnets with a length of 150 mm, width and height of 50 mm. The total length of the pre polarized magnet is 1600 mm, which is composed of eight cylindrical magnets with a radius of 55 mm and a length of 200 mm.At the logging speed of 150 m/h-200 M/h, the polarizability of the pre polarized magnet to the formation is greater than 94%. Through the overall simulation of the magnet, the magnetic field strength of the probe magnet can reach 177 GS and the height of the sensitive area is 40 cm when the detection depth is 14 cm. The design of the pre polarized magnet compensates for the main detection.The magnetic field strength of other detection areas outside the area makes the magnetic field strength of each detection direction tend to be consistent, and the difference of magnetic field strength in each detection direction becomes smaller. This unique design helps to reduce the impact of seawater interference on the measurement in the drilling ship operating environment and improve the adaptability of the probe to the drilling ship operating environment.

References

[1] L.Zhao,S.Wang,J.Wang, et al. Study on Quantitative Characterization Method of Micro-Pore Structure of Carbonate Reservoir Based on Nuclear Magnetic Resonance Logging,Processes,vol. 13(2025)No.3,p.729-729.

[2] J.Super.Looking toward the future of ocean drilling, Nature Geoscience, vol.17(2024)No.12,p.1189-1192.

[3] J.Schönzart,B A.Barnes.Miniaturized magnets for NMR above 50 tesla,Journal of Magnetic Resonance Open(2026),Vol. 26, p.100216-100216.

[4] A.M.F,R.L.R.Designing and Shimming Compact Iron-Core Dipole Magnets for NMR Spectroscopy,Applied Magnetic Resonance,vol.54(2023)No.11,1663-1687.

[5] M.Tremblay .DRILLSHIPS IN THE DIGITAL AGE,Ocean News & Technology,vol.37(2025).

[6] D.Normile.China's 'dreamy' scientific drilling ship takes global command,Science (New York, N.Y.),vol.386(2025)No.6727,p.1202-1203.

[7] Information on https://www.nmrlogging.com/welllogging/