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RESEARCH STATUS OF MECHANICAL ANTENNA COMMUNICATION TECHNOLOGY

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Abstract: Compared with electrically adjustable antennas, mechanical antennas have a completely new definition of electrical parameters. The frequency of their signals is only related to the material machine carrying the radiation field. It is related to the frequency of mechanical motion, thus overcoming the dependence of the electrically adjustable antenna signal frequency on the size of the antenna, and can use small equipment to generate low-frequency signals. Used in the design of underwater and underground portable low-frequency communication equipment. Load three types of radiation field characteristics, radiation field generating devices and information. This paper introduces the current research status of mechanical antenna communication systems and summarizes the technical difficulties that need to be solved in the development of mechanical antennas.
Keywords: Low-frequency communication equipment; Mechanical antenna; Radiation field; Information loading

1. INTRODUCTION

As a converter, the antenna converts the guided waves on the transmission line into Change to electromagnetic waves propagating in space or perform the opposite transformation, and its The frequency at which the signal is produced is strongly related to the physical size of the antenna nature, the lower the frequency of the signal you want to generate, the size of the antenna required The bigger the inch.

In the field of underground and underwater communications, especially submersible communications, High-frequency signals have poor penetration and fast attenuation, and the propagation distance cannot reach the actual To meet the needs of applications, low-frequency signals with strong penetration and long propagation distance must be used. Therefore, many expensive large-scale long-wave radio stations have been built. Some radio stations consume huge amounts of energy and have extremely high communication costs.. With the development of society, the demand for underwater and underground short-range communication is increasing day by day. In the face of conventional antenna communication, With the current situation that the cost is too high, there is an urgent need to obtain low-cost, single-person portable equipment. New communication technologies.

Mechanical antennas work by utilizing electric or magnetic dipoles or electric monopoles A new type of antenna that reciprocates to excite electromagnetic fields. This type of antenna is no longer Due to the limitation of antenna size, it does not even need to match the load, with With electrical parameters that are completely different from conventional antennas, a small device can be used to generate low-frequency signals with practical value, which can be carried by a single person underground or underwater. It has great application value in the design and manufacturing of wireless communication equipment.

U.S. Defense Advanced Research Projects Agency Advanced Research Proj ects Agency, DARPA) pioneered the use of mechanical antennas As a strategic goal, the project was launched in 2017 Mechanical antenna released in June item Head levy Inquire book (A M electronically B ased Antenna, AMEBA), Focus on development and design based on the basic principles of mechanical antennas Single-person portable wireless communication equipment to meet practical communication needs beg [1]. For different levels of needs, AMEBA the mechanical antenna Research is broken down into ULF and VLF two frequency bands and quantified the work Corresponding technologies such as frequency, magnetic field strength, efficiency, volume and mass Indicators [2].

Research on mechanical antenna communication systems mainly includes radiation field characteristics, There are three parts: radiation field generating device and signal loading. Among them, the main research content on radiation field characteristics is the excitation of mechanical antenna radiation field. The propagation characteristics of transmission and signals and the design of reception schemes. The main research on radiation field generation devices focuses on how to improve radiation intensity and reduce Minimize driving difficulty and improve radiation efficiency, the main points in signal loading The main task is to find feasible and optimal solutions for various types of mechanical antennas. modulation method. This paper summarizes the above work and analyzes further Difficulties that need to be solved in further research.

2. MECHANICAL ANTENNA RADIATION FIELD CHARACTERISTICS

Mechanical antennas can be divided into two types: magnetic dipole type and electric dipole type. Class, the radiation field mechanism generated by different types of mechanical antennas is shown in Figure 1 shown.

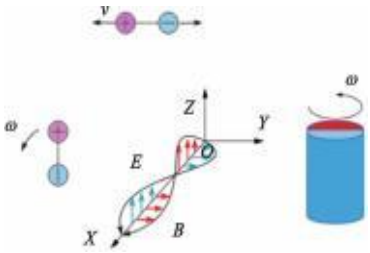

Fig. 1 Mechanism of radiation field generation of mechanical antenna

Radiation field characteristics are the basis for all research on mechanical antennas and are the basis for information The generation, radiation and dissemination of signals, the establishment of systems and even the loading of information Therefore, it is necessary to conduct research on the radiation field of moving dipoles. Qualitative analysis.
Regarding the radiation problem of moving charges and moving magnetic dipoles, Ding Chunquan et al [3] Detailed analysis was performed to derive the vibration and rotation Mathematical expressions of the radiation fields of electric and magnetic dipoles in two modes of motion. Chen Mingdong from Guangzhou Normal University and others [4] According to the magnetic induction formula, derive And compared the radiation in the near field region and far field region of a uniformly rotating electric dipole. Similarities and Differences in Shooting Ranges. Ningbo University Yang et al. [5] used piezoelectric crystals to Plate resonant materials, analyzed and verified the electromagnetic radiation characteristics of piezoelectric materials when they vibrate resonantly, and clarified the radiation power and vibration of piezoelectric materials. frequency relationship. Ren Yan from Central China Normal University and others [6] Starting from Poynting 's theorem, the near-field and far-field radiation of the rotating dipole is analyzed and verified. characteristic. Wu Yaxiong, Xi'an University of Electronic Science and Technology [7] On the basis of the above, the vibration and rotating dipole models were analyzed, and the radiation generated by the radiation field was compared. With attenuation characteristics, it is concluded that rotating permanent magnets are preferred in low frequency bands and near-field regions. scheme, the conclusion is that the rotating electret scheme is preferred in the far field region.
Based on the above research foundation and practical needs, researchers have conducted in-depth The radiation characteristics of the near-field region of the rotating permanent magnet are analyzed.. Dalian Communications University Learn from Wang Xiaoyu et al [2] The rotating permanent magnet is equivalent to its surface ampere current, an analytical model of radiation power is established, and the radiation power of the rotating permanent magnet is verified. The relationship between radiated power and permanent magnet remanence and other parameters. National Defense University Shi Wei et al [8] Based on radiation field theory, mechanical rotating permanent magnets were studied Equivalent relationship between body and magnetic dipole. Draper Laboratory, Cambridge, USA Bickford et al [9-10] Use rotating electrets to generate time-varying magnetic fields, The relationship between the near-field attenuation of the rotating electret and the signal frequency is verified, which is The development of efficient, small-sized, mechanically driven antennas in the future has laid the foundation for On the basis. Liu from Xi'an University of Electronic Science and Technology [11] simulated
The magnetic field generated by the rotating permanent magnet mechanical antenna in seawater and air
The propagation attenuation characteristics at the air-water interface provide the basis for the next practical application.
lay the theoretical foundation. Based on previous research, Zhang from Xi'an University of Technology Duojia [12] The radiation source type, radiation field propagation distance and radiation Field strength relationship curve, research on radiation field of mechanical antenna The staged summary is of great reference value for the next step of research.
The current research has basically clarified the radiation field of mechanical antennas. Radiation attenuation characteristics, for a rotating magnetic dipole, its magnetic field strength It has nothing to do with the rotational speed and is inversely proportional to the cube of the distance; its electric field intensity is The speed is directly proportional to the square power and inversely proportional to the square power of the distance. for For a rotating electric dipole, its magnetic field strength is positive to the square of the rotational speed. The ratio is inversely proportional to the square of the distance; its electric field strength has nothing to do with the rotational speed. It is inversely proportional to the cube of distance, and the research results are consistent with the reciprocity theorem.
Currently, mechanical antenna signal transmission is limited by low radiation intensity. The transmission distance cannot be too far. The transmission distance is relative to the low-frequency signal it generates. In terms of the wavelength of the signal, it belongs to the ultra-near field area. It is difficult to communicate in the near field area that is slightly farther away. The application in the far field area is not basically feasible. gender, which is also a difficulty that needs to be solved urgently at this stage, so the current and next The research focus at this stage is still focused on the near field area.
The research background on the radiation field characteristics of the above mechanical antennas is mostly based on In an ideal environment, fewer parameters are considered when building a model, which is different from the actual application. The complex scenarios faced by users are too different to effectively reflect the mechanical Antennas may encounter problems in the complex underground and underwater environments where they are intended to be used. practical issues. Therefore, it is necessary to analyze the application scenarios of mechanical antennas in detail and establish a reasonable signal propagation environment model. On this basis The propagation attenuation characteristics of the signal generated by the mechanical antenna are further analyzed.

3. RESEARCH ON RADIATION FIELD GENERATING DEVICE

Depending on the radiation field generating device, the mechanical antenna can be It is divided into two categories: mechanical direct drive type and electrical stimulation drive type: mechanical direct drive type and electrical stimulation drive type. Continuously driven mechanical antennas are driven by mechanical external forces such as motors. The motion state of the signal source changes, thereby stimulating the radiation field. Common There are permanent magnet type, electret type, etc.; electrical stimulation driven mechanical antenna is Refers to the use of the material's own characteristics to deform it through electrical stimulation and activate it. Emitting radiation fields, common ones include piezoelectric material type and magnetoelectric composite material type wait. Based on this classification, this section introduces the system of corresponding mechanical antennas. system design, focusing on the occurrence and propagation of its radiation field. Focus on improving radiation efficiency, enhancing radiation intensity and other technologies Research.

3. 1 Mechanical Direct Drive Mechanical Antenna

Permanent magnets and electrets can maintain A constant magnetic or electric field that changes its motion when driven by an external force state, an alternating radiation field will be excited at the receiving point, and the mechanical antenna will It is transmitted based on this information [12]. The principles of permanent magnet and electret type mechanical antennas are shown in Figure 2 and Figure 3 shown.

Fig. 2 Rotating permanent magnet type mechanical antenna

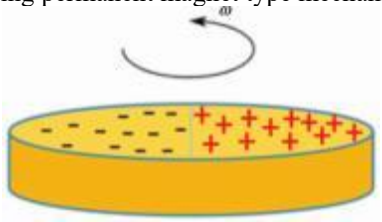

Fig. 3 Rotating electret type mechanical antenna

Focus on the main technological development directions of mechanically driven mechanical antennas How to improve the radiation field intensity, simplify signal modulation and improve radiation Radiation efficiency, etc.. University of Florida Burch et al [13] Reasonable Theoretically and experimentally analyzed the receiver of rotating permanent magnet mechanical antenna The directional effect confirms that this type of mechanical antenna can operate at 100 m Sent within range The feasibility of sending electromagnetic signals for communication and proposed by measuring The relative intensity of the radiated field component of the generated electromagnetic field is used to detect the source's New ideas for location and orientation.

Researchers from Beijing University of Aeronautics and Astronautics [14-16] A mechanically driven machine based on composite polymer electret nanomaterials is proposed. Mechanical antenna low-frequency communication method, which generates low-frequency The generation characteristics of communication signals are analyzed, and its power loss composition and Attenuation characteristics in different media, and built in finite element analysis software A corresponding model was built for simulation research, and the actual implementation of the mechanical antenna prototype was The comparison of the measurement results confirms that the electret rotation plane and the maximum propagation The corresponding relationship between the directions verifies the electret nanomaterial mechanical antenna feasibility. Zhuang Kaijie et al. from Shanghai Jiao Tong University [17] Respectively Theoretically and practically verified the permanent magnet mechanical antenna and electret Feasibility of mechanical antennas for communications, researchers could exploit Its corresponding theoretical model, design better design ideas, find ways to improve Line performance methods.

In order to increase the intensity of the radiation field, Fawole of Salt Lake City University in the United States wait people [18] An electromechanically modulated permanent magnet antenna is designed for use in harsh electromagnetic environments. The intensity of the radiation field is increased with the help of active bias, so that it can operate under 22 Effective transmission of binary signals at an operating frequency of 70 Hz About cm. dense University of Michigan Mantegchi [19] Based on the reciprocity theorem and resonance principle, A new structural design is proposed to improve the magnetic dipole of magnetic dielectric balls. moment, which increases the total radiation field strength of

the entire antenna system by about 100 dB. sword Bridge Draper Laboratory Bickford et al [20] Dielectric mass signal transmitter, which utilizes electret rotation to generate 167 Hz radiation field test, experiments show that as the frequency increases, the radiation efficiency Improvement has gradually gained practical value.

In addition, the mechanical Antenna radiation intensity. Researchers from the University of California [20-24]. In order to effectively generate low-frequency radiation, a magnetic pendulum array based Column (Magnetic Pendulum Array, MPA) of portable electromechanical systems, giving the system in 1.03 kHz A demonstration of the concept demonstrated that the system can achieve a higher quality factor than traditional coils, from to improve transmission efficiency. Compared to coils of the same size, MPA has 447 Hz The resonant frequency can be increased by approximately 10 dB transmission efficiency. On this basis, a new type of mechanical antenna — two Dimension stacking MPA, Further improving the performance of the antenna array, the experiment Prove that the resonant frequency is 727 Hz, quality factor is 94 Case_Below, compared to a single solenoid of the same size, the MPA transmission efficiency Improved by 18 dB.

In terms of drive control, the Aerospace Information Innovation Research Institute of the Chinese Academy of Sciences Liu Wenyi and others from the Institute [25] Using servo AC motors to drive permanent magnets The rotation generates ultra-low frequency electromagnetic waves, and the host computer programs them through the motion controller. The servo motor motion parameters are set by the programming software and sent to the controller. time to control the motor movement, you can use 20. 35 cm 3 The permanent magnet radiation source is 44 The power consumption of W achieves a code rate of 1 b/s ultra-low frequency communication. Madanayake, University of Akron, USA et al [26] designed a miniaturized and highly efficient device based on the mechanical rotation of permanently polarized dipoles. ULF/VLF Underground and Submarine Wireless Communications Transmitter Proposing an Integrated Design and Control Strategy for Electromagnetic and Mechanical Design Challenges. Zhang Miao et al. from Southwest University of Science and Technology [27]. The "return beam" structure further reduces the size of the antenna, and uses piezoelectric sheets to adjust the output The input voltage controls the vibration response mode of the permanent magnet to achieve information load. Generally speaking, the main features of mechanical direct drive mechanical antennas are The research direction is to improve the system's ability to drive objects with large rotational inertia to change motion. Sensitivity in the dynamic state, reducing the transition between different motion states time, serving higher speed information transmission.

3.2 Electric Stimulation Driven Mechanical Antenna

The main material of electrical stimulation driven mechanical antenna is piezoelectric material material. The electric dipole contained in the piezoelectric material changes depending on the external current. The changes produce corresponding deformations, which in turn produce an alternating radiation field at the receiving point. Since there is no need to use an external drive system for signal generation and modulation, In principle, the radiation source can be made larger, and the radiation intensity and frequency can be Higher, system design is simpler. Piezoelectric material principle model such as Figure 4 shows.

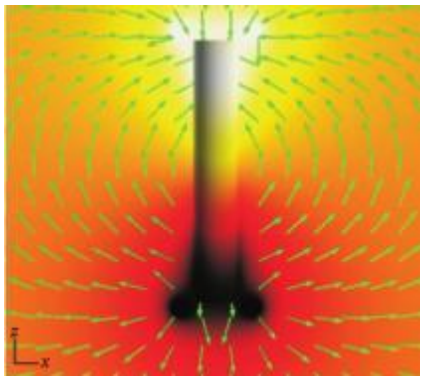

Fig. 4 Piezoelectric material schematic diagram

accelerator laboratory Kemp of Stanford University in the United States et al. [28] designed and manufactured a niobic acid-based Piezoelectric mechanical antenna with lithium piezoelectric electric dipole, applying alternating current to The two ends of the quadrilateral piezoelectric crystal enable the crystal to respond to the applied electrical signal. Regular expansion and contraction deformation under the influence, thus producing alternating changes around it radiation field. After analysis, this solution has better radiation efficiency than traditional electric antennas. The efficiency is increased by nearly 300 times, but it is limited by the stretching and deformation scale of the piezoelectric crystal. is limited, the radiated power of the transmitter is still small, and the effective transmission distance is difficult to further improve. Northeastern University Rezaei et al. [29] proposed A new solution using the magnetoelectric effect, through acoustic resonance or mechanical Electrical resonance to achieve transmitting and receiving 30 Hz ~ 1 000 Electromagnetic waves between MHz, but the signal strength is still very weak, and its transmission distance after attenuation It is still difficult to meet the demand for use.

Electrical stimulation-driven mechanical antennas are limited by developments in the material field level, the cost and size of piezoelectric materials cannot meet the requirements, and the radiation is strong The intensity and radiation efficiency cannot be further improved, and corresponding research is difficult to continue.. However, due to its higher radiated signal frequency and simpler A single control system, in the future, if we want to use mechanical antennas to achieve longer distances, For more efficient information transmission, this type of mechanical antenna still has the most potential research direction.

4. MECHANICAL ANTENNA INFORMATION LOADING

Electrical stimulation-driven mechanical antenna can change the input voltage The size is very convenient to adjust, but the mechanical direct drive type machine The signal loading of the antenna requires changing the carrier carrying the moving dipole. The state of motion changes the characteristics of the excited electromagnetic signal, and then Send message. The main method of loading mechanical antenna information is amplitude shift keying (ASK), frequency shift keying (FSK) and spatial polarization modulation, etc., three types of addition Each transmission method has its advantages and disadvantages. The current research focus is the modulation method. selection.

For ASK modulation, University of Wisconsin-Madison, USA Strachen et al [30] By changing the magnetic field of the shield around the mechanical antenna conductivity, so that the generated magnetic field is amplitude modulated to generate the ASK signal, which optimizes Structural design simplifies the speed adjustment operation process. Xi'an University of Electronic Science and Technology Xue Cao et al [31] An ASK communication system based on electromechanical coupling is designed to solve the problem of information encoding and synchronization processing. Letter testing verified the feasibility and effectiveness of the system. ASK It can solve the problem of poor stability of mechanical antenna system, low modulation efficiency, and information It is difficult to implement projects in transmission applications, but the shielding layer The performance requirements are very high, otherwise the antenna's already weak radiation will be The intensity is further weakened, further reducing the propagation distance of the signal.

For FSK modulation, Cao et al. [31] of Xi'an University of Electronic Science and Technology used a mechanical antenna of rubidium iron boron magnet material to generate a 2 FSK signal through rotational speed conversion modulation, but the experiment was only a feasibility analysis. The experimental model is too simple and difficult to put into practical use. American Stan Kemp _ et al [28] Designed and manufactured a pressure sensor based on lithium niobate Electric mechanical antenna, using relays to switch electrical signals to achieve rotational speed changes to achieve 2 FSK modulation, and the crystal speed at three different frequency shift keying rates was measured, and the frequency shift keying speed was discussed. Effect of rate on input impedance and power. Researcher at University of California, USA member [20-twenty four] A mechanical system consisting of a rotating magnet array was designed. By changing the system spin angle frequency, the antenna can be OOK or FSK modulation. Researchers at the National University of Defense Technology [32-33] developed a base Rotating permanent magnets for high-speed permanent magnet servo motors and NdFeB permanent magnets The principle prototype of the mechanical antenna was preliminarily verified through near-field testing. Rotating permanent magnet mechanical antenna to achieve 2 FSK feasibility and effectiveness. China division study hospital null sky letter interest create new research study hospital Liu arts one et al. [25] Innovative use of airspace direct antenna modulation technology to generate 2 FSK signal, experiments were carried out using the developed mechanical antenna prototype, The results prove that the antenna has obvious advantages in miniaturization and low power consumption.. FSK Modulation can ensure that the signal strength is not affected by the modulation system And lower, but FSK The heat generated by frequent changes in the speed of the modulated motor will cause resulting in signal instability, and in addition, there is no frequency conversion time interval. Problems such as low modulation efficiency and frequency doubling interference cannot be avoided.

The principle of spatial polarization modulation of mechanical antennas is to utilize high magnetic permeability Different arrangements of shielding materials in specific directions at different times affect Spatial distribution of radiation field at receiving point. Accordingly, Xi'an University of Technology and Xi'an Researchers from An Electronic Science and Technology University [7, 12, 34-35] proposed a basis The ultra-low frequency mechanical antenna modulation method based on magnetic shielding technology will radiate and modulation are separated and performed independently, overcoming the problem of rotating mechanical antennas FSK Mechanical Issues Facing Modulation. Spatial polarization modulation has no Frequent motor speed conversion reduces the requirements on the control system, However, this modulation requires frequent changes in the orientation of the shielding material, and the modulation rate Still restricted.

In addition to the above modulation methods, mechanical antennas can also use modulation Phase modulation, frequency doubling modulation, phase modulation, etc., but each has its own technical difficulties. Comparison of modulation performance, such as electrical The highest frequency of machine rotation, unit is Hz, Refers to the motor 1 s Number of turns ; f is the modulation signal frequency, the unit is Hz.

5. RESEARCH RECOMMENDATIONS

Mechanical antennas span electromagnetic, motor, material and other fields and are an important part of communication At the forefront of field development, its technological development is comprehensive but not refined. In this segment, there are still many technical difficulties that need to be solved, mainly including Including material innovation, design innovation, drive innovation, etc.

6.1 Material Innovation

The development of mechanical antenna radiation sources has encountered a bottleneck, the third generation of rubidium iron boron The magnetic flux density of permanent magnets has reached the theoretical limit. It is difficult to further increase the volume of electrets and piezoelectric materials. The potential of magnetoelectric composite materials Practical research is still in the theoretical stage and can only start from changing the magnetization method and Only by changing the structure of the signal source can we further improve the radiation Strength, thereby extending the communication distance and improving communication quality.

6.2 Design Innovation

This kind of innovation is expected to meet the hardware requirements of the smallest possible size. Obtain a stronger radiation field and solve the problem that conventional mechanical antennas cannot be enlarged problems while improving the channel capacity of the communication system. mechanical antenna The arraying of mechanical antennas is a hot topic in this type of research, but the array of mechanical antennas Research on the difference between columnarization and conventional antenna arraying is still a Blank, conventional research is still in the exploratory stage, for mechanical antenna arrays Research on column layout and control currently has no relevant theoretical support, only There is engineering practice, and key breakthroughs are needed in the next step.

6.3 Drive Innovation

Drive innovation mainly solves the problem of mechanical direct drive mechanical heaven. The technical bottleneck encountered by the line in driving is in the energy conversion of the driving system. During the switching process, frequent speed conversions will cause excessive heat loss, affect the stability of the motor and radiation source, and reduce system efficiency.. in addition, The mechanical antenna drive system cannot complete instantaneous changes in motion state, It is not conducive to signal loading and greatly limits the improvement of system communication rate. high, so it is necessary to study more efficient signal loading methods to reduce the impact on driving dynamic dependence to improve system life.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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