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Comprehensive Review, Challenges of Superconductivity and Quantum Levitation in Advanced Material Research

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ABSTRACT

Considering engineering point of view, superconductivity and quantum levitation have mostly remained physics research topics, but they have enormous promises in many different sub-fields. Superconductors are low resistance systems that provide optimum efficiency with the least amount of energy loss and heating. The phenomenon of superconducting material floating on a magnetic surface is known as quantum levitation. As a result, the motion is practically perfect, with almost no inertia. Research is made feasible in a wide variety of applications in the mechanical, electrical, biological, etc. sectors because of the simplicity of the design and concept of quantum levitation. There is still a need to identify and investigate applications for superconductors and quantum levitation, despite some recent experimental evidence showing potentially advanced uses in the mechanical and biological fields.

KEYWORDS Superconductivity; Quantum levitation; Quantum locking; Meissner effect; Magnetic flux.

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1. INTRODUCTION

Superconductivity and Quantum Levitation have been considered a revolution in the area of physics and materials science. Such development has enabled us to identify and develop the novel materials with properties of superconductivity and magnetic levitation. A superconductor is an element which loses complete electrical resistivity when it cools at low temperature. In another word, a super conductor material permits electrical current to flow through it without creating any resistance or without losing energy. Therefore, practically, existence or production of superconductors is rare. Supercurrent is the term used to describe the current that flows through superconductor material. There are two different kinds of superconductors: Type I and Type II. When a material is cooled below its critical temperature (Tc), the molecular mobility inside the material decreases and electricity can flow through it without any resistance. These materials are known as type I superconductors. As an example in the metallic field, aluminum is a conductor at room temperature but when cooled below 1.75K, it becomes a superconductor. Another example of a superconductor is Lanthanum Decahydride or LaH_{10} which exhibits the properties of superconductivity at 250K. Type II superconductors are those materials which are not good conductors at room temperature but they become superconductors after gradual transmission. The mechanism behind the gradual transmission in Type II superconductor materials is still not fully understood. Type II superconductors are typically paramagnetic metallic compounds and alloys (Huang et al., 2019; Savaskan, Abdioglu and Ozturk, 2020).

1.1 Objective of review

The primary focus of this article is to concentrate on how these two phenomena may be utilized to yield some real world applications. They may be used for energy production, mass measurements, characterization of ideal motion laws and verification, automotive industry, body imaging, and much more. The potential is yet to be explored, and in this review, we present a few ideas which may be a reality in this and upcoming decades

1.2 History of superconductors and quantum Levitation

The history of superconductors may be traced to the liquefaction of Helium (He) at 4.5K by Kamer lingh Onnes in July, 1908 (Ouboter, 1997). This was followed by the development of BCS Theory by Bardeen, Cooper and Scrieffer in 1972 about the superconducting theory (Bardeen, Cooper, and Schrieffer, 1957). Later on, Brian David Josephson advanced this theory to describe how paired superconducting electrons in a material can tunnel through one another. Meissner and Ochsenfeld, 1933 conducted experiments to measure the distribution of magnetic fields in superconducting states for lead and tin single crystals that were extremely clean. To do this, a cooling vessel filled with liquid helium was placed over a lead plate, causing ferrite magnets to levitate over the plate without coming into contact with the dish's base. Another crucial aspect of superconductivity is this phenomena, known as the Meissner effect. Nevertheless, other oxide superconductors with a Tc higher than the liquid nitrogen (LN_2) temperature (77K) were found following the discovery of the La-Ba-Cu-O superconductor by Bednorz and Müller in 1986. Currently, LN_2 can be used to observe the Meissner effect (Jha and Matsumoto, 2019; Sheng and Hermann, 1988; Yu et al., 2020).

2. WORKING OF SUPERCONDUCTORS AND QUANTUM LEVITATION

The working of levitation is based upon the generating magnetic field with the help of a superconductor. At room temperature, the electrons in the outermost orbit bump into the atoms and pass the current as a conductor but also loses energy with each collision. When the material cools below a critical temperature, the flow of electrons can occur freely through the conductive material without any collision or energy loss. Aluminium or niobium can obtain extremely low critical temperatures, under the medium of liquid helium lying around. On the other hand, there are some materials such as ceramics which allow electrons to move freely within the material under slightly higher than most critical temperatures.

The Meissner effect states that when a material is chilled to demonstrate superconductivity, the magnetic field flows through it at room temperature, the expulsion due to the magnetic field is produced. Figure 1 indicates how the superconductor levitates above the magnetic material. The primary reason here is that due to free flow of electrons, the material binds the magnetic flux lines in the given orientation to stabilize itself. This locking effect is known as Quantum Locking which helps the superconductor to levitate hence due to quantum effects, Quantum levitation is observed.

3. LITERATURE REVIEW

Many metallic materials under Type I of superconductivity show drastic drop in resistivity to zero when it is cooled up to some temperature above absolute zero. The temperature is known as critical temperature. This property of material is called superconductivity. Research on finding mechanisms of gradual transmission of conductive material to superconductors and finding possible applications are still lacking. In this regard, in 1986, there was an attempt by two physicists to develop a ceramic based superconductor. It was concluded that some ceramics at low temperature -200˚C i.e. supercooled state can provide stable magnet levitation (Blundell, 2009).

Zero electric resistivity and zero energy loss of the superconductor was confirmed by Onnes et al. 1997 in which they used Pb wire to develop a superconducting closed circuit. For cooling purposes, liquid Helium was used and a magnetic field was created to induce the current. The motion of magnetic flux induced in the metallic alloy superconductor was proposed and shown by magnetic lines (Abrlkosov1957; van Delft and Kes, 2010).

A small number of Type 2 superconducting materials have also been found, but most study is focused on Type I superconductors (Oya and Saur, 1979; Matthias, Geballe and Compton, 1979; Matthias, Geballe, Geller and Corenzwit, 1954; Tomita and Murakami, 2003). Nb3Sn was found to exhibit superconductivity at 18K, and it was deduced that the material's current characteristics were dependent on both temperature and an external magnetic field. Furthermore, these materials exhibited superconducting behavior at elevated magnetic fields. As a result, Nb3Sn is employed as a superconductor in the majority of applications (Dietderich & Godeke, 2008).

4. RECENT AND PROPOSED APPLICATION OF SUPERCONDUCTORS AND QUANTUM LEVITATION

Superconductors use perfect diamagnetism, hence levitation is possible. One of the real life application is making of high-speed trains: A 3 inch diameter plate with a width of 2mm can carry almost 1 tonne, hence we can use multiple superconductors, an alternating magnetic polarity and specialized rail tracks where the changing polarity will pull the train fitted with superconductors. The rate of change in polarity may be replaced by an initial thrust. This may provide highly efficient high speed trains.

After conducting an experiment, Tomita and Muralami, 2003 found that a single Y123 bulk grain impregnated with reinforced carbon fiber and wood's metal could retain a 17.24T magnetic field at 29K. Also, holes in the Y123 structure would increase the net surface area, hence promoting oxygen diffusion enhancing electromagnetic properties. Hence, reinforcement of metal components under magnetic or Lorentz force by this approach.

Stronger magnetic separators having smaller form factors relative to the existing systems, making experiments more feasible and more dynamic in nature (Zakharov, 2023; Zhang and Xu, 2022).

Smaller, yet stronger particle accelerators would be highly useful in conducting physics experiments and understanding the fabric of space time due to the electro-magnetic nature of particles. This allows for analysis and better understanding of subatomic particles and how we can use them in understanding supermassive black holes and curving of light around the singularity.

The use of superconductors may be used in purification of fluids. This will yield massive improvements in the automobile and energy sector as oils, air, water and similar fluids play a vital role in the overall efficiency of the system. Also, as clean water becomes less and less viable, superconductors may yield to development of portable devices to clean water. Use of quantum levitation may also help in enhancing overall efficiency of a compressor by eliminating the loss of power at the TDC and BDC of a reciprocating compressor.

As ball bearing has 2 metal races where both are separated by balls which provide enhanced load carrying capacity, superconductivity may be used in making ball bearing.

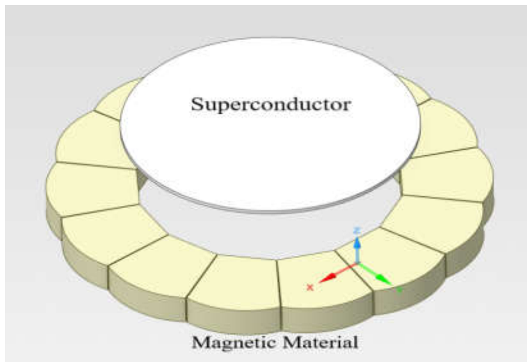

Figure 1: Superconductor and quantum levitation phenomena

5. CONCLUSION

In the present work, potential application of superconductor and quantum levitation has been reviewed. Various possibilities and applications have been highlighted. It can be concluded that there is a strong need to identify the temperature of transition. The principle of quantum levitation is simple, which opens up research opportunities in a variety of fields, including mechanical, electrical, and biological. Its application as Magnetic levitation bullet train is one of the revolution and opened the door for other future scope. The future of biomedical and mechanical engineering holds a lot of promise for the concept of superconductivity and quantum levitation.

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