ISSN XXXX XXXX © 2018 IJESC

Research Article Volume 8 Issue No.3

# Theory of Superconductivity and Use of Superconductors in Magnetic Levitation System

Ankit M. Thorat[1], Deepak S.Patil[2], Tejas R. Nadge[3]
Research Scholar[1, 3], Professor[2]
Department of Mechanical Engineering
L.G.M. Institute of Engineering Education and Research, Nashik , Maharashtra, India

**Abstract:**
In this study, we tried to concentrate on basics of superconductors, types of superconductors, their properties and application in magnetic levitation system. A superconductor is a diamagnetic material which has zero resistivity which is used in Electrodynamic suspension system (EDS) of maglev train recently under research phase in Japan. A superconductor can work in either low temperature or high temperature. A superconductor has ability to possess electricity even in condition of power off. A superconductor has zero electrical resistance which provides smooth motion without energy loss to atoms. The SC Maglev train is one of the important application of superconductor developed by Japanese engineers is currently highly researchable topic for all over worldwide scientists. A global warming, air pollution, excessive energy demand and competition between countries to developed a economical and environmental friendly transportation system are the problems which facing worldwide. To overcome among these problems, a maglev train can gives better solution than any other system but cost estimation is necessary to develop a highly adaptive and safe maglev syatem.

**Keywords:** Superconductor, Superconductivity, zero resistivity, Magnetic levitation system, etc.

## I. INTRODUCTION

A material having ability to conduct electricity with zero resistance is called as Superconductors. It means that instead of other conductors like copper or steel, superconductors having ability to carry current indefinitely without losing any energy.A superconductor is also a diamagnetic material means “no magnetic field can exists within a superconductor.”

When the superconductors are cooled below the characteristic critical temperature, they give behaviour of expulsion of magnetic flux. In 8th April 1911, Heike Kamerlingh Onnes, a Dutch physicist had the credit to discover the superconductor. He found that like ferromagnetism and atomic spectral lines, superconductivity is a quantum mechanical phenomenon which is characterized by the Meissner effect.

It’s a Basic rule of nature that whenever a material is kept at low temperature, it possesses decrement in an electrical resistance. A Generally used conductor like copper or silver can gives this decremented electrical resistivity at a certain limit because of impurities and other defects. In 1986, it was discovered that some cuprateperovskite ceramic materials have a critical temperature above 90 K (-189 $^{0}$c). Such a high transition temperature is theoretically impossible for conventional superconductors, leading the materials to be termed high-temperature superconductors.

The cheaply available coolant liquid nitrogen boils at 77 K, and thus super conduction at higher temperatures than this facilitates many experiments and applications that are less practical at lower temperatures. In Maglev train, which works on magnetic levitation phenomenon, had three working system. Electrodynamic suspension system (EDS) is one of them in which superconductors are used to create levitation. This system is under research phase in Japan.

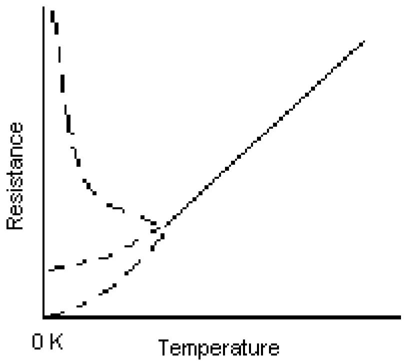


**Figure.1.Reaction of resistance to extreme low temperatures**

## II. CLASSIFICATION

**The superconductors are classified as follows:**

1) On the basis of Material of Superconductors: Superconductive material is classes including chemical elements such as mercury and lead, alloys like niobium-titanium, germanium-niobium and niobium nitride, ceramics like YBCO and magnesium diboride, organic superconductors such as fullerenes and carbon nanotubes.
2) On the basis of Critical temperature:
High temperature superconductors: when cooled using liquid nitrogen at 77K Low temperature superconductors
3) On the basis of Theory of operation:
It is explained by BCS theory and considered as conventional
4) On the basis of Magnetic field response
A superconductor having single critical field above which all superconductivity is lost and below which the magnetic field is completely expelled from the superconductor is a Type I superconductor. A superconductor has two critical fields, between which it allows partial penetration of the magnetic

field through isolated points called as TypeII superconductors. These points are called as vortices.

## III. PROPERTIES OF SUPERCONDUCTORS

The properties of superconductors are varying from material to material like heat capacity, critical temperature, critical field and critical current density at which superconductivity is destroyed.

### 1. Zero electrical DC resistance

As per the Ohm's law,

R=V/I

Where, R= Resistance occurred in Ohm
V= Applied voltage
I= Current

From the above equation we can easily understand resistance is directly proportional to the applied voltage and inversely proportional to the current. Now, to measure the electrical resistance of any material is to place that material is to place in electrical circuit in series with a current I source and measure the voltage across the sample. If the voltage is zero, it means that the resistance is zero. Superconductors are also able to maintain a current with no applied voltage, superconductive electromagnets which are found in MRI machines possesses this property. In an ordinary conductor like copper or steel, an electric current is in the form of fluid of electrons moving across a heavy ionic lattice. The collision of electrons and ion in the lattice constantly and this collision cause absorption of some amount of energy by lattice and converted into heat and released in atmosphere, which is a kinetic energy of lattice ions. This energy is carried by a current and constantly dissipated. This phenomenon is electrical resistance and Joule heating. This situation is different in superconductors. In superconductors, the electronic fluid cannot be resolved into individual electrons. It consists of a pairs of electrons called as Cooper pairs. This pairing is occurred due to an attractive force between electrons from exchange of phonon.

### 2) Superconducting phase transition

When the temperature 'T' of material is lower than critical temperature '$T_c$' then material shows superconductivity characteristics. The value of critical temperature is different for every material. A conventional superconductor has value of critical temperature between 20K to less than 1K. For example, solid mercury has critical temperature of 4.2K. In 2009, the highest critical temperature found for a conventional superconductor is 39K for magnesium diboride ($MgB_2$).

### 3) Meissner effect

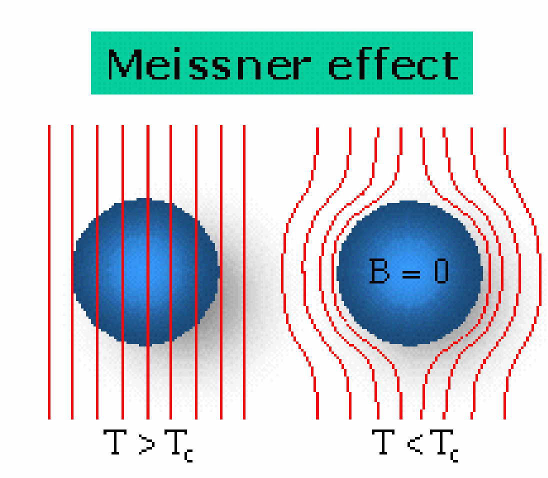


**Figure. 2. The Meissner effect**

In 1933, an important development in superconductors was made by Meissner and Ochsenfeld. In addition to being a perfect conductor a superconductor is also a perfect diamagnetic were a thin gap existed between the surface of super conductor and the magnetic field. Its means "induced currents in it would meet no resistance so they would persist in whatever magnitude necessary to perfectly cancel the external field change." This is term as "Meissner effect." The super conductor then excludes any magnetic field that would normally flow through by inducing current loop to exactly cancel magnetic field. An example is shown in below figure.

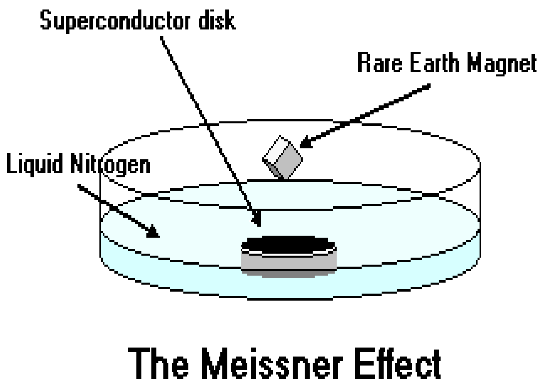


**Figure.3. the Meissner Effect in levitation**

### 4) Superconductive materials

There are two types of super conductive materials termed type I and type II super conductors. Before understand the applications of super conductor it is necessary to understand specific characteristics of these two type of superconductors.

### A) Type I superconductors

Normally the general conductors like copper, gold, silver are not super conductor due to their small lattice vibrations. Superconductors have an attractive force to the cooper pairs due to their lattice vibrations. The type I superconductors are included under BCS theory. Type I super conductors shows softer characteristics at lower temperature and they can lose their superconductivity at higher temperature. The table listed below gives type I superconductors with their critical temperatures.

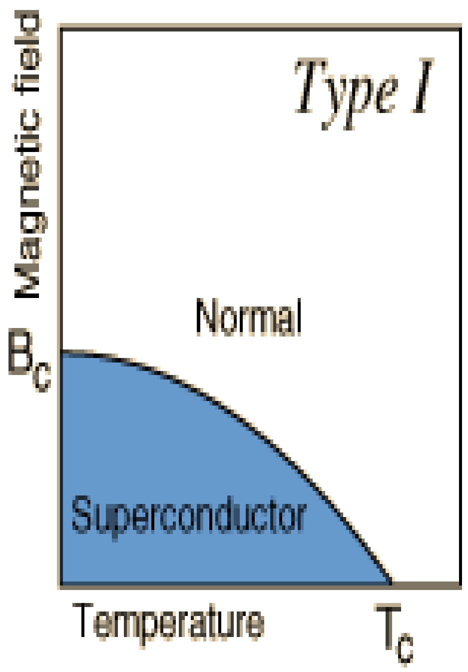


**Figure.4. Reaction of Superconductivity to Magnetic Fields**

**Table.1. Table of Type I Superconductors**

| Materials | Critical Temp. (Tc) | Materials | Critical Temp. (Tc) |
|---|---|---|---|
| Be | 0 | Gd | 1.1 |
| Rh | 0 | Al | 1.2 |
| W | 0.015 | Pa | 1.4 |
| Ir | 0.1 | Th | 1.4 |
| Lu | 0.1 | Re | 1.4 |
| Hf | 0.1 | Tl | 2.39 |
| Ru | 0.5 | In | 3.408 |
| Ox | 0.7 | Sn | 3.722 |
| Mo | 0.92 | Hg | 4.153 |
| Zr | 0.546 | Ta | 4.47 |
| Cd | 0.56 | V | 5.38 |
| U | 0.2 | La | 6.00 |
| Ti | 0.39 | Pb | 7.193 |
| Zn | 0.85 | Tc | 7.77 |
| Ga | 1.083 | Nb | 9.46 |

### B) Type II superconductors

The type II superconductors possess harder characteristics and retain higher critical temperature. It also has ability to produced high power magnetic fields. In addition to above it possess a higher threshold tolerance to magnetic fields so that they retain their superconducting properties even when in contact with a stronger magnetic field. Type II superconductors are most technologically useful because a second critical field can be quite high, enabling high field electromagnet to be made out of superconducting wire. Niobium –tin wires have a $B_{c2}$ as high as 24.5Tesla, which is useful for applications requiring high magnetic fields such as Magnetic Resonance Imaging (MRI) machines. Superconducting electromagnets are used because the current only has to be applied once to the wires, which are then formed into a closed loop and allow the current to persist indefinitely-as long as the superconductor stays below the critical temperature. So that the external power supply can be switched off.

| Material | Transition Temp (K) | Critical Field (T) |
|---|---|---|
| NbTi | 10 | 15 |
| PbMoS | 14.4 | 6.0 |
| $V_3Ga$ | 14.8 | 2.1 |
| NbN | 15.7 | 1.5 |
| $V_3Si$ | 16.9 | 2.35 |
| $Nb_3Sn$ | 18.0 | 24.5 |
| $Nb_3Al$ | 18.7 | 32.4 |
| $Nb_3(AlGe)$ | 20.7 | 44 |
| $Nb_3Ge$ | 23.2 | 38 |

**Figure.6. Table of Type II Superconductors**

It is being referred wrongly amongst some people that the term "type II" refers to the copper oxide based a high temperature superconductors discovered in the late 1980's. These are type II superconductors, but many have been discovered before that time.

## III. APPLICATIONS OF SUPERCONDUCTORS

1) One of the application of superconductors is to replace a existing high voltage power line with superconducting power line the idea of driving a high power line over miles and miles of terrain with no loss due to resistance is appealing to both the public and power companies. As critical temperature of type II superconductors are near to the boiling point of nitrogen these option is more viable. Currently liquid helium are used as cooling agent as it has low critical temperature than nitrogen, however its cost is high so it is not feasible for large scale application.

2) Another application of superconductors is the magnetically levitated or "Maglev" trains. Superconductors produced ultra-strong magnetic field which is utilized in these application. The train is levitated with the help of strong opposition of magnetic field so that it does not come in contact with the track .It provides clear benefits over other form of transportation such as the train never comes into contact with the rail so theoretically there is no need of maintenance as there are no moving parts also there is no friction between the train and railways because it is levitated. As a result of this the train can travelled at higher speed although there is still friction due to air. In addition to above the ride is smoother in maglev as there are no bumps as compared to the conventional trains.

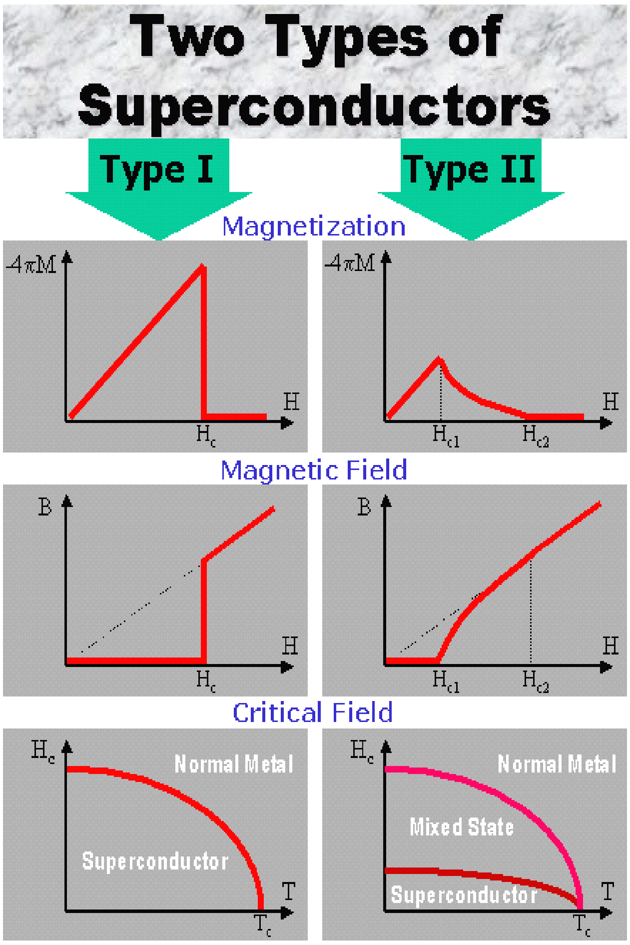


**Figure.7. Differences in Trend between Type I and Type II**

## IV. ELECTRODYNAMICS SUSPENSION

The Electrodynamics Suspension (EDS) is a form of magnetic levitation in which there are conductors creates magnetic fields. It induces eddy current in the conductor which creates magnetic field which holds two objects apart. These magnetic fields can caused by relative motion between two object. In that, one magnetic field is permanent magnet or superconducting magnet and when the magnetic field induced from changes of the field that the magnet moves to a conductor in another object. Electrodynamic suspension can be obtained when an electromagnet driven by an AC electric supply produced the change in magnetic field. EDS system is used in maglev trains, such as Japanese SCMaglev and it is also used in magnetically levitated bearing.

**Principle of electrodynamics suspension**

The conductive loop experiences a change in magnetic field, from faraday's law; the changing magnetic field produces an electromotive force (EMF). The EMF is 90 degrees phased ahead of the field for sinusoidal excitation. Since the field and potentials are out of phase both attractive and repulsive forces are produced and thus it might be expected that no net lift would be generated. However, although the EMF is at 90 degrees to the applied magnetic field, the loop inevitably has inductance.

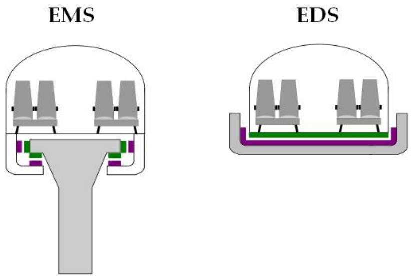


**Figure. 8. Difference between EMS and EDS system**

An attractive force system is used in EMS to levitate the train while in EDS system which is developed by Japanese engineers uses magnets that has same polarity to create a repulsive force between magnets and guideway magnets. This repulsive force will be high enough to counter gravitational force and helps to levitation. The core difference between EMS & EDS system is EDS maglev contains super-cooled, superconducting electromagnets. These magnets having ability to conduct electricity even after power supply has been off. This situation is not possible in EMS maglev which uses electromagnets. The coils only conduct electricity when the power supply is present. EDS system is a energy saving system but it is expensive. Another one important drawback of EDS system is that train must be roll on rubber tyres until it reaches up to velocity of 100km/h for levitation. However Japanese engineers say that rollers are advantage in case of power failure situation. The EDS train can levitate nearly 10 cm above guide way. EDS train can produces high intensity magnetic field, the passengers section of train should be shielded from the magnetic field, and otherwise it can be causes of accidental situations. Central Japan Railway Company invented SC Maglev i.e. superconducting maglev which works on a EDS system. On 21st April 2015, a manned seven car SC Maglev train reached

**Figure.9. JR Central SC Maglev**

a speed of 603 km/h whereas same train reached 590 km/h before week. In 2009, Japan's Ministry of Land, infrastructure, Transport and Tourism gave confirmation for SC Maglev train's commercial use and in 2011 the ministry gave JR Central permission to operate the SC Maglev system. In 2015, JR Central & Mitsui and General Electric in Australia partnered to made joint adventure named CLARA (consolidated Land and Rail Australia) to provide a commercial funding model using private investors that could build the SC Maglev linking Sydney, Canberra and Melbourne.

## V. CONCLUSION

A superconductivity of material means a phenomenon of zero electrical resistance and expulsion of magnetic field occurring in particular materials, that we called superconductors when cooled below a critical temperature. Whenever, a atoms travelling through a material it contains a some amount of energy and when these positive atoms and negative charged atoms collide with each other due to lattice vibrations they loss some amount of energy in the form of heat. To overcome with this problem superconductor was discovered to supply highest possible amount of energy with less loss as possible. The two types of superconductor type I and type II are currently using worldwide. A superconducting material is expensive and its commercial use may be difficult. But the research among worldwide can improve the drawbacks facing by scientists and researchers, and it will be revolution in the field of energy management and energy production. A EDS maglev train system is one of the best and revolutionary commercial use of superconductor. A high speed train which is dream project for world which can make human life more comfortable and easy with the help of this technology, but as its commercial use is recently more expensive than expectation, we have to wait for further revolutionary research in this field. It's important characteristics are it is environmental friendly system, which does not using fuels which make this system more reliable and flexible for economy and our day to day life. In short, a high speed transportation system with the help of superconductors is possible at high cost but with the benefits of environmental and energy saving situations. It is sure that the Maglev train and superconductors will be the next revolutionary results for human beings in next few years.

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