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# Study of Quantum Levitation and Locking in High Temperature Superconductors and Ways of Cooling

Harsh Tank[1], Saumil Chakraborty[2], Avinash .S[3], Abhishek Chandorkar[4], S. Esakkiyappan[5]
B.Tech Student[1, 2, 3, 4], Assistant Professor[5]
Department of Mechanical Engineering
SRM Institute of Science and Technology, Ramapuram, Chennai, India

**Abstract:**
The aim of this project is to study the properties of quantum levitation and locking, and provide ways to improve the efficiency and speed of current transportation systems (high speed trains, levitating cars and hover boards), and idea of creating bearings with negligible friction. It revolves around the phenomenon of superconductivity and the properties of superconductors by which they expel all the magnetic field. We came up with various ways of synthesizing high temperature superconductors, efficient ways of cooling the material below the critical temperature so as to become superconductors, and applications of the phenomenon of quantum levitation and locking.

**Keywords:** London Equation, Electromagnetic Free Energy, London Penetration Depth, superfluid, quenching.

## I. INTRODUCTION

Quantum levitation, as the name suggests, uses quantum physics to levitate a superconductor material. The reason behind using only superconductor material is the property of zero resistance. Superconductors expel all the magnetic fields through it when placed in a magnetic field. The phenomenon is called as Meissner effect. According to the Meissner effect, the magnetic fields are always expelled from a superconductor and thus bend the magnetic field around it. When a superconductor is placed in magnetic field, it does expel all the magnetic fields but is not in equilibrium. This is when quantum locking comes into play. It is explained by a phenomenon called as flux pinning. If the superconductor is a type- II superconductor, or is very thin, some of the magnetic fields do penetrate through it. However, occurs in discrete quantities which are called flux tubes. When these flux tubes penetrate the superconductor it basically turns off the superconductor in that specific region, due to which the superconductor creates an opposite force to resist any kind of motion in relation to the magnetic field. Due to this the superconductor gets locked into that position, thus called„ quantum locking‟.

## II. SUPERCONDUCTORS

When temperature of a material is lowered below its critical temperature, the electrical resistance decreases to near zero. The material then is called a superconductor. The property of expelling the magnetic field occurs only in superconductors, which is explained by Meissner effect. The temperature to which a material should be lowered ranges from 20 K to even less than 1 K for conventional superconductors, whichis why high temperature superconductors are preferred. This project deals with type- II (high temperature) superconductors. "Type- II" means it has two critical fields between which the magnetic fields penetrate, these two points are called „vortices‟. Type- I superconductors have single critical field which means superconductivity is lost above the point; and below the point, magnetic field is completely expelled making the phenomenon of quantum locking impossible.

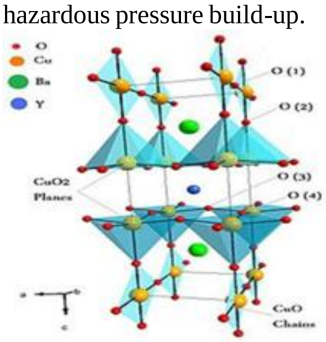
### *A. Preparation of high temperature superconductors*

The most common way of preparing high temperature superconductors is process of solid state thermo chemical reaction which involves mixing, calcination and sintering. Ball mill is used to mix appropriate amount of oxides and carbonates, known as precursor powders. There are alternative methods to prepare the homogeneous mixture for example co precipitation, freeze-drying and sol-gel methods. These powders are supposed to be calcinated for several hours in the temperature range of 800 °C to 950 °C. The above process is repeated several times to get a homogenous material. Then the mixture is compacted to pellets and then sintered. The important factors that affect the preparation of higher temperature superconductors include atmosphere, temperature, annealing time and cooling rate.

### *B. High $T_C$ superconductors*

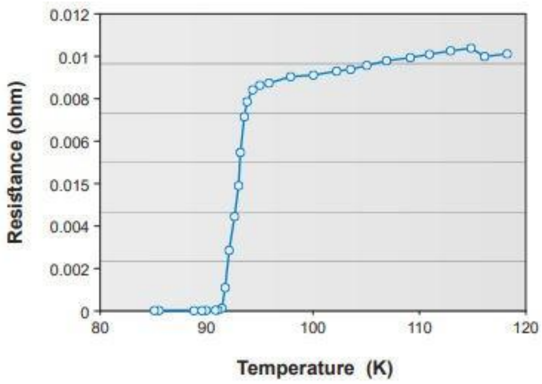
#### *1. Yttrium barium copper oxide (YBCO)*

$YBa_2Cu_3O_{7-x}$ is known to be the first cuprate superconductor that was discovered (1986). The critical temperature of YBCO is 92 K. The other materials which were prepared before 1986 showed superconducting properties at temperatures near 4 K. the boiling point of liquid helium is known to be 4.2 K, which was used to cool the materials earlier. Cooling at temperatures as low as 4.2 K caused problems such as formation of plugs of frozen air that can block cryogenic lines, which could cause potentially hazardous pressure build-up.




*YBCO unit cell*

The critical temperature of YBCO being 92 K is greater than the boiling point of liquid nitrogen (> 77 K), which makes it easier to bring down it down to superconducting conditions. The $YBa_2Cu_3O_{7-x}$ unit cell contains two layers of CuO2. These Cu-O chains are majorly responsible for superconductivity. Critical temperature when $x \approx 0.15$ is near 92 K (i.e. maximum) and the structure is orthorhombic. When $x \approx 0.6$, the superconductivity decreases to zero and the structure of YBCO transforms from orthorhombic to tetragonal.




YBCO is synthesized by heating a mixture of metal carbonates at temperatures around 1000 K and 1300 K.

$4\ BaCO_3 + Y_2(CO_3)_3 + 6\ CuCO_3 + (1/2-x)\ O_2 \rightarrow 2\ YBa_2Cu_3O_{7-x} + 13\ CO_2$

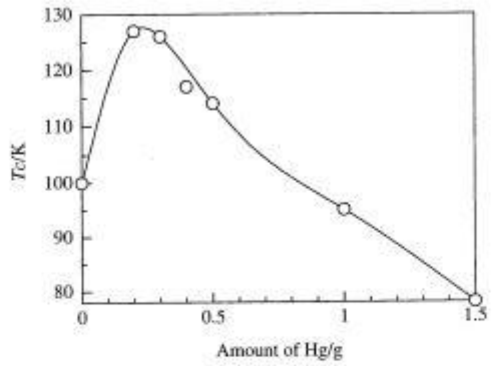
Corresponding oxides and nitrates are used in modern synthesis processes. Using CSD (chemical solution deposition) technique is very helpful in preparation of long YBCO tapes. This lowers the temperature to around 700 °C that is necessary to get the correct phase which makes this method very promising to synthesize scalable YBCO tapes.

### *2. $Bi_2Sr_2Ca_{n-1}Cu_nO_x$ Compounds*

In the Bi-Sr-Ca-Cu-O system, the compound with the ideal formula $Bi_2Sr_2Ca_2Cu_3O_{10}$ shows superconductivity up to 110 K. The magnetic measurements reveal the presence of two phases in the samples with superconducting transitions up to 80 K and 110 K. By varying the composition and the thermal treatment of those samples, an increase in the amount of the superconducting phase with Tc up to 110 K is observed. This one gives an electronic specific heat coefficient similar to the one of YBaCuO compounds. The Bi-Sr-Cu-O system has a general formula $Bi_2Sr_2Ca_{n-1}Cu_nO_x$. $T_c$ equal to 20 K at n = 1, 85 K at n = 2 and 110 K at n = 3. However, the superconducting phase at 110 K is hard to stabilize. This phase only appears in few samples and in very small amounts. This phase was particularly sensitive to annealing temperatures so lead oxide was introduced in order to stabilize the 110 K phase.

### *3. $TI_2Ba_2Ca_{n-1}Cu_3O_{2n+4}$ compounds*

TI based superconductors, TI2Ba2Can-1Cu3O2n+4, are another type of superconductors which show superconducting properties at critical temperatures of around 127 K. the TI2Ba2Ca2.5Cu3Oy compound can be synthesized in an evacuated quartz tube by sintering at 860 °C for 12 hours. The time required for sintering is much less than those for other preparation methods of superconductors. Doping of Hg into the TI2Ba2Ca2.5Cu3Oy compound stabilize the structure and the composition phase TI1.8Hg0.2Ba2Ca2.5Cu3Oy shows superconductivity at 127 K.




## III. MEISSNER EFFECT

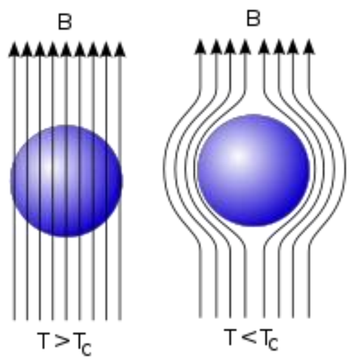
The phenomenon of expulsion of magnetic field from superconductor during its transition to the superconducting state is known as Meissner effect. It is named after a German physicist Walter Meissner who discovered this phenomenon in 1933 by measuring magnetic field distribution with lead and tin superconducting samples. When a superconductor is placed in a magnetic field, since the electrical resistance is negligible, opposite electric current is generated near its surface. The magnetic field due to this surface current is large enough to cancel the applied magnetic field within the superconductor. This magnetic field cancellation does not change with time i.e. the current producing this effect does not decay with time as long as the temperature of the superconductor is below its Tc. However, the magnetic field expulsion is not constant throughout the superconductor; it varies exponentially which is explained by the London equation. Fritz and Heimz London gave a phenomenological explanation to Meissner effect which stated that electromagnetic free energy in a superconductor is minimized when, thin or is a type- II superconductor, which is the cause for „Quantum Locking‟.

## IV. WAYS OF COOLING

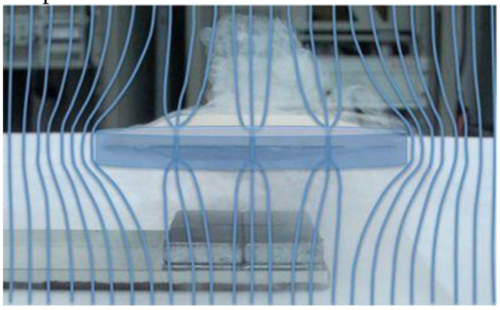
To achieve the superconducting properties for quantum levitation and locking, it is necessary to get temperatures to below critical temperature of the material. However, dropping the temperature to such low levels is not as simple as increasing the temperature; cooling the material has always been the greatest challenge. In this project various ways of cooling were studied and comparison was done.

$\nabla^2 H = \lambda^{-2} H$

Where „H‟ is the magnetic field and „λ‟ is London penetration depth. „London penetration depth‟ is the distance to which magnetic field is penetrated into a superconductor. It results from ampere‟s circuital law and the London equation. $B(x) = B_0 \exp(-x/\lambda L)$ Here λ is the distance across which magnetic field is decreased e times.



This figure shows the expelled magnetic field when the temperature of the material is decreased below the critical temperature.



The above figure shows the flux tubes that pass through superconductor when the superconducting material is very

### *A. Using liquid helium*

Helium is extracted from natural gas fields or is created through natural radioactive decay. Helium liquefies at 4.2 K and does not freeze at atmospheric pressure. The reason liquid helium is used is its low molecular weight and weak interatomic interactions. Helium is generally used as coolant as its properties allow components to be kept cool over long period of time. Liquid helium has two phases i.e. helium-I and helium-II. Helium-I shows thermodynamic, hydrodynamic and quantum properties of classical fluids. However, below 2.17 K, helium transitions to He II and becomes a quantum superfluid with zero viscosity. Properties of this superfluid helium include very high thermal conductivity; it is a very efficient heat conductor, which makes it an excellent refrigerant for cooling.

| **Properties of Liquid Helium** | **Helium-4** | **Helium-3** |
|---|---|---|
| Critical Temperature | 5.2 K | 3.3 K |
| Boiling Point at One Atmosphere | 4.2 K | 3.2 K |
| Minimum Melting Pressure | 25 atm | 29 atm at 0.3 K |
| Superfluid Transition Temperature at Saturated Vapour Pressure | 2.17 K | 1 mK in the absence of a magnetic field. |

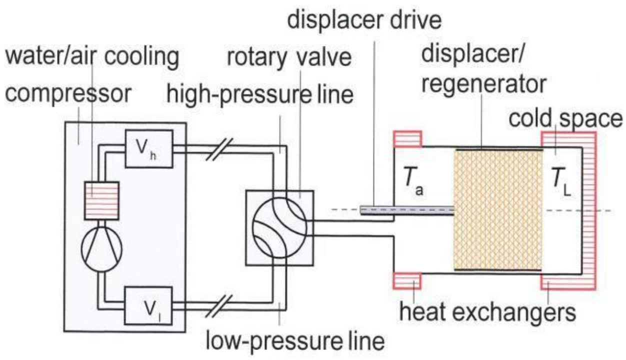
However, liquid helium has some problems. Even though helium is the second most abundant material in the universe, it is scarce on earth due to its light weight, and therefore it gets escaped to space. Also, there is a generation of heat when superconductivity is disturbed, called as „quenching". Due to this reason, helium rapidly boils off, which is why it is needed to be stored in vacuum containers.

### *B.Using liquid nitrogen*

Nitrogen liquefies at a temperature of 77 K. liquid air is sent thorough fractional distillation, thus producing liquid nitrogen. Liquid nitrogen is generally referred as LN2 or "LIN" or "LN". Liquid nitrogen is also cryogenic fluid. It causes rapid freezing on contact with living tissue. Liquid nitrogen can be stored and transported in vacuum containers i.e. when insulated properly from ambient heat. It can be stored in the vacuum containers up to few weeks depending on the size and design of the container. With the development of pressurised and super-insulated vacuum vessels, liquefied nitrogen can be stored and transported over longer period of time with 2% or less losses. The temperature of liquid nitrogen can readily be lowered to 63 K (−210 °C; −346 °F) which is its freezing point, with vacuum creation, The only problem with liquid nitrogen is that it readily boils when brought in contact with an object at relatively higher temperature, enveloping the object in insulating nitrogen gas. A faster way of cooling can be used by putting an object into a mixture of solid and liquid nitrogen rather than liquid nitrogen alone. The use of liquid nitrogen seems to be more efficient than liquid helium since liquid nitrogen is easily produced. Liquid nitrogen is also produced for direct sale. It Is also a by-product of steel making plants while manufacturing liquid oxygen, making it very inexpensive.

### C. *Mechanical cooling.*

It is a method for cooling superconducting systems using two- stage mechanical refrigeration. This method is preferred over the use The two stage mechanical refrigerators are known as cryocoolers. Generally two types of mechanical cryocoolers are employed which provide enough power to cool and maintain the material below of liquid helium due to high cost and less availability their critical temperature. The most common type of cryocooler is Gifford-McMahon cryocooler and has been commercially available since 1960s. The G-M regenerator cycle works on the same principle as the heat exchanger using a piston type displacer. A better design of cryocooler was then available with low vibration and long service interval by using acoustic process instead of mechanical displacement; it is known as pulse tube cryocooler. Similar to two stage refrigerators, in the first stage the cooling capacity is high but at a temperature ~ 77 K. in second stage less than two watts of power is used, lowering the temperature to ~ 4.2 K.




## V. MAGLEV TRACK/BASE

Maglev track or base is major factor while considering the efficiency and speed of transportation system using „quantum levitation and locking systems". To levitate and lock a superconductor, strong magnetic fields are required. in order to provide strong magnetic fields either strong permanent magnets or electromagnets can be employed depending upon the application.

### *a.Neodymium magnet*

It is a permanent magnet made up of neodymium, iron and boron. It has a tetragonal crystalline structure with the structural formula Nd2Fe14B, which is also responsible for its high strength. The neodymium magnets have high saturation magnetization typically of 1.3- tesla. Thus, the amount of magnetic energy is stored in them is as high as eighteen times as the ordinary magnets. The magnetic properties of these magnets depend on the employed manufacturing techniques, alloy composition and the microstructure.

**b. *Electromagnets***

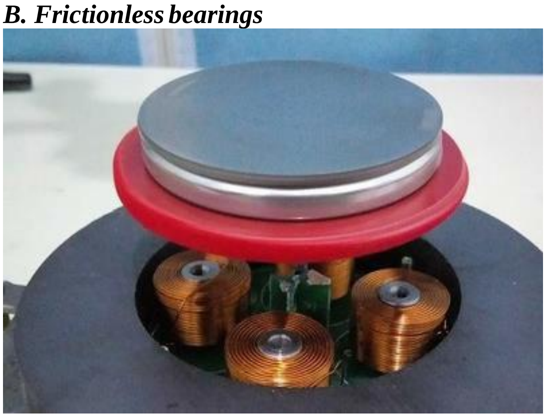
Permanent magnets are not the ultimate way to use as the base track when big projects like levitating trains are considered. Also, using electromagnets have advantage of changing the magnitude of magnetic field and even turning off whenever required. Strong electromagnets are not difficult to make. The strength of magnetic field of an electromagnet depends on three factors: the magnitude of current, number of coil windings and the type of core used. Using a ferromagnetic core gives high magnetic field as the core itself conducts current. Cu-Ag alloys are easy in manufacturing as well as have high strength and conductivity. Employing proper combination of heat treatment and cold working, Cu-Ag alloys exhibit uniform strength.

## VI. SCOPE OF WORK

### *A. High speed Quantum levitating trains*

Maglev trains are already being used for transportation, which use two sets of magnets (electromagnets). Quantum levitating trains have the potential to be more efficient as compared to maglev trains. Quantum levitating superconductor can carry 70,000 times its own weight, which increases the load carrying capacity of Quantum levitating trains. Also, Quantum levitating trains promise far more stability due to the phenomenon of quantum locking. As superconductors are being employed, the requirement of magnetic field is much less than maglev systems. Quantum levitating trains use only one set of electromagnet which makes it far more energy efficient. As quantum locking system locks the super conductor in a fixed position, the external force can be of either type (attractive or repulsive). Thus, the tracks can even be constructed over the trains and given desirable heights, which improve the space efficiency. Talking about space efficiency, two trains can be levitated on a common track i.e. one over the track and another under the track.

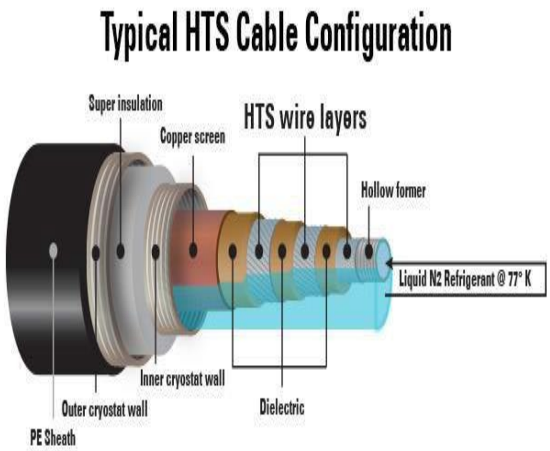
### *B. Frictionless bearings*



Using„ quantum levitation and locking‟ frictionless bearings can be produced. Due to the perpendicular force acting on the bearing a lot of energy is wasted in bearing friction. But when quantum levitation is implied the bearings would remain suspended in mid- air, therefore the friction would not be present in the system. One of the rotors must be made up of a permanent magnet and the other must be high temperature superconductor cooled below the critical temperature. Since there would be absolutely no contact, the friction between the two rotors becomes zero, increasing the efficiency by large amount. Having no physical contact gives one more advantage of having no wear at all. Using these frictionless bearings in various machines would have large benefits.

### *C. High temperature superconducting cables*

The transmission of electrical power is done almost by copper wires. According to EIA 18% of electricity is lost in India during transmission process, which results in huge loss of money. An efficient way of transmitting electricity is through HTS power cables, which provides 0% loss of electrical current during transmission. HTS- cables are made up using high temperature superconductors, with proper insulation, and liquid nitrogen as coolant. Due to zero electrical resistance, high amount of power can be transmitted through it. Superconducting cable can also make overall cost of construction lesser than that of conventional cable. A 4 mm x 0.2 mm cable can carry critical current of more than 130 A per wire. It has an improved mechanical property of high tensile strength of around 140 MPa which makes it very practical. The HTS power cables require less material than copper wire to transmit electrical energy. HTS power cables increase the grid efficiency and they also reduce the carbon footprint.




## VI. CONCLUSION

Quantum levitation and locking systems provide a promising future in terms of transportation, creating lossless machines, high temperature superconducting cables and various other similar fields. This paper depicts various ways of creating high temperature superconductors which seems to be the biggest challenge. More efficient ways of cooling the superconductor are explained. Quantum levitation systems are far more energy efficient as compared to other systems.

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