DEVELOPMENT OF EXPERIMENTAL SET UP FOR MEASUREMENT OF ELECTRICAL RESISTANCE AT LOW TEMPERATURE

A PROJECT REPORT

Submitted by

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REG NO: TKM21MEIR04

to

The APJ Abdul Kalam Technological University

in partial fulfilment of the requirements for the award of

M. Tech degree in Industrial Refrigeration and Cryogenics Engineering.

Department of Mechanical Engineering

TKM College of Engineering, Kollam

May 2023

DEPARTMENT OF MECHANICAL ENGINEERING

TKM COLLEGE OF ENGINEERING, KOLLAM

CERTIFICATE

This is to Certify that this report entitled '**DEVELOPMENT OF EXPERIMENTAL SET UP FOR MEASUREMENT OF ELECTRICAL RESISTANCE AT LOW TEMPERATURE**' is the report of project presented by **ASHIK NAUSHAD**, Reg. No: **TKM21MEIR04** during **2022-2023** in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Industrial Refrigeration and Cryogenics Engineering of the *APJ Abdul Kalam Technological University*.

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DECLARATION

I, Ashik Naushad, hereby declare that this project report entitled "Development of experimental set up for measurement of electrical resistance at low temperature", is the bonafide work of mine carried out under the supervision of Dr. Rijo Jacob Thomas., Assistant Professor in the Department of Mechanical Engineering, TKM College of Engineering, Kollam. I declare that, to the best of my knowledge, the work reported herein does not form part of any other project or dissertation on the basis of which a degree or award was conferred on an earlier occasion to any other candidate. The content of this report is not being presented by any other student or any other university for the award of a degree.

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ACKNOWLEDGEMENT

Any attempt at any level cannot be satisfactorily completed without the support and guidance of learned people. I owe to great many people whose constant support and motivation that has encouraged me to come up with this project. I would like to express my heartfelt thanks to **Dr. Rijo Jacob Thomas,** Assistant Professor, Department of Mechanical Engineering, TKM College of Engineering for being instrumental in the completion of my project with his guidance.

I express my deep sense of gratitude to **Dr. Dileep P. N.**, Professor and Head of Department, TKM College of Engineering from bottom of heart for lending me all facilities and support for completion of this project. I thank, **Dr. Shafi K. A.** P G coordinator, Department of Mechanical Engineering, TKM College of Engineering and **Dr. Sreenivasan Kasthurirengan.**, Rtd. Professor, Centre for Cryogenic Technology, IISC Bangalore for giving their constant support for doing this project. I take this opportunity to extend my deep appreciation to family and friends, for all that they meant to me during the crucial times of the completion of this project. Finally, I thank **Almighty God** for being with me all the time and guiding me with their divine light.

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ABSTRACT

The aim of the experiments is to measure the resistance of commonly used materials like aluminium, copper, and nichrome at both room temperature and cryogenic temperature (77K). To achieve this, an experimental setup will be developed using instruments such as the kelvin double bridge and LCR meter. Another setup will be created to measure the resistance of the materials as they are cooled from room temperature to 77K, and the measurements will be continued as the materials are gradually warmed back up. By analyzing these measurements, we can determine how the resistance of the materials changes at different temperatures. These experimental setups will provide valuable information on the resistance characteristics of materials at different temperatures, potentially leading to new applications in cryogenic cooling technology for medical and diagnostic purposes. The experiment conducted with BSCCO 2223 (HTS) using different constant currents (100mA, 200mA, 500mA, and 1000mA) demonstrated an average transition temperature of 104K, which falls within the reported range of BSCCO 2223's Tc in various literature, validating the reliability of the proposed experimental setup. Furthermore, aluminium and copper show a significant decrease in resistance at cryogenic temperatures, while nichrome's resistance remains relatively stable at 77K. This suggests that, in general, resistance materials experience minimal changes in resistance when exposed to cryogenic temperatures. Although there is a slight variation in resistivity compared to literature values for all three tested materials, the experimental values still follow a consistent trend in resistance with temperature, as described in the literature.

Keywords: HTS, Experimental Setup, BSCCO 2223, GM Cryocooler

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

For metallic conductors, electric charges e are transported by n ‘free electrons’, and the electrical conductivity is $\sigma = nl_e e^2(m_e v_f)$, where m_e is the mass of an electron and l_e denotes the mean free path of the electrons. The electrical resistivity is $\rho = \sigma^{-1}$. At ambient temperature, the electron free path l_e is dominated by electron scattering from thermal vibrations of the crystal lattice (phonons). At low temperature, it is limited mainly by scattering off chemical and physical crystal lattice imperfections (chemical impurities, vacancies, dislocations). Considering the two contributions, the electrical resistivity can be written as (Matthiesen’s rule):$\rho(T) = \rho_{ph}(T) + \rho_i$, the subscript i denoting imperfections. ρ_i is generally not dependent on the temperature but varies from one sample of a material to another due to the imperfection content. However, ρ_{ph} is the same for different samples of a material as it depends on the frequency of the collisions of electrons with thermal phonons (and electrons). For $T > \theta_D$, the concentration of phonons is proportional to the temperature, and so $\rho_{ph} \propto T$ and thus $\rho \propto T$. As $T \rightarrow 0$, $\rho \rightarrow \rho_i$, with ρi proportional to T^n (with $1<n<5$).

As $\rho_{T\rightarrow 0}(T) = \rho_i(0)$, an indication of the impurities and crystallographic defects in a metal (imperfections) is provided by the determination of the Residual (electrical) Resistivity Ratio (RRR):

$$RRR = \frac{\rho(273k)}{\rho(Ok)} \approx \frac{\rho(273k)}{\rho(Ok)}$$

Therefore, the smaller the imperfection content in a material, the smaller the $\rho(0) \approx \rho_i(0)$ and the larger the RRR

The empirical Wiedemann–Franz law indicates that the ratio has almost the same value for different metals at the same temperature. Theoretically, and thus, the more pure a material is, the larger its electronic thermal conductivity

$$\frac{K_e}{\sigma_T} = \frac{\pi^2}{3}\left(\frac{K_B}{e}\right)^2 = 2.445 \, . \, 10^{-8} (\mathrm{W.\Omega.K^{-2}})$$

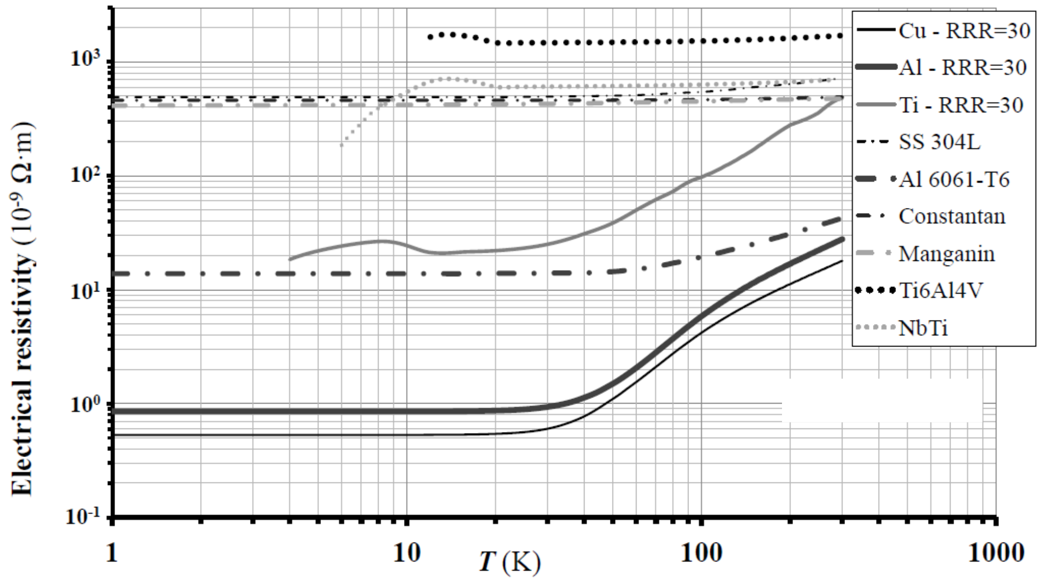

Fig: 1.1 Electrical resistivity of various materials versus temperature

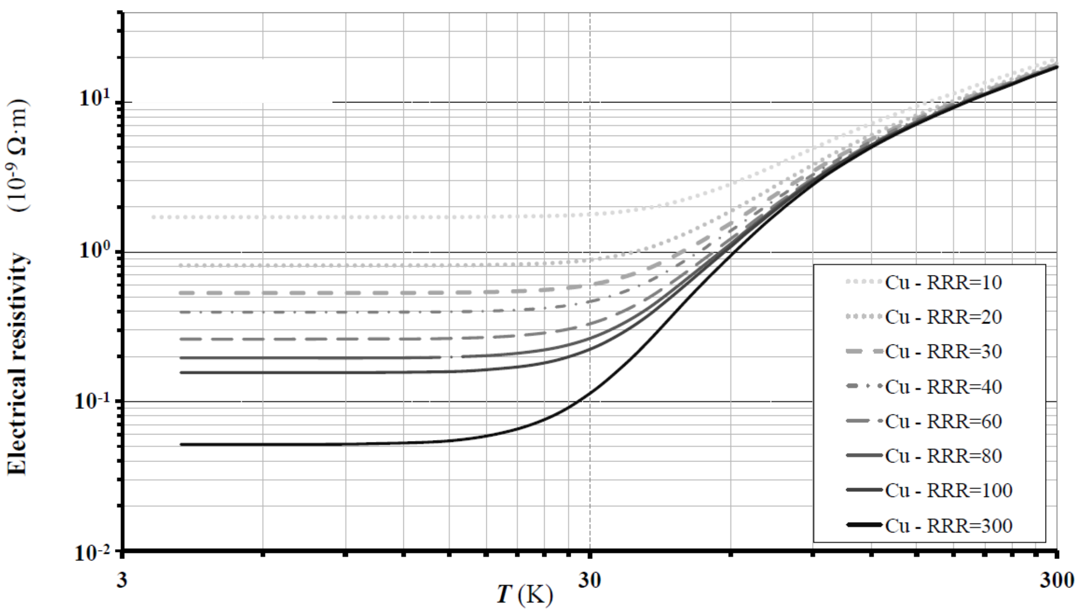

Fig1.2: Electrical resistivity of different coppers.

1.1 Electrical resistivity of semiconductors

For semiconductors, electric charges are transported by conduction band electrons and holes in the valence band. Around the ambient temperature, lattice vibrations are predominant and electrical properties are not modified by impurities. The electrical resistivity can be expressed as $\rho(T) = a.e^{\delta/2K_BT}$, where a is an experimental constant and δ is the energy band depending on the material. At low temperature, lattice vibrations are negligible and impurities play an important role in the transport of charges. Thus, the resistivity of semiconductors is very non-linear: it typically increases as temperature drops due to there being fewer electrons in the conduction band. An important application of this property is the use of semiconductors as temperature sensors (thermistors).

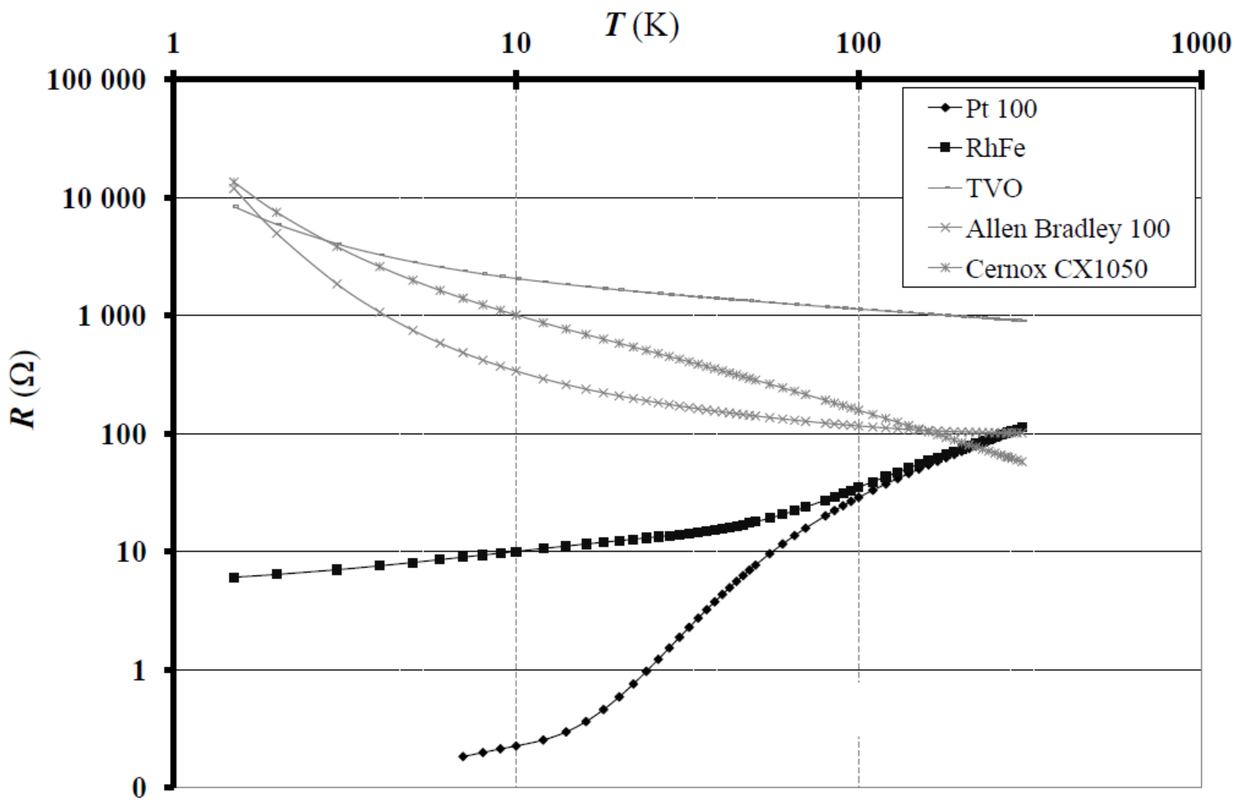

Fig 1.3: Resistivity of various thermistors

1.2 Superconductivity

Superconductivity refers to a property of certain materials where they can conduct direct current electricity without any energy loss when they are cooled to a specific temperature known as Tc. Additionally, these materials will expel magnetic fields as they transition to this superconducting state. Superconductivity is an intriguing quantum process found in nature that was initially discovered more than a century ago in mercury that had been cooled to the temperature of liquid helium, which is approximately -452°F.

Since the discovery of superconductivity in mercury, scientists have observed this phenomenon in other low-temperature materials such as several metals and a niobium-titanium alloy that can be quickly transformed into wire. The lack of electrical resistance in superconducting wires means that they can handle high electrical currents; however, if the electron pairs break up beyond a certain "critical current," superconductivity is destroyed. Superconducting wires have led to new technological applications, including windings for powerful magnets. In the 1970s, scientists used superconducting magnets to generate the high magnetic fields necessary to develop MRI machines. Recently, scientists have introduced superconducting magnets to guide electron beams in synchrotrons and accelerators in scientific user facilities.

In 1986, scientists discovered a new group of copper oxide materials that exhibit superconductivity at much higher temperatures than metals and metal alloys. These materials are referred to as high-temperature superconductors. Although they still require cooling, they remain superconducting at significantly warmer temperatures, with some even remaining superconducting at temperatures higher than liquid nitrogen.

1.3 How Does Superconductivity Work?

Superconductors typically function by allowing electrons to overcome their natural repulsion and form Cooper pairs, leading to decreased electron identity certainty and allowing for easier movement through atoms, resulting in zero resistance to electric current flow. A material is considered a superconductor if it exhibits this property as part of its physical characteristics. Unlike normal conductors, where conductivity increases as temperature decreases, a superconductor's conductivity reaches maximum and resistance drops to zero at a critical temperature.

There are two types of superconductors: Type I and Type II. Type I superconductors undergo a sudden transition from normal to superconducting states and display a complete Meissner effect below the transition temperature, meaning they completely expel magnetic field flux. In contrast, Type II superconductors exhibit a partial Meissner effect before displaying a complete Meissner effect within a range of applied magnetic fields between two critical values. The Meissner effect is commonly used in the design of suspended trains and has many other practical applications.

1.4 Properties of Superconductors

The exceptional electrical properties of superconductors are a significant aspect because they differentiate them from other materials. The property of zero electrical DC resistance is universal to all superconductors, despite variations in other properties like critical temperature and heat capacity, which can differ between materials. As mentioned earlier, the phenomenon of superconductivity is closely related to a decrease in temperature. All superconducting materials exhibit a similar behavior - their resistance becomes zero when the temperature falls below a certain critical value. Therefore, superconductivity is a thermal property that is independent of the physical properties of the material. During the transition from a non-superconducting state to a superconducting state, the material's physical properties, which are characteristics of the phase transition, undergo significant changes. The onset of superconductivity occurs when the temperature falls below the critical temperature, triggering a magnetic field effect. However, if an external magnetic field surpasses the critical magnetic field, the superconductor loses its superconducting properties and begins behaving like a regular conductor. This change in the phase of the superconducting material is due to a difference in the Gibbs free energy. In the superconducting phase, the conductor's free energy is lower than in the normal, non-superconducting phase. When an external magnetic field is applied, and a finite amount of free energy is supplied, the free energy of the superconductor increases gradually, and eventually, the superconductor undergoes a phase transition from the superconducting phase to the non-superconducting phase.

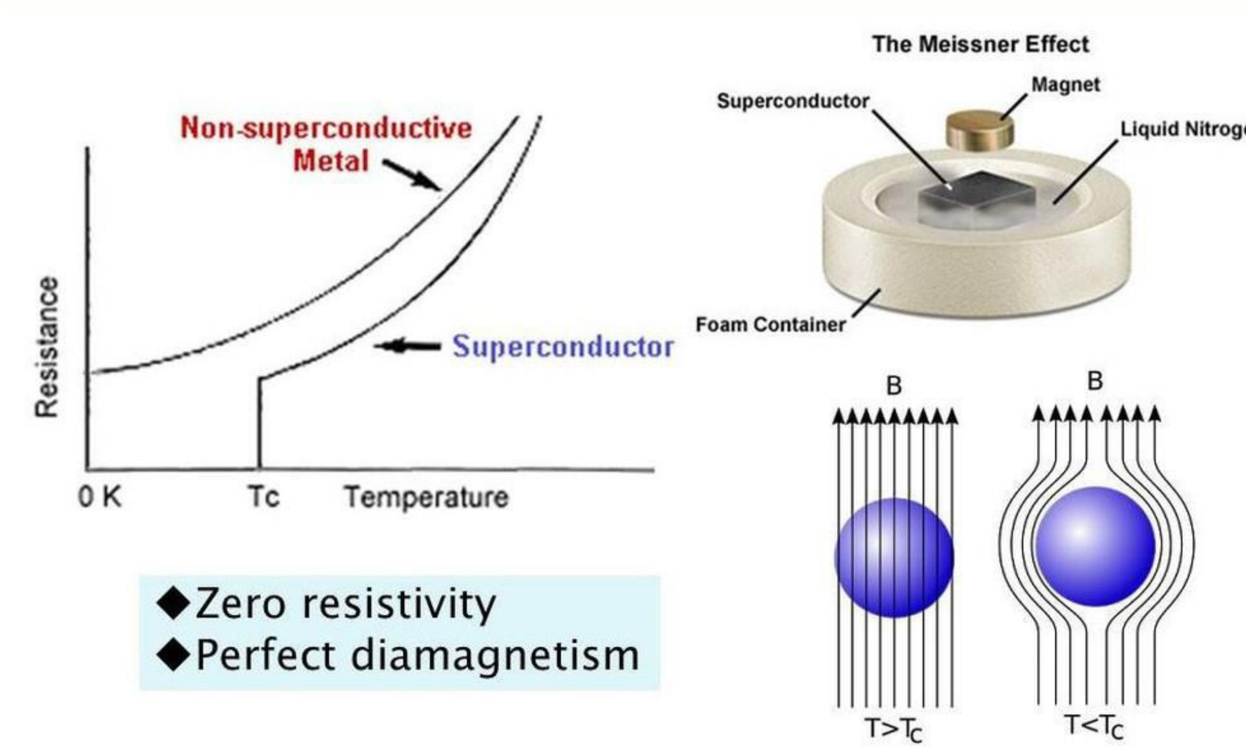

Fig 1.4: Diagram showing superconductivity and Meissner effect

1.5 Thermal Properties of Superconductors

Superconductors exhibit thermal properties that differ significantly from ordinary electrical conductors. In a typical conductor, conduction electrons are free to move around in the material and represent an electric current. However, these electrons are often scattered by various factors such as impurities, dislocations, and lattice vibrations. In contrast, superconductors exhibit order among the conduction electrons that prevents scattering, allowing current to flow without resistance. This order is referred to as Cooper pairing and includes the momentum of the electron, rather than its position. The energy per electron associated with this order is minimal.

Superconductors have several advantages due to their zero DC electrical resistance. Applications that take advantage of these properties include those that require low energy loss, high-speed operation with zero resistance and continuous current, and high sensitivity. Examples of superconductors include mercury, niobium-tin, lanthanum-valium-cuprate, and yttrium-valium-cuprate. Examples of applications for superconductors include medical MRI/NMR devices, magnetic energy storage systems, motors, generators, transformers, computer components, and sensitive instruments for measuring magnetic fields and currents.

1.6 PROBLEM DEFINITION

The electrical properties of resistance materials at cryogenic temperatures are generally lower compared to pure metals. This means that resistance materials have higher resistance and lower conductivity at cryogenic temperatures.

Most of the studies related to physical properties of resistance materials are conducted after the materials have undergone cryotreatment. Cryotreatment involves cooling the materials to extremely low temperatures in order to improve their physical properties, such as increasing their resistance to wear and tear.

Compared to pure metals, alloys such as nichrome exhibit a wider range of characteristics from their parent metals. This is because alloys are composed of different metals or non-metals in specific proportions, which can affect their electrical properties at low temperatures.

In order to better understand and study the resistance of materials at low temperatures, it is important to have a reliable and accurate experimental setup for measuring their electrical properties at cryogenic temperatures. Such a setup would enable researchers to better understand the behavior of resistance materials at low temperatures and develop more efficient and effective cryogenic systems.

1.7 OBJECTIVES

The first objective of the project is to measure the resistance of commonly used materials at both room temperature and cryogenic temperature. This can be done by subjecting the materials to varying temperatures and measuring their resistance using a multimeter or other specialized equipment. This measurement is essential as it helps to determine the suitability of these materials for use in low-temperature applications.

The second objective of the project is to develop an experimental setup for measuring resistance from cryogenic temperature to room temperature. This involves building a system that can accurately measure the resistance of a material at varying temperatures. The system may include a temperature control unit, a sample holder, a measuring instrument, and other specialized components.

The third objective of the project is to measure the resistance of High Temperature Superconductor BSCCO 2223 from 77K to room temperature. HTS materials are known for their excellent conductivity at low temperatures, and measuring their resistance over a wide temperature range can provide useful insights into their properties. This measurement can be done using the same experimental setup developed in the second objective.

CHAPTER 2
LITERATURE REVIEW

This literature review mainly includes researchers' numerical and experimental works on resistance at low temperature HTS cables and certain other commonly used materials.

S.Gijoy and K.E Reby Roy conducted a study in 2022 where they used finite element electromagnetic network analysis and simulation to examine a 14-wire high-temperature superconductor (HTS) Roebel cable. The results of this study will be compared to other studies. They also used H-formulation techniques to model the problem, but they performed some numerical simulations to optimize the HTS Roebel cable. However, there has been no previous work using finite element analysis to examine the complete 3D structure of the Roebel cable. Thus, this study can be considered as the first step in conducting a 3D finite element analysis of the electromagnetic properties of the HTS Roebel cable.

The objective of this study was to examine how the electromechanical stability of Roebel cables is affected by various geometric parameters using 3D finite element analysis. Parameters such as the inner and outer fillet radius, Roebel angle, and strand width were investigated. The standard geometry was first modeled and its electromechanical simulation was conducted under various load conditions. Next, each parameter was modified in the standard geometry, and the electromechanical simulation was carried out for each set, comparing their effects with the default geometry. The researchers also observed the impact of changing the distance between stacks of strands in the crossing section and straight section on the mechanical stability and electromagnetic properties of the cable.

J Yang et al. (2022) aim to create a 3D finite element model of a CORC cable in their study. The model includes complex geometries, angle-dependent critical currents, and periodic settings. They validate the model by measuring the transport loss of a two-layer CORC cable. The simulation results show that as the current increases, the primary transport loss shifts from the former to the superconductor. The loss in the outer layer is greater than in the inner layer due to the shielding effect between the layers. This effect also leads to non-uniformity in the current of the CORC cable. In contrast to the two-layer case, the copper former's eddy current loss is always dominant without cancelling the reverse winding layer. Therefore, the simulated single-layer structure shows stronger frequency dependence. The AC transport loss is compared between pure HTS tape, double-layer cable, and single-layer cable, and it is confirmed that the two-layer structure minimizes loss. The work is a valuable reference for the structural design of the CORC cable, as it provides insight into the electromagnetic behavior inside the cable.

Low-temperature electrical resistance measurement system for metallic and semiconductor materials" (Shi et al., 2019): This study presents an experimental setup for measuring the electrical resistance of metallic and semiconductor materials at temperatures as low as 10 K. The setup consists of a cryostat, a sample holder, and a measurement circuit. The cryostat is used to cool the sample to the desired temperature, while the sample holder provides electrical contacts to the sample. The measurement circuit is used to measure the electrical resistance of the sample as a function of temperature.

A low-temperature resistivity measurement system with a novel sample holder for thin films" (Pandya et al., 2016): This study presents a low-temperature resistivity measurement system for thin films. The system consists of a cryostat, a sample holder, and a measurement circuit. The sample holder is designed to minimize thermal gradients and to provide electrical contacts to the sample. The measurement circuit is used to measure the resistivity of the sample as a function of temperature.

Development of a cryogenic electrical resistance measurement system for low-temperature superconductor wires" (Matsui et al., 2017): This study presents an experimental setup for measuring the electrical resistance of low-temperature superconductor wires at temperatures as low as 4.2 K. The setup consists of a cryostat, a sample holder, and a measurement circuit. The cryostat is used to cool the sample to the desired temperature, while the sample holder provides electrical contacts to the sample. The measurement circuit is used to measure the electrical resistance of the sample as a function of temperature.

A compact and low-cost system for electrical resistance measurement of metallic thin films at low temperatures" (Choi et al., 2020): This study presents a compact and low-cost experimental setup for measuring the electrical resistance of metallic thin films at temperatures as low as 10 K. The setup consists of a cryostat, a sample holder, and a measurement circuit. The sample holder is designed to minimize thermal gradients and to provide electrical contacts to the sample. The measurement circuit is used to measure the electrical resistance of the sample as a function of temperature.

T. Morie and M. Y. Xu (2012) took a purely theoretical approach to studying cooling capacity and losses in the regenerator and heat exchangers. The authors developed a specialized numerical simulation software for this purpose. The simulation results for pressure and volume variation, as well as P-V energy in the second-stage expansion volume, were consistent with measurements. However, the actual cooling capacity was lower than the P-V power due to additional enthalpy flow from the second-stage regenerator. The observed pumping loss was lower than the shuttle loss. Additionally, the impact of pulse tube cooling was relatively small due to limited volume in the clearance or spiral groove.

Ion Beam Application (IBA) researchers led by Y. Paradis, V. Nuttens, Lamon, E. Forton T (2016) are working to develop a low-cost technique for maintaining cryocoolers. They have developed a heating system that maintains the cold mass at an extremely low temperature, heating both phases of the cryocooler to room temperature using a specialized testing platform with turbopumps and additional heating system components. In each of the four-second stages, two kW of electricity and 1.5 KW of power were installed. After cooling the SC magnet, a local heating system was used to warm up each cryocooler head in order to simulate a maintenance scenario. While the first stage was kept at room temperature for 40 minutes, the second stage was kept there for 30 minutes. The maximum cold mass temperature during this maintenance simulation was 65 K.

S.C. Chang and B.J. Huang (1995) developed a new method for analyzing a GM (Gifford-McMahon) cooler's regenerator. Instead of analyzing the regenerator's transient heat transfer, they used a regenerator half-cycle average energy approach. They first calculated the dynamic equations of the GM cooler's momentum and mass events and numerically solved for the time variables. Then they used the regenerator half-cycle average energy equation to obtain the half-cycle average variables and the regenerator effectiveness. An iterative process was used to arrive at the final answers, and this helped to evaluate the system capacity of the GM cooler. They also developed a systematic study of a single-stage cryocooler using the PC-based simulation program GMSYS. Their study was empirically validated by demonstrating that the predicted performance closely matched the test results.

XU Xiang-dong and HONG Chao-sheng (1994) suggest that when selecting the matrix material for the regenerator, it is important to choose a material with high values of Cm (T) within the temperature range where the material is compressed (typically between 4 K and 6 K for Er3Ni and ErNi2). This will result in a lower f value and less loss during refrigeration. If the values of Cm (T) are relatively low at elevated temperatures, increasing the duration of the regenerator can help offset these negative effects. For regenerators with matrix porosity of p=0.4, it is recommended that the regenerator void volume be slightly larger than the volume required to hold all of the M at the end of the cold phase, with a regenerator volume-to-expansion space volume ratio of 3 to 3.5 for Er3Ni and ErNi2.

C Wang, J Cosco, and A Olesh (2017) have optimized and modified the regenerator, heat exchanger, and stem shield of the Cryomech type AL600, a large cooling power GM cryocooler, and improved its operational parameters. The output capacity of this cryocooler is 129 W at 30 K, 701 W at 80 K, and 1005 W at 120 K, and it is considered the most efficient, effective, and fastest cooling GM cryocooler available to date [21]. By using a new bumper design, cold head vibrations were reduced by 82%, making the latest generation AL600 GM cryocooler more attractive for many applications.

Anand Bhatt, Nipun Raval, and Tejas Raval (2017) measured the rate of heat transfer from radiation, pipe conduction, and molecular gas conduction at a constant temperature of 4 K. The rate of heat transfer from radiation was found to be 0.371 W, while pipe conduction and molecular gas conduction contributed 1.0932 W and 0.00292 W, respectively. These values were measured with the sample holder placed on a cold finger at 4 K. The total heat transfer rate at a constant temperature of 4 K was calculated to be 1.46712 W, which is below the cryocooler's rated capacity of 1.5 W at the same temperature.

Rui Li, Mingyao Xu, Qian Bao, and Akihiro Tsuchiya (2015) state that compact cryocooler size is necessary for superconducting electrical equipment, and digital equipment based on superconducting technology faces significant challenges due to its large size and high energy consumption compared to semiconductor devices. The cryocooler design must meet several critical requirements, including a first-stage cooling power of 1 W, a second-stage cooling capacity of 20 mW at 2.3 K, and a no-load second-stage temperature of 2.2 K. The simulation results showed that the first-stage and second-stage temperatures were 45 K and 4.2 K, respectively. The P-V power at the first and second stages were 17.4 W and 3.27 W before considering the real gas effect. However, after considering all factors, these values decreased to 17.2 W and 0.56 W, respectively.

A.O. Pecharsky, V.K. Pecharsky, and K.A. Gschneidner, Jr (2002) present an interesting technique for modifying regenerator materials through alloying. This involves adding either rare-earth or non-rare-earth metals to alter the low-temperature magnetic heat capacity of a material. However, when conducting alloying substitutions, certain parameters must be considered, such as the deGennes factor, crystalline electric field influences, RKKY contact, and lattice heat capacity [9]. Although there are established patterns, unexpected variations can occur when the concentration of the alloying agent is changed. Therefore, it is necessary to use a combination of systematic and Edisonian approaches to develop superior regenerator components for cryocoolers that operate below 10K

This compilation encompasses the entirety of the existing literature and research pertaining to the ongoing advancements in electrical resistance across diverse materials and their distinct structural configurations. The present study has been formulated and organized with reference to the aforementioned literature sources.

CHAPTER 3
METHODOLOGY

Based on the literature review and the objective of the work the methodology is formulated as shown in the flow chart (Fig 3.1) which illustrates the various methods employed in this study to accomplish the set objectives. This visual representation outlines the step-by-step procedures implemented throughout the work. By referring to the flow chart, one can gain a comprehensive understanding of the specific approaches utilized and the sequence in which they were executed. The chart serves as a roadmap, highlighting the systematic and organized manner in which the research goals were pursued and achieved.

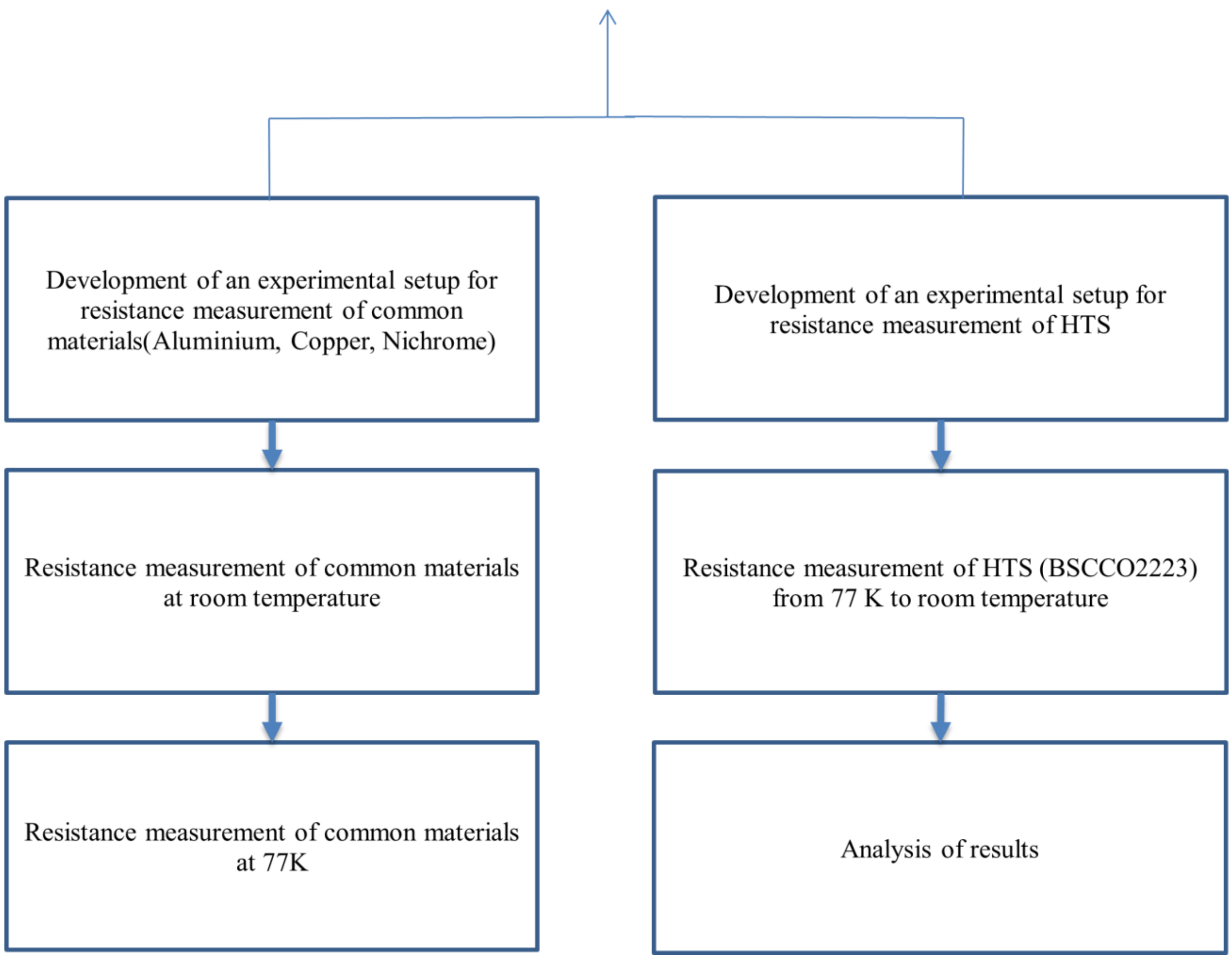

Fig 3.1: Flow chart of methedology

The development of an experimental setup for resistance measurement of common materials, such as aluminum (Al), copper (Cu) and nickel (Ni), involves a systematic procedures such as:

1. Experimental Setup Design:
    a. Determine the specifications and requirements of the experimental setup. Consider factors such as the desired range of resistance measurements, precision, and accuracy.
    b. Identify the necessary components, including a power supply, voltmeter, electrical contacts, and appropriate wiring.
    c. Plan for the inclusion of additional components for low-temperature resistance measurements, such as a cryostat or a dewar flask.
2. Component Selection and Calibration:
    a. Choose a power supply that can deliver the required current range with good stability and accuracy.
    b. Calibrate the gauge to ensure their accuracy and proper functioning. Use known resistance standards or calibration devices for this purpose.
3. Room Temperature Resistance Measurement:
    a. Prepare the samples of aluminum (Al) and nickel (Ni) by obtaining suitable specimens or cutting them into appropriate sizes for the experiment.
    b. Clean the sample surfaces to remove any contaminants or oxide layers that could affect the resistance measurement.
    c. Mount the samples securely between the electrical contacts in the chosen circuit configuration.
4. Low-Temperature (77K) Resistance Measurement:
    a. Acquire a cryostat or a dewar flask capable of maintaining a low temperature of 77K.
    b. Ensure proper installation and insulation of the cryostat or dewar flask to prevent heat transfer and maintain a stable low temperature.
    c. Place the prepared samples of aluminum and nickel inside the cryostat or dewar flask, ensuring good thermal contact with the cooling medium (liquid nitrogen).
    d. Connect the electrical contacts and wiring from the cryostat to the power supply and voltmeter outside the low-temperature environment.

5. Data Analysis and Interpretation:
    a. Record the resistance measurements obtained at both room temperature and 77K for aluminum and nickel samples.
    b. Compare the resistance values between room temperature and 77K measurements to observe any changes or variations.

Additionally, the objective of the methodology is to create a practical arrangement for measuring the resistance of HTS (BSCCO 2223). This involves conducting resistance measurements across a temperature range spanning from 77K to room temperature. The subsequent step is to analyze and interpret the acquired data and involves:

1. Developing an experimental setup for resistance measurement of HTS (BSCCO 2223): The focus of this project is to create a setup or apparatus specifically designed to measure the resistance of a High-Temperature Superconductor (HTS) called BSCCO 2223. HTS materials exhibit superconductivity at relatively high temperatures, which makes them suitable for various applications. In this case, BSCCO 2223 is the specific HTS material under investigation.
2. Measuring resistance from 77K to room temperature and analyzing the results: The experimental setup aims to measure the resistance of the BSCCO 2223 HTS material over a temperature range spanning from 77 Kelvin (K) to room temperature (typically around 298 K or 25 degrees Celsius). This temperature range is significant because it covers the transition temperature of the HTS material, where it switches from a superconducting state to a resistive state.

CHAPTER 4

MEASUREMENT OF RESISTANCE OF COMMONLY USED MATERIALS AT CRYOGENIC TEMPERATURE

4.1 Procedure for Measurement of Resistance of Common Materials

To determine the resistance of aluminum, copper and nichrome, which are frequently utilized materials, an experiment was conducted with varying lengths and diameters of 0.9mm, 0.84mm and 0.289mm respectively. The resistance measurements were taken at both room temperature and 77K, achieved by submerging the materials in liquid nitrogen. The experiment also involved comparing the resistance of the two materials at the two different temperatures. A simple experimental setup was devised to determine the resistance of the materials and its schematic diagram is as shown in Fig 4.4.

4.2 Kelvin Double Bridge

The Kelvin Bridge or Kelvin Double Bridge is a modified version of the Wheatstone bridge that can accurately measure resistance values in the range 1-0.00001 ohms. It was named because it uses a different set of ratio arms and galvanometers to measure unknown resistance values. An experimental setup developed with Kelvine Double Bridge used to measure resistance at LN2 temperature is shown in Fig 4.1.

Wheatstone bridges are used to measure resistance above 1 ohm, but when measuring resistance below 1 ohm, the leads connected to the galvanometer measure the resistance of the galvanometer device., Resistance is added. As the number of leads increases, there will be discrepancies in the actual resistance measurement. Therefore, a modified bridge called the Kelvin bridge can be used to solve this problem.

Fig 4.1: connection of specimen at LN2 temperature to Kelvin double bridge

4.3 HIOKI LCR Meter

Hioki LCR Meter (Fig 4.2) is a type of electronic instrument used for measuring the inductance, capacitance, and resistance of electrical components. It is a device commonly used by engineers and technicians for testing and characterizing various electronic components such as capacitors, inductors, and resistors. The Hioki LCR meter typically provides high accuracy, speed, and a wide measurement range for measuring different types of electrical components. Additionally, some Hioki LCR meters are equipped with additional features such as automatic component identification and sorting, making them a useful tool for both laboratory and field testing.

Fig 4.2: LCR Meter

Fig 4.3: Setup for measuring resistance at LN2 temperature

The setup used to measure the resistance of materials at LN2 temperature by using LCR meter is as seen in Fig 4.3 and the schematic representation of this simple setup to measure the resistance at low temperature is shown in Fig 4.4.

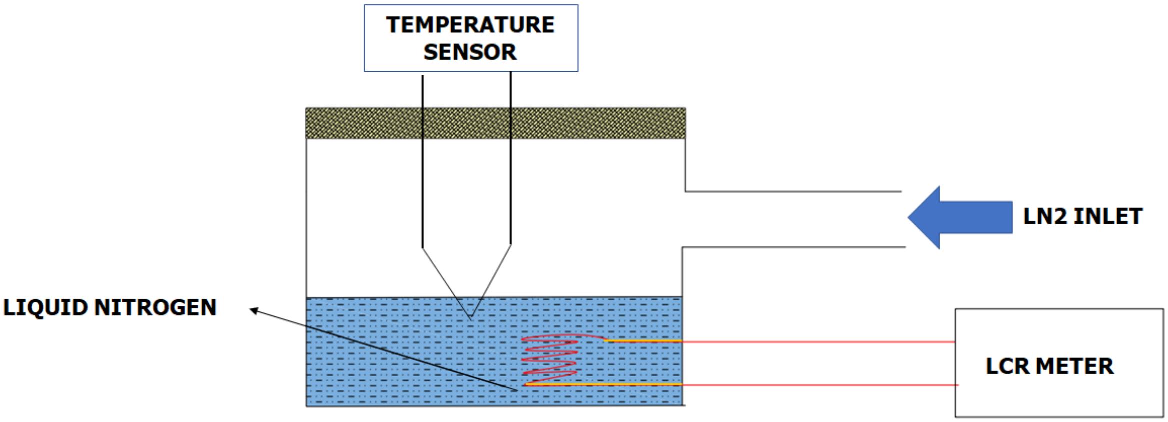

Fig 4.4: Schematic of the setup for measuring resistance

4.4 RESISTANCE MEASURED ON TEST SPECIMEN

Length (cm)	Resistance at room temperature (mΩ)	Resistance at LN2 temperature (mΩ)
22.1	10.457	9.812
31.2	14.797	12.481
40.8	19.337	17.64
50.7	24.333	22.7

Table 4.1: resistance of copper at room and LN2 temperature

Length (cm)	Resistance at room temperature (mΩ)	Resistance at LN2 temperature (mΩ)
22	5.46	5.46
30	8.03	8.09
40.8	10.36	17.64
50.2	12.92	22.7

Table 4.2: resistance of nichrome at room and LN2 temperature

Length (cm)	Resistance at room temperature (mΩ)	Resistance at LN2 temperature (mΩ)
22	216.387	159.38
40.8	317.06	254.8

Table 4.3: resistance of aluminium at room and LN2 temperature

The experimental setup described in this chapter has limitations in measuring the electrical resistance of materials across a broad range of increasing temperatures. As a result, a novel experimental configuration has been devised to effectively achieve the primary objective of this study.

CHAPTER 5

RESISTANCE MEASUREMENT OF HIGH TEMPERATURE SUPERCONDUCTOR

5.1 Development of an Experimental Setup

The developed experimental arrangement comprises a constant power supply of 10μA for a PT100 sensor, which is affixed to the sample, and the entire specimen unit is insulated thermally with multiple layers of insulation. Two wire connections from the HTS cable are connected to a current or voltage source, allowing for current adjustments by setting a constant voltage, and there is also a connection to a channel in DAQ for acquiring voltage drop readings across HTS at different temperatures, ranging from 77K to 304K (room temperature). Additionally, there is another channel in DAQ connected to the junction between the PT100 sensor and the constant current source, enabling voltage drop readings in the PT100 sensor to be obtained and converted to corresponding temperatures using the standard PT100 sensor equation. To achieve a temperature range of 77K to 304K, the sample is initially immersed in liquid nitrogen and then allowed to warm up to room temperature. The two channels' readings are obtained from the DAQ using a LabVIEW program on the computer. The schematic of the experiment is as shown in Fig 5.1 and the experimental setup is shown in Fig 5.2.

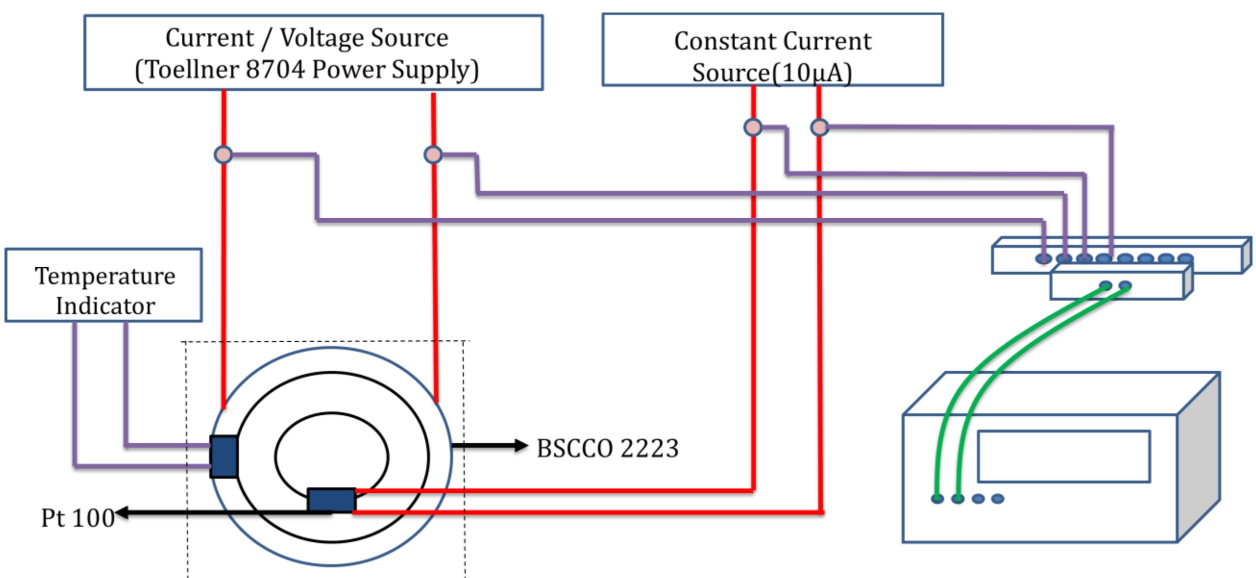

Fig 5.1: Schematic of the developed experimental setup

Fig 5.2: Developed experimental setup

The Fig 5.3 shown below depicts the HTS (BSCCO 2223) attached with lead wires to connect with DAQ for obtaining the voltage drop across it.

Fig 5.3: HTS attached with lead wires

In Fig 5.4 the HTS is attached and insulated together with PT100 sensor to determine the varying temperature of HTS during the warm up time.

Fig 5.4: HTS attached with PT100 sensor and the specimen is insulated

5.2 Components in Experimental Setup

5.2.1 Constant Current or Voltage Source

The Toellner 8704 power supply is a high-performance programmable DC power supply (Fig 5.6) manufactured by Toellner Systems, a company based in Germany. The 8704 model is designed to provide precise and stable DC power for a wide range of applications, including research, development, testing, and production.

Some of the key features of the Toellner 8704 power supply include:

1. Voltage output range from 0 to 80V
2. Current output range from 0 to 60A
3. Power output up to 4800W

4. High precision and stability with 1mV/1mA resolution
5. Programmable via USB, RS-232, or LAN interfaces
6. Overvoltage, overcurrent, and overtemperature protection
7. Remote sensing capability to compensate for voltage drop in the cables
8. User-friendly graphical interface with easy-to-use menus and functions

The Toellner 8704 power supply is a reliable and versatile instrument that can be used in a variety of applications that require precise and stable DC power. It is widely used in research, development, testing, and production environments, especially in the electronics, semiconductor, and automotive industries

5.2.2 Data Acquisition System

The Keithley 2000 is a high-performance digital multimeter (DMM) manufactured by Keithley Instruments, which is now part of Tektronix. The 2000 model is designed to provide accurate and reliable measurements of DC and AC voltage, DC and AC current, resistance, frequency, and continuity. One such model is as seen in Fig 5.5.

Some of the key features of the Keithley 2000 multimeter include:

1. 6.5-digit resolution for accurate measurements up to 200,000 counts
2. Basic DC accuracy of 0.0024%
3. Wide measurement range for voltage (100nV to 1,000V), current (100pA to 3A), and resistance (100mohms to 100Mohms)
4. Built-in functions for capacitance, temperature, diode testing, and dBm measurements
5. Programmable via GPIB, RS-232, or USB interfaces
6. Front-panel USB memory slot for data storage
7. Backlit LCD display with dual display capability and bar graph
8. Built-in math functions for statistical analysis, scaling, and offsetting

The Keithley 2000 multimeter is a versatile and reliable instrument that is widely used in research, development, testing, and production environments, especially in the electronics and semiconductor industries. Its high accuracy, wide measurement range, and programmability make it a popular choice for a variety of applications, including precision voltage and current measurements, circuit testing and debugging, and quality control

5.2.3 PT100 SENSOR

A PT100 sensor is a type of resistance temperature detector (RTD) that is commonly used to measure temperature in industrial, scientific, and medical applications. It is made of a thin film of platinum with a resistance of 100 ohms at 0°C. As the temperature changes, the resistance of the PT100 sensor also changes, providing a measure of the temperature.

The PT100 sensor is designed to have a linear and repeatable resistance-temperature characteristic over a wide range of temperatures, typically from -200°C to +850°C. This makes it suitable for use in applications where accurate temperature measurement is required, such as in laboratory equipment, food processing, HVAC systems, and industrial processes.

PT100 sensors are typically used with specialized measurement instruments, such as temperature controllers, data loggers, and process controllers. These instruments are designed to provide precise and accurate temperature readings based on the resistance changes of the PT100 sensor. The sensor that is used in the experimental setup is shown in Fig 5.7.

One advantage of PT100 sensors is their high accuracy and stability over a wide temperature range. They are also resistant to vibration and shock, making them suitable for use in harsh environments. However, they can be more expensive than other types of temperature sensors and require specialized measurement equipment to read and interpret the signals accurately.

Fig 5.5: DAQ system


Fig 5.6: Constant current or voltage supply

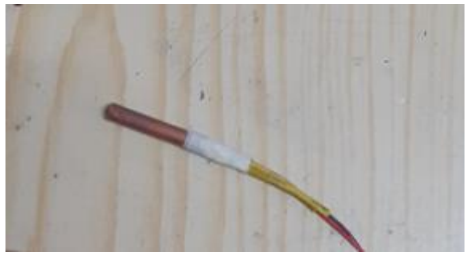

Fig 5.7: PT100 Sensor

5.3 Specification of the HTS Subjected to Study

The BSCCO 2223 material has been selected for investigation in the experimental arrangement. BSCCO 2223 is a high-temperature superconductor material that belongs to the family of cuprate superconductors. It is named after its chemical composition, which includes bismuth (Bi), strontium (Sr), calcium (Ca), copper (Cu), and oxygen (O).

BSCCO 2223 has a critical temperature (Tc) of around 110 K, which makes it a high-temperature superconductor. At temperatures below Tc, it exhibits zero electrical resistance and can conduct electricity without any energy loss, which makes it a promising material for various applications, including power transmission, magnetic levitation, and high-speed computing.

BSCCO 2223 is typically manufactured as a thin film or bulk material using various techniques, including chemical vapor deposition, sputtering, and solid-state reaction. The material has excellent mechanical properties and can be easily fabricated into different shapes and sizes.

BSCCO 2223 is widely studied and researched in the field of superconductivity due to its unique properties and potential applications. Ongoing research is focused on improving the material's superconducting properties, developing new fabrication techniques, and exploring new applications.

Fig 5.8: BSCCO 2223 HTS cable [J yang et.al]

The HTS wire opted for the experiment here is a 1st Generation wire known as BSCCO 2223 (Fig 5.8). It has a current density of 9300A per square centimeter, and a maximum ampere rating of 135A. The wire has a width of 4.4mm and thickness of 0.32mm. It can be bent at a minimum double bend diameter of 50mm. The maximum rated tensile strength of the wire is 200Mpa and it can withstand a maximum wire tension of 25kg.

The insulation options for the wire include Teflon and Polymide, providing a choice for the user to select the most appropriate insulation type based on the requirements of the application. Overall, the BSCCO 2223 HTS wire offers a high current density and ampere rating, making it suitable for various applications that require high-performance conductors. Its specific dimensions and insulation options make it a versatile option for different applications.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Resistance of Aluminium at Room Temperature and 77K

In Figure 6.1, the chart clearly displays a comparison between the resistance values of Aluminum under two different conditions: at room temperature and at a significantly lower temperature of 77K (Kelvin). The lengths of Aluminum samples being compared are 22 cm and 40.8 cm. The data presented in the chart reveals a noteworthy finding. It demonstrates that there is a considerable decrease in resistance when Aluminum is subjected to lower temperatures, specifically when compared to its resistance at room temperature. This decrease in resistance indicates that Aluminum exhibits improved conductivity or electrical flow when exposed to colder temperatures. The plotted chart provides a visual representation of this phenomenon, allowing researchers and readers to easily comprehend and analyze the observed trend. The data depicted in the chart highlights the significance of temperature in influencing the resistance properties of Aluminum, underscoring the importance of considering temperature effects in electrical conductivity studies or practical applications involving this metal.

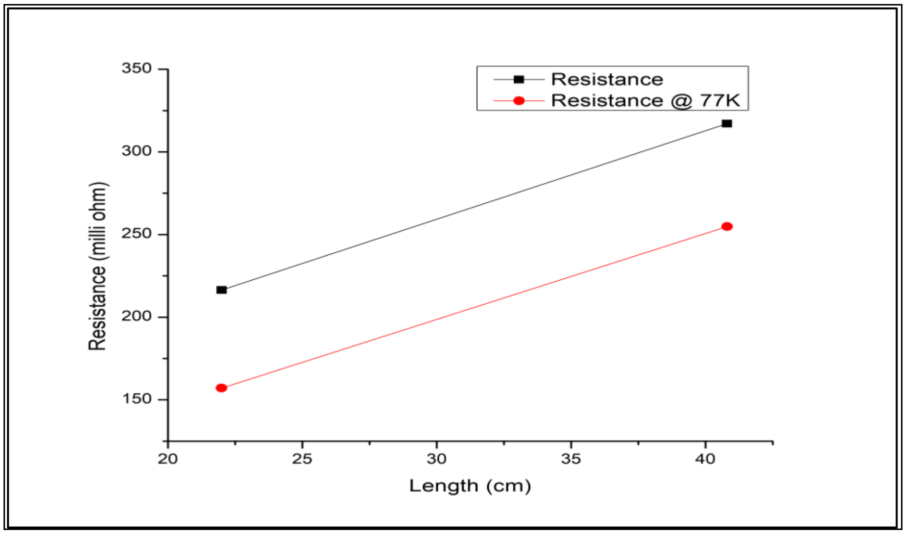

Fig 6.1: Resistance of aluminium at ambient and LN2 temperature

6.2 Resistance of Copper at Room Temperature and 77K

Figure 6.2 presents a plotted chart that showcases a comparison between the resistance values of Aluminum under two distinct conditions: at room temperature and at an extremely low temperature of 77K (Kelvin). In this analysis, the resistance values are evaluated for four different lengths of Aluminum samples, namely 22 cm, 31.2 cm, 40.8 cm, and 50.7 cm. The chart effectively illustrates a significant observation. It reveals a noticeable decrease in resistance when Aluminum is subjected to cryogenic temperatures (77K) in comparison to its resistance at room temperature. This finding implies that Aluminum exhibits enhanced conductivity or improved electrical flow when exposed to extremely low temperatures. The plotted chart visually conveys this outcome, enabling researchers and readers to easily interpret and analyze the observed trend. The data depicted in the chart emphasizes the considerable impact of cryogenic temperatures on the resistance properties of Aluminum. Consequently, this information holds significance for studies or practical applications involving Aluminum in cryogenic environments, where the reduced resistance can be leveraged for enhanced electrical performance.

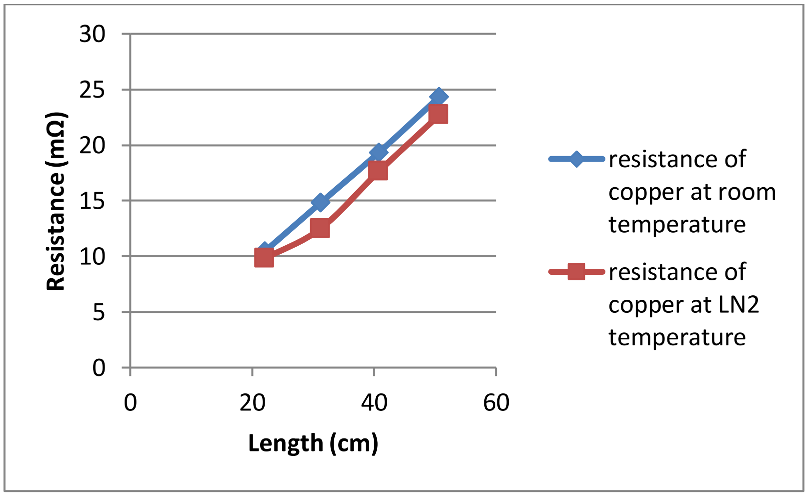

Fig 6.2: Resistance of copper at ambient and LN2 temperature

6.3 Resistance of Nichrom at Room Temperature and 77K

The analysis of Figure 6.3 suggests that Nichrome wire experiences a small decrease in resistance with increasing temperature, while Aluminum exhibits a more pronounced decrease in resistance. Additionally, it emphasizes that materials with high resistance typically display limited changes in resistance when exposed to cryogenic temperatures.

- Resistance Decrease in Nichrome Wire: The examination of the plotted chart reveals a trend in the resistance values of Nichrome wire as the temperature changes. The statement suggests that as the temperature increases, the resistance of Nichrome wire decreases.
- Marginal Decrease in Resistance: However, the decrease in resistance observed in Nichrome wire when subjected to different temperatures is described as marginal. This means that the change in resistance is relatively small or insignificant in comparison to other materials.
- Significant Drop in Aluminum Resistance: In contrast to Nichrome wire, the statement highlights that Aluminum exhibits a significant drop in resistance as the temperature decreases. This suggests that the resistance of Aluminum decreases more dramatically with decreasing temperature compared to Nichrome wire.
- High Resistance Alloys and Metals: The statement further mentions that alloys and metals with high resistance (presumably other than Nichrome wire and Aluminum) do not show drastic changes in resistance when exposed to cryogenic temperatures. This implies that certain materials with high resistance properties maintain their resistance relatively well even under extreme cold conditions.

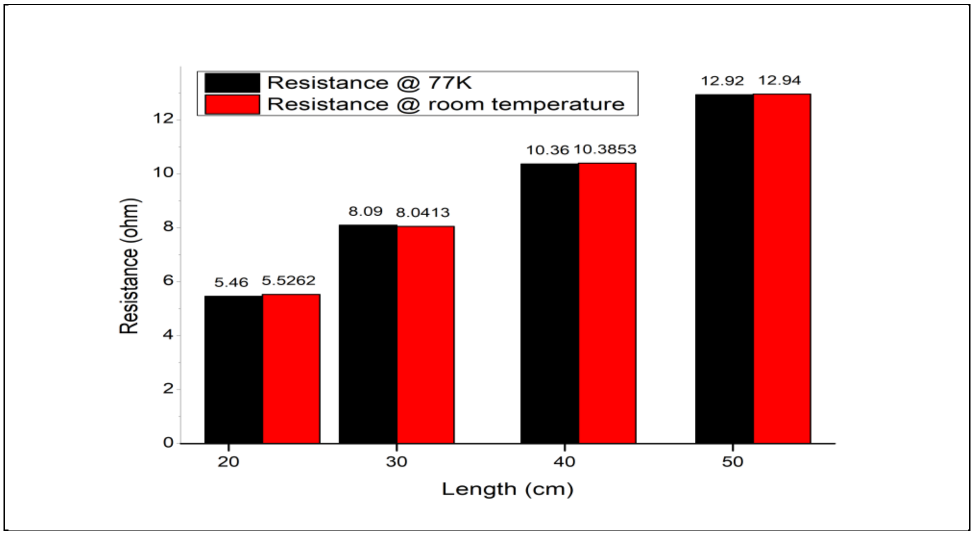

Fig 6.3: Resistance of nichrome at ambient and LN2 temperature

6.4 Comparison of Resistivity of Copper With Literature Values

The Table 6.1, presents a comparison between the resistivity of copper obtained from an experiment and its literature value. Here's a detailed explanation of the statement:

- Experimental vs. Literature Resistivity: The table provides two sets of resistivity values for copper: one obtained from an experiment and the other from the literature source referenced as [4]. Resistivity is a measure of how strongly a material opposes the flow of electric current.
- Slight Deviation: The statement notes that there is a slight deviation between the experimental results and the literature value for copper's resistivity. This means that the resistivity values obtained from the experiment differ slightly from the established or accepted values found in the literature.
- Same Trend as Literature Value: Despite the slight deviation, the statement highlights that the experimental results still follow the same trend as the literature value. This implies that the changes in resistivity observed in the experimental measurements align with the expected behavior of copper at both room temperature and LN2 (liquid nitrogen) temperature.
- Room Temperature and LN2 Temperature: The comparison between the experimental and literature resistivity values is discussed in relation to both room temperature (presumably ambient temperature) and LN2 temperature (the extremely low temperature

achieved by using liquid nitrogen). The statement suggests that the experimental results for copper's resistivity are consistent with the literature value for both temperature conditions.

Temperature (K)	**Experimental Values of Resistivity (Ωm)**	**Literature Values of Resistivity (Ωm)**
77	0.236	0.193
304	0.262	0.198

Table 6.1: Resistivity values of copper in both experimental and literature

6.5 Comparison of Resistivity of Aluminium With Literature Values

The statement refers to Table 6.2, which provides a comparison between the resistivity of aluminum obtained through experimentation and its documented value. Here's a detailed explanation of the statement:.

- Experimental vs. Literature Resistivity: Table 6.2 displays two sets of resistivity values for aluminum: one obtained from an experiment and the other from a literature source referenced as [4]. Resistivity is a measure of how strongly a material opposes the flow of electric current.
- Minor Deviation: The statement mentions that there is a minor deviation between the experimental results and the literature value for aluminum's resistivity. This indicates that the resistivity values obtained from the experiment differ slightly from the documented or accepted values found in the literature.
- Consistent Pattern: Despite the minor deviation, the statement emphasizes that the experimental findings exhibit a consistent pattern in relation to both room temperature and LN2 temperature. This suggests that the changes in resistivity observed in the experimental measurements align with the expected behavior of aluminum at both temperature conditions.
- Room Temperature and LN2 Temperature: The comparison between the experimental and literature resistivity values is discussed in the context of both room temperature (presumably ambient temperature) and LN2 temperature (the extremely low temperature

achieved using liquid nitrogen). The statement suggests that the experimental results for aluminum's resistivity maintain a consistent pattern in line with the literature value for both temperature conditions.

Temperature (K)	**Experimental Values of Resistivity (Ωm)**	**Literature Values of Resistivity (Ωm)**
77	7.368×10^{-7}	8.234×10^{-7}
304	9.169×10^{-7}	10.784×10^{-7}

Table 6.2: Resistivity values of aluminium in both experiment and literature

6.6 Comparison of Resistivity of Nichrome With Literature Values

The statement describes Table 6.3, which presents a comparison between the resistivity of nichrome obtained from an experiment and its documented value. Here's a detailed explanation of the statement:

- Experimental vs. Literature Resistivity: Table 6.3 provides two sets of resistivity values for nichrome: one obtained from an experiment and the other from a documented source referenced as [4]. Resistivity is a measure of how strongly a material opposes the flow of electric current.
- Slight Deviation: The statement mentions that there is a slight deviation between the experimental results and the literature value for the resistivity of nichrome. This indicates that the resistivity values obtained from the experiment differ slightly from the documented or accepted values found in the literature.
- Consistent Trend: Despite the slight deviation, the statement emphasizes that the experimental results demonstrate a consistent trend with respect to both room temperature and LN2 temperature. This suggests that the changes in resistivity observed in the experimental measurements align with the expected behavior of nichrome at both temperature conditions.
- Room Temperature and LN2 Temperature: The comparison between the experimental and literature resistivity values is discussed in the context of both room temperature (presumably ambient temperature) and LN2 temperature (the extremely low temperature

achieved using liquid nitrogen). The statement suggests that the experimental results for nichrome's resistivity exhibit a consistent trend in accordance with the literature value for both temperature conditions.

Temperature (K)	Experimental Values of Resistivity (Ωm)	Literature Values of Resistivity (Ωm)
77	1.665×10^{-6}	1.407×10^{-6}
304	1.669×10^{-6}	1.483×10^{-6}

Table 6.3: Resistivity values of nichrome in both experiment and literature

6.7 Temperature-Resistance Curve of BSCCO 2223 at Various Constant Current

The statement discusses the analysis of results obtained from an experiment involving BSCCO 2223, a specific material. Here's a detailed explanation**:**

- Figure 6.7: The obtained results are plotted in Figure 6.7, which serves as a visual representation of the data. The figure clearly shows the transition temperature of BSCCO 2223 at constant currents of 100mA, 200mA, 500mA, and 1000mA.
- Transition Temperature: The transition temperature refers to the temperature at which a material undergoes a significant change in its properties. In this case, it is the transition temperature of BSCCO 2223 that is being examined.
- Average Transition Temperature: From Figure 6.7, the average transition temperature of BSCCO 2223 is determined to be 104K. This means that, on average, the material undergoes its transition at approximately 104 Kelvin.
- Consistency with Literature Range: The statement notes that the average transition temperature of 104K falls within the range of Tc (102K-110K) reported in various literature sources. This implies that the experimental findings align with the expected values based on existing knowledge from other published studies.
- Validation of Experimental Setup: The agreement between the experimental results and the literature range of Tc is seen as validation for the reliability of the proposed experimental setup. The fact that the obtained results are consistent with the known range of transition temperatures provides confidence in the accuracy and effectiveness of the experimental setup.

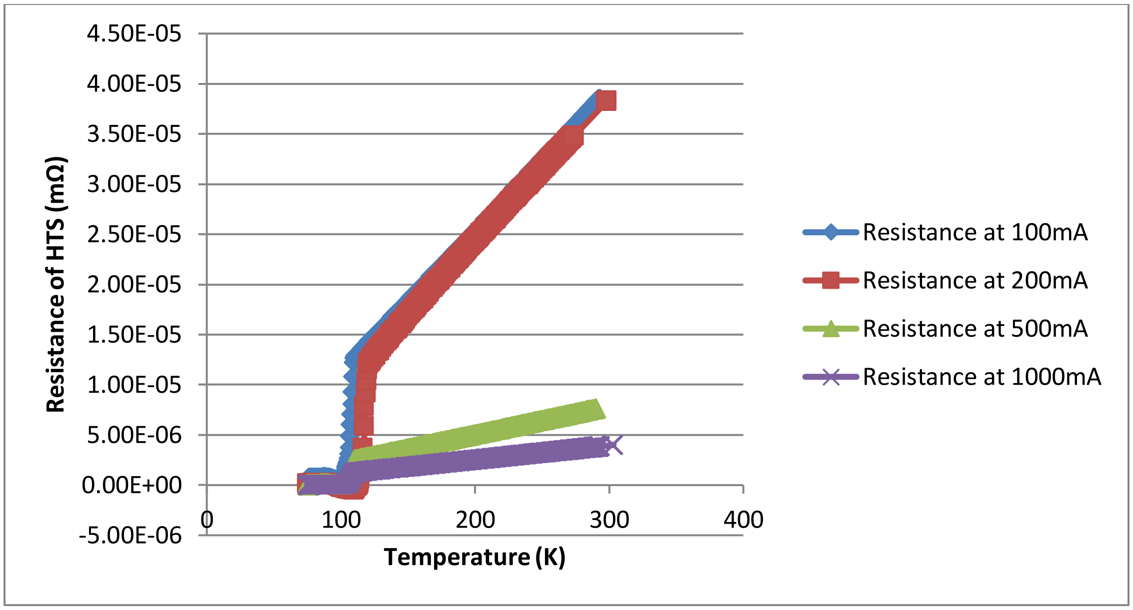

Fig 6.7: Resistance Curve of BSCCO 2223

Based on the agreement between the experimental results and the literature range of Tc, the statement concludes that the obtained results from this study are considered reliable. This indicates that the data collected and analyzed in the experiment can be trusted and used for further analysis or interpretation.

CHAPTER 7

CONCLUSION

The conclusion states that Aluminum and Copper exhibit a significant decrease in resistance when exposed to cryogenic temperatures, while Nichrome shows minimal loss at 77K. This suggests that, in general, materials experience only minimal changes in resistance at cryogenic temperatures. The conclusion notes that although there is a slight variation in resistivity compared to the literature values for all three tested materials (Aluminum, Nichrome, and Copper), the experimental values still follow a consistent trend in resistance with temperature as described in the literature. This implies that the experimental results align with the expected behavior of these materials. The conclusion highlights the development of an experimental setup for measuring the resistance of High-Temperature Superconductors (HTS). The results obtained from measuring the resistance of BSCCO 2223 at different constant currents (100mA, 200mA, 500mA, and 1000mA) indicate an average transition temperature of 104K. This value falls within the range of critical temperature (Tc) values reported in various literature sources (102K-110K). Based on the agreement between the obtained results and the literature range of Tc for BSCCO 2223, the conclusion concludes that the experimental setup utilized in this study is reliable for resistance measurements of HTS. This indicates that the setup can be trusted for future investigations into the resistance of materials and HTS at various temperatures. The conclusion suggests that the work conducted in this study holds promise for medical instrumentation and diagnosis. By understanding the resistance of materials and HTS at different temperatures, it is inferred that there may be practical applications in the field of medical instrumentation and diagnosis. In summary, the conclusion emphasizes the observations made in the experimental studies, the reliability of the experimental setup for HTS resistance measurements, and the potential future applications in medical instrumentation and diagnosis. It affirms the alignment of experimental results with existing knowledge and highlights the significance of the conducted research.

7.1 Scope of future work

The scope of work for an experimental setup measuring electrical resistance at cryogenic temperatures typically includes several key factors such as Review existing literature and research on electrical resistance measurements at cryogenic temperatures to understand the current state of knowledge and techniques and Define the objectives and hypothesis of your experiment, determining the specific aspects of electrical resistance you intend to investigate. Likewise, Design an experimental setup that is suitable for your research, taking into account the temperature range, sample characteristics, and desired measurement precision. There is a scope of developing an alternate setup by Cryogenic System Design and Construction include Selection of an appropriate cryogenic system for achieving the desired low temperatures, such as a cryostat or a dilution refrigerator and Design and construct the necessary components for the cryogenic system, including insulation, cooling mechanisms (such as liquid helium or a cryocooler), and temperature control systems. The Electrical Measurement Setup future works include, Design and construct the electrical measurement setup, including appropriate current and voltage sources, amplifiers, and signal conditioning circuits. Thereby Implement a method for accurate and precise electrical measurements, such as a four-point probe technique or a bridge circuit and Consider potential sources of noise or interference and implement shielding or filtering techniques to minimize their impact on the measurements. The following related must ensures the Calibration and Validation effectively for a proper experimental setup. Calibrate the measurement setup by using reference samples with known resistance values at cryogenic temperatures and Validate the experimental setup by comparing the obtained results with established data or through collaboration with other researchers in the field. It's important to note that the specific scope and complexity of the work will depend on the objectives of the experiment, the desired temperature range, the materials being studied, and the available resources. The scope outlined above provides a general framework for conducting electrical resistance measurements at cryogenic temperatures.

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