Development of resistance and temperature measurement system for cryogenic equipment

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Abstract. Cryogenic equipment is used especially for the research on superconductors as the tools to create a condition of low temperature and high magnetic field. However, it needs the measurement system to be used to analyze the material properties. This work developed a control program of resistance measurement system using instruments of current source, nanovoltmeter and temperature controller. We designed and developed a measurement system by building a connection of the instruments and creating a new control program. The created control program can be revised or modified easily when we have to replace or add the instruments. LabVIEW program was used as a control program, and designed for measuring the resistance value, a sensor to determine the temperature and a heater to control the temperature. The developed measurement system was tested using standard superconductor sample. It clearly showed the graph of the temperature dependence of resistance. And it showed sharp drop of resistance around 98K, indicating its critical temperature.

1. Introduction
Superconductors are the materials that can conduct electricity or transport the electrons with no electric resistance. This means no heat, sound or any other form of energy would be released from the materials when it is below "critical temperature" (Tc), or the temperature at which the materials become superconductors. Unfortunately, most materials must be in an extremely low energy state (very cold) in order to be superconductors [1]. Superconducting materials that mostly used are Nb₃Sn and NbTi (Low Temperature Superconductors, LTS) superconducting wires. Nb₃Sn and NbTi superconducting wires generally are used for high magnetic field equipments. In addition, High Temperature Superconductors (HTS) type superconducting wires have started to be used for many applications in the fields of electricity, such as electrical transport for high voltage power cables [1].

Conducting research on superconductivity requires the resistance measurement system which could be used at low temperature inside cryogenic equipment. The resistance measurement system available on the market is very expensive and using the LabView (Laboratory Virtual Instrument Engineering Workbench) program that cannot be modified or revised. The user only can set and controls the parameters in the front panel. The block diagram of the program cannot be displayed or edited.
So that, the aim of this study is to develop the resistance measurement system controlled by LabVIEW programs [2, 3]. The created LabVIEW program has source code or block diagram that can be modified easily.

As a general-purpose measurement instrument, a nanovoltmeter (Keithley 2700) was used to measure the voltage of the samples, and a current source (Keithley 6221) was used to generate electrical current. A programmable temperature controller (Oxford Mercury iTC) was employed to control and measure the sample temperatures. The system was controlled by a set of dedicated LabVIEW applications running on computers. The communication between computers and instruments was done via GPIB bus, TCP/IP and USB. LabVIEW is a system-design platform and development environment for a visual programming language from National Instruments [3]. The measurement system attached in existing equipment was the built-in programs and instruments. Thus, the original programs can’t be revised when we need to add or replace the instruments.

The cryogenic magnet equipment that we used can create super low temperature (as low as 1.5 Kelvin) and high magnetic field (up to 8 Tesla). This study developed the measurement system of resistance and temperature. We developed this measurement system that also can be used as current density measurement system to analyze the performance of superconducting wires. This resistivity measurement system is using the state of the art programmable temperature control (Mercury iTC), nanovolt meter (Keithley 2700) and current source (Keithley 6220), thus we can measure low noise and precise resistivity value. We are combining this measurement system with the using of cryogenic magnet that made this measurement system is the first and the only programmable resistivity measurement system for cryogenic system that developed in Indonesia. We used Bi$_2$Sr$_2$CaCu$_2$O$_x$ (or Bi-2212) standard superconducting film to test the developed measurement system.

2. Development Methods
To develop a measurement system for cryogenic equipment, it requires a control or processing unit that can handle several tasks such as measuring and controlling temperature, storing, transmitting and analyzing data. These tasks can be performed by using LabVIEW program [4-6]. The applications of the LabVIEW programs (VI) have two components, which are the user interface and underlying code. The user interface take place at front panel and the underlying code is located at the block diagram.

Each VI has a front panel that can be used to design the user interface. We designed user interface by placing controls and indicators on the front panels. The controls are used to supply inputs, and the indicators are used to see the results. The indicators are typically in the form of graphs, charts, LED’s, and status strings [7-8].

3. Results and discussions
3.1. Measurement system
The resistance measurement system was conducted using four-point probe method. The sample was put into cryogenic equipment to be measured under low temperature. Electrical resistance is frequently measured using 4-terminal-potentiometric DC methods. This method involves the connection of two current leads and two potential leads to the sample [7]. The scheme and the image of the four-point probe method were shown in figure 1. As shown in figure 1(a), resistance value is calculated and temperature value is collected using the following loop program in figure 2.
Standard sample Bi$_2$Sr$_2$CaCu$_2$O$_x$ (or Bi-2212) superconductor was installed on the sample holder as shown in figure 1(b). The sample holders were included as complementary of cryogenic equipment.
Sample holder has 24-pins connector that used to connect the sample and measurement instruments. Pin #1 to pin #8 were connected to the scanner card (Keithley 7709) at back of Keithley 2700 instrument [9-11]. The sample holder was mounted on the bottom of the sample rod and then inserted into cryogenic equipment. The voltage was measured using nanovoltmeter (Keithley 2700) controlled with LabVIEW program. Superconductor sample was tested from room temperature to low temperature. The measurement system was performed using nanovoltmeter, current source, and temperature controller instrument.

**Figure 3.** The scheme of the resistance measurement system and cryogenic magnet equipment.

![Figure 3](image)

**Figure 4.** (a) All measurement instruments. (b) An addition instrument to measure the current density

Figure 4(a) shows all measurement instruments which consists of Current Source (Keithley 6221), Nanovoltmeter (Keithley 2700), and Temperature Control (Oxford Mercury iTC) that were connected to the computer. Figure 4(b) shows additional instruments which consists of a rectifier and an ampere...
meter for measuring current density. We developed the program that could identify and control these instruments. Since the original program provided by the manufacturer is an executing program and cannot be modified, we have to develop our program that can be revised and modified. The revision and modification are needed when we have some trouble with the program and when we have to replace and add the instruments.

Keithley 2700 is a 6½-digit high performance multi-meter/data acquisition system with Keithley 7709 module inside. It measured the sample voltage, which was used to calculate the resistance of the sample. The measurement system was using Keithley 6220 to generate current source. Oxford Mercury iTC was used as a temperature controller for controlling the heater and monitoring the temperature of the sample. All of these instruments were controlled remotely using a computer via GPIB and TCP/IP communications.

| Instrument name     | Address                  | Function               |
|---------------------|--------------------------|------------------------|
| Keithley 2700       | GPIB0::16::INSTR         | Voltmeter              |
| Keithley 6221       | GPIB0::30::INSTR         | Current source         |
| Keithley 7709       | GPIB0::8::INSTR          | Scanner card           |
| Oxford Mercury iTC  | tcpip::192.168.001.247::7020::socket | Temperature Controller |

Table 1 shows that each instrument has its own address to be connected with the computer program. Three instruments from Keithley connected with GPIB communication and Oxford Mercury iTC is connected with TCP/IP communication.

![Image of the measurement system layout](image)

**Figure 5.** Layout of the measurement system

Figure 5 shows the layout of the measuring system. Scanner card was inserted inside Keithley 2700. Scanner card worked to close and open terminal/ channel of the probes of the current and the
voltage of the sample. Scanner card also was used to measure two samples instead of one sample. Temperature of the sample was controlled by temperature controller using a temperature sensor and a heater located near the sample. Current source, nanovoltmeter, temperature controller and scanner card were controlled by LabVIEW programs developed in this study. LabVIEW program was controlling sample temperature from room temperature to as low as 1.5 K, at the same time measuring the resistance of the sample and then saving the data into a file.

### 3.2. Controller system

Figure 6(a) shows the user interface of the LabVIEW program from built-in program and figure 6(b) shows the program developed in this study. The built-in program is an executing program that cannot be upgraded, modified or changed. The developed program can be upgraded, modified and changed easily. The developed program has block diagrams that can be opened and modified. The program was running during the measurement process. It continuously measured the resistance, controlled the temperature, collected data and saved the data into a file.

![Figure 6](image)

**Figure 6.** (a) Front panel of the original built-in software. (b) Front panel of the developed software

Figure 7 shows the block diagram of the LabVIEW program developed in this study. LabVIEW is a graphical language program that uses graphical items and wires as its source code. It can also display indicators and graphs. The graph of temperature dependence of resistance was set to be shown so that we can analyze the results during measurement process. The program was controlling the temperature using a heater. Measurement parameters, calculated resistance data and temperature data were saved on a file during the measurement process.
3.3. Testing result

Figure 8 shows the result of the measurement test using the standard superconducting sample. The measurement was conducted from room temperature to low temperature using the LabVIEW program developed in this study. It showed a sharp drop of resistance at around 98K and the zero resistance below 98K, indicating its critical temperature.

The measurement result was clear and had a very small noise. It indicated that the LabVIEW program developed in this study had been successfully performed measuring temperature and resistance of the sample.

Figure 8. Bi-2212 standard sample measurement result.
4. Conclusions
The development of the resistance measurement system for cryogenic equipment controlled by LabVIEW program has been done. The developed LabVIEW program can be modified and revised. The instruments can also be replaced and added easily. When we have to replace or add some instruments, we only have to modify the block diagram of the LabVIEW program. We also can modify the program when we have to develop another measurement system, such as specific heat, etc. It was using several instruments to measure voltage, generate electrical current, and determine/control the temperature of the sample. Samples were measured by four-point probe method to calculate the resistance value and a temperature sensor to determine the temperature of the sample.

The developed measurement system was tested using standard superconducting sample. It clearly showed its temperature dependence of resistance, and it showed that critical temperature is at around 98K, indicating that the measurement system was successfully developed. The measurement system has its advantages to be able to measure current density too.

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