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# A Study on the development and calibration method of a modular internal resistance meter to improve the safety of reusable batteries

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***Abstract***

*Battery use is increasing worldwide to achieve carbon neutrality and improve energy efficiency, but batteries are a finite resource and their application is determined by capacity and specifications. Battery performance deteriorates as the number of uses increases. A certain level of battery performance degradation has become an issue in the field of reuse and recycling, and various studies are being conducted on reuse to solve power shortages. Waste batteries from electric vehicles are suitable for building ESS based on reusable batteries, and for stable use, technical skills are needed to accurately predict battery life and determine status information. Predicting battery life and determining status information are difficult due to non-linearity due to internal structure or chemical changes. In this paper, we manufactured a modular internal resistance measuring device and compared the measured values with Hioki equipment to minimize the error rate through a correction method. As a result of testing Hioki equipment and modular measuring instruments to ensure efficiency and safety based on reusable batteries, an accuracy of over 95% was confirmed.*

***Keywords:*** *Internal Resistance, Impedance, Calibration, Reusable Battery*

## 1. Introduction

As the market for electric vehicles (EV) and energy storage systems (ESS) expands domestically and internationally, battery performance degradation and reuse are recognized as important issues in various application fields that use batteries. In order to ensure the safety of ESS construction using reused batteries of electric vehicles, diagnostic technology that can determine accurate battery status information is required [1]. Recently, various battery diagnostic technologies have been developed, and the diagnostic method using internal resistance can be said to be common. Internal resistance can be interpreted as a cause that interferes with electrical transmission when a chemical (oxidation-reduction) reaction occurs at the electrode [2-3].

In this paper, a battery jig was manufactured to generate various fixed resistances, and the internal resistance measurements for each fixed resistance were compared with the Hioki equipment and a modular internal resistance meter [3]. The error rate that may occur was minimized based on Hioki equipment through a correction method, and accuracy was improved.

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## 2. System Design

Figure 1 shows a resistance jig for internal resistance correction was manufactured to generate a fixed resistance in the range of 50mΩ to 500mΩ and to accurately measure it. At the bottom of Figure 1, we produced a modular internal resistance measuring device that can sequentially measure the internal resistance of 30 cells based on OS [4].

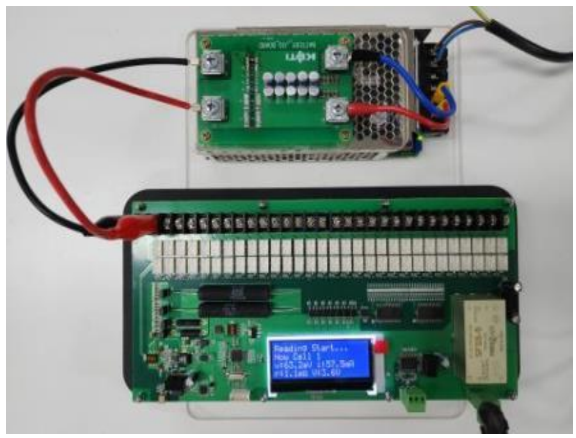

**Figure 1. Modular measuring instruments and resistance jigs**

Fixed resistance values were set at 50mΩ intervals in the internal resistance correction jig manufactured as shown in Figure 2, and internal resistance values in the range of 50mΩ to 500mΩ were measured using Hioki equipment. The measured data was divided into standard fixed resistance values and Hioki measured values, and the internal resistance values measured using a modular internal resistance measuring device were compared [5].

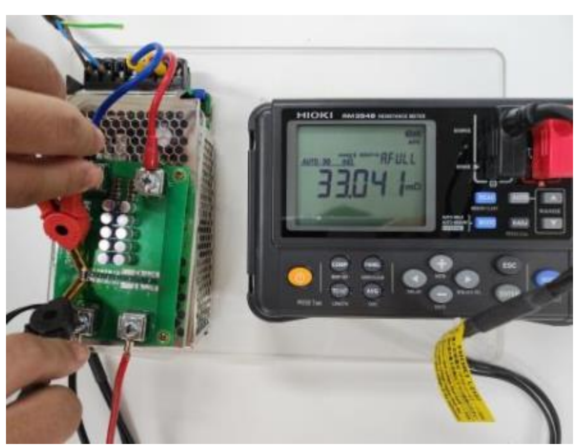


**Figure 2. Internal resistance measurement using Hioki equipment**

Table 1 shows the three measured data were divided into tables according to the setting range of 50mΩ to 500mΩ. The modular internal resistance meter measures micro-voltage and micro-current values based on the OS every 4 seconds and converts them to rms values and displays them.

In the case of Hioki equipment, 99% accuracy can be confirmed excluding the connection cable resistance value of about 25mΩ, but in the case of the modular internal resistance measuring device, a large error value occurred.

**Table 1. Measurement value comparison table**

| Reference R (mΩ) | Hioki Equipment (mΩ) | Modular internal resistance meter | | | |
|---|---|---|---|---|---|
| | | register | ADC | 4sec | dc-load |
| 50 | 76.6 | 0x1D | 1255582 | Voc | 3.6109624 |
| | | 0x1E | 1260267 | 20R_V | 3.5888128 |
| | | 0x13 | 2002586 | 2R_V | 3.411617 |
| | | 0x14 | 61045 | R | 0.1350991 |
| 100 | 124.5 | 0x1D | 2042297 | Voc | 3.6115611 |
| | | 0x1E | 2045589 | 20R_V | 3.5810306 |
| | | 0x13 | 1993852 | 2R_V | 3.3379853 |
| | | 0x14 | 60771 | R | 0.1898856 |
| 150 | 174.5 | 0x1D | 2430927 | Voc | 3.6115611 |
| | | 0x1E | 2433437 | 20R_V | 3.5708542 |
| | | 0x13 | 1992838 | 2R_V | 3.2547751 |
| | | 0x14 | 60704 | R | 0.2545632 |
| 200 | 224 | 0x1D | 2902174 | Voc | 3.6115611 |
| | | 0x1E | 2903864 | 20R_V | 3.5630717 |
| | | 0x13 | 1994653 | 2R_V | 3.1889253 |
| | | 0x14 | 60786 | R | 0.3076844 |
| 250 | 275 | 0x1D | 3327702 | Voc | 3.6115611 |
| | | 0x1E | 3328892 | 20R_V | 3.5546911 |
| | | 0x13 | 1978287 | 2R_V | 3.1242726 |
| | | 0x14 | 60223 | R | 0.3622141 |
| 300 | 323 | 0x1D | 3558207 | Voc | 3.6115611 |
| | | 0x1E | 3558400 | 20R_V | 3.54631 |
| | | 0x13 | 1879734 | 2R_V | 3.0572255 |
| | | 0x14 | 56734 | R | 0.4217887 |

| | | | | | |
|---|---|---|---|---|---|
| 350 | 375 | 0x1D | 3879282 | Voc | 3.610364 |
| | | 0x1E | 3878728 | 20R_V | 3.5355344 |
| | | 0x13 | 1903814 | 2R_V | 2.9841921 |
| | | 0x14 | 57490 | R | 0.4886441 |
| 400 | 425 | 0x1D | 4072172 | Voc | 3.610364 |
| | | 0x1E | 4071267 | 20R_V | 3.5277522 |
| | | 0x13 | 1896062 | 2R_V | 2.9321108 |
| | | 0x14 | 57265 | R | 0.5385357 |
| 450 | 475 | 0x1D | 4289696 | Voc | 3.6109624 |
| | | 0x1E | 4288303 | 20R_V | 3.5193715 |
| | | 0x13 | 1898497 | 2R_V | 2.8746421 |
| | | 0x14 | 57293 | R | 0.5967385 |
| 500 | 525 | 0x1D | 4412675 | Voc | 3.6109624 |
| | | 0x1E | 4411517 | 20R_V | 3.5103917 |
| | | 0x13 | 1893347 | 2R_V | 2.8129828 |
| | | 0x14 | 57137 | R | 0.6610043 |

## 3. Implementation

As a result of checking the results of the modular internal resistance measuring device based on the data table as shown in Figure 3, it was confirmed that as the jig resistance value increased, the resistance value of the measuring device also increased. As a result of the confirmation, it can be seen that errors have occurred in each section [5].

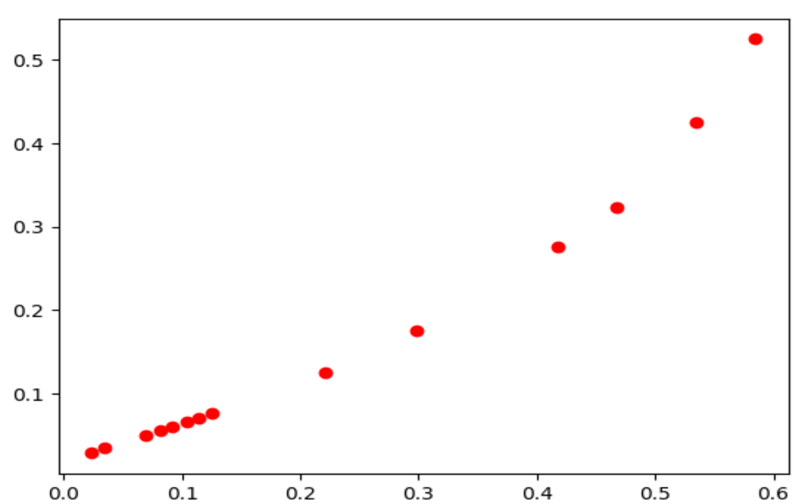


**Figure 3. Comparison of modular internal resistance meter and jig resistance**

As shown in Figure 4, a graph comparing the Linear function approximation made from the data of the set resistance through the calibration jig and the measured value of the modular internal resistance meter shows that the accuracy is low.

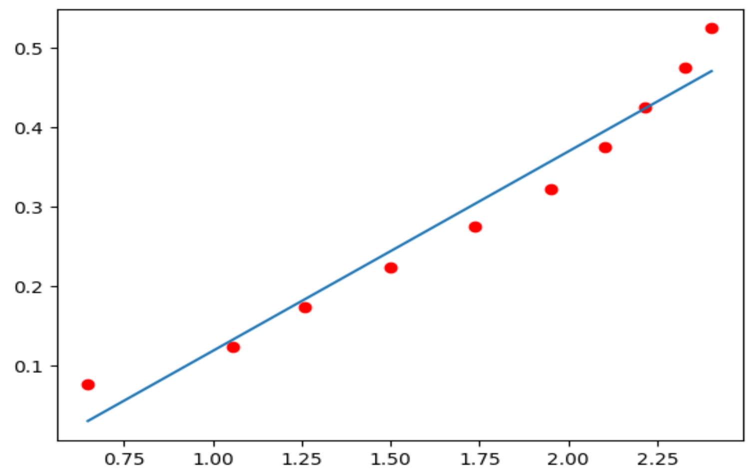


**Figure 4. Linear function approximation generated from jig internal resistance data**

As shown in Figure 5, to correct the error rate and measured value, it was assumed that the set resistance value and the modular measured value were proportional. Since the characteristics of the graph are similar to a cubic equation, the correction results were confirmed through the slope and intercept [6-7].

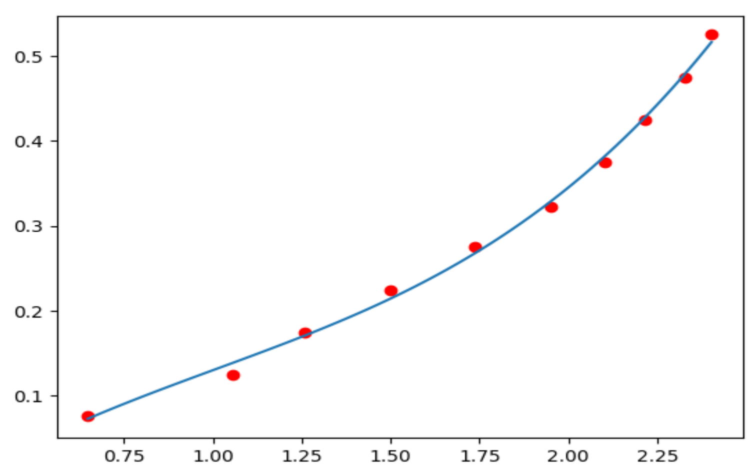


**Figure 5. Cubic function based on jig internal resistance data**

In this paper, the least squares method was used to calculate the slope and intercept. As shown in Figure 6, using Python, the x-axis was set as the modular measuring instrument value and the y-axis was set as the resistance value. As a result of calculating the approximate third-order function and creating and testing an interpolation function using a single resistor, the results shown in Figure 5 were obtained [8].

```
import numpy as np
```

```
import matplotlib.pyplot as plt

x = np.array([0.02354, 0.03484, 0.06954, 0.08116, 0.09202, 0.1043, 0.1146, 0.1257, 0.2205, 0.2988, 0.418, 0.4668, 0.5351, 0.5846])
y = np.array([0.005, 0.010, 0.025, 0.030, 0.035, 0.040, 0.045, 0.050, 0.100, 0.150, 0.250, 0.300, 0.400, 0.500])

coefficients = np.polyfit(x, y, 3)
polynomial = np.poly1d(coefficients)

print("Function:", coefficients)

def calculate_y(x_val):
return polynomial(x_val)

x_val_example = 0.08345
print(f"x={x_val_example} y:", calculate_y(x_val_example))

x_line = np.linspace(min(x), max(x), 100)
y_line = polynomial(x_line)
plt.plot(x_line, y_line, label='Cubic Function')
plt.scatter(x, y, color='red', label='Real Data')

plt.show()

x_line = x_line[0:20]
y_line = y_line[0:20]

plt.plot(x_line, y_line, label='Cubic Function')
plt.scatter(x[0:6], y[0:6], color='red', label='Real Data')

plt.show()

print(calculate_y(0.237))
print(calculate_y(0.1456))
```

**Figure 6. Source code for calculating the slope and intercept of a cubic equation using the least squares method**

## 4. Test results applying the Calibration method

As shown in Figure 7, the calibration graph is calibrated based on the pure resistance value of the calibration jig, so it can be confirmed that the modular internal resistance meter falls within the category of high accuracy.

The internal resistance values measured with the Hioki equipment were measured including the circuit board and cable resistance values, which resulted in differences.

There was a difference of about 13mΩ between the results measured with the Hioki equipment based on the calibration jig and the results from the calibrated modular measuring instrument. As a result of subtracting this value from the connection resistance value, an accuracy of 98-99% was obtained.

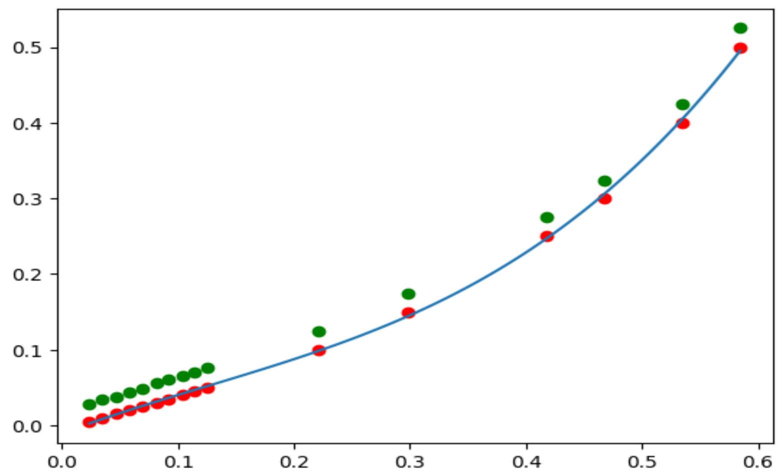


**Figure 7. Source code for calculating the slope and intercept of a cubic equation using the least squares method**

## 5. Conclusion

Despite the global increase in battery usage to achieve carbon neutrality and improve energy efficiency, batteries are finite resources that face performance degradation over time. When this occurs, issues related to their reuse and recycling arise. In this process, technologies and equipment for predicting battery lifespan and determining their status are essential, leading to the release of many related products.

While these devices can easily measure batteries, they are expensive and bulky. Additionally, they do not measure and diagnose in real-time, leading to accuracy variations depending on the battery type. Therefore, this paper proposes a modular real-time internal resistance measurement method. Through the application of a cubic polynomial correction method, an accuracy of 98-99% was confirmed.

The use of this modular internal resistance measuring device is expected to enhance the safety of the usage environment for reused batteries. Especially in Energy Storage Systems (ESS) used to alleviate power shortages, the real-time measurement method is anticipated to be the most effective way to prevent fires.

## 6. Acknowledgement

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