**Experimental Analysis of the Automatic Monitoring of Heat Flow Through a Shunt**

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**Abstract:** This study presents the experimental analysis results aimed at the automatic monitoring of heat flow through a shunt. During the research, shunt, current transformer, and thermocouple mini-modules were used. Through it, temperature-dependent current variations were measured and analysed. The experiments were conducted using the Instrumentation and Automation (IA) laboratory equipment. The equipment is designed for operation at a nominal voltage of 220 V, a frequency of 50 Hz, and a temperature range of +10 to +30 °C. The connection circuits of the current transformer mini-module used in the measurement process were optimised. By expanding the measurement limits, the stability of the monitoring system was ensured. In addition, the parameters related to the measurement accuracy of the thermocouple sensor mini-module were analysed. The obtained experimental results demonstrated the advantages of applying an automatic heat-signal flow monitoring system through a shunt in practical processes.

**Keywords:** shunt, heat flow, current transformer, thermocouple, PID, experimental analysis.

**INTRODUCTION**

In the process of monitoring heat flow, the thermodynamic parameters of the environment play an important role. Because temperature variations give rise to processes such as an increase in electromagnetic interference in electrical windings [1]. In such situations, the use of PID control blocks is effective for stabilising the system. These blocks provide the capability to monitor and analyse multichannel heat flow in real time [2]. Because, with the help of PID control blocks, the variable temperature gradients of mutually parallel-connected contacts are monitored [3]. In contact environments made from different materials, various heat flows are formed within parallel objects [4]. These charge flows arising in the contacts convert the heat flow into electrical voltage [5]. The resulting voltage is controlled through an adaptive shunt depending on the orientation of the electrodes [6]. Connecting contact environments in series or parallel ensures efficiency in converting heat flow into voltage [7].

Deviations in the process of converting heat flow into voltage may lead to improper operation or failure of the modules [8]. Therefore, shunt converter technologies are being employed to reduce uncertainties and stabilise the process [9]. Through these technologies, the stability of converting heat flow into voltage is ensured [10]. As a result, the heat flow is converted into voltage through a shunt connected in parallel to the electrical circuit. This reduces losses in the parameters of the measurement system devices. It normalises energy transmission and ensures efficiency [11]. Thus, monitoring heat flow through a shunt not only stabilises the voltage source but also reduces energy losses [12].

**METHODS**

Current measurement through a shunt.

A four-terminal resistor shunt was used to convert the current into a voltage signal. Two of its terminals serve as current input terminals, while the remaining two function as output terminals. The measuring mechanism is connected to the output terminals of the shunt, enabling the conversion of current into voltage. The nominal measurement parameters of the shunt are determined by the nominal value of the input current *Iu* and the nominal value of the output voltage *Uu*:

(1)

Shunts are used to extend the measurement range of current-measuring devices. It is typically utilised in measurement systems, signal conditioning converters, and automatic control devices.

**DC**

***Iu***

***Uu***

***RC***

***I***

**FIGURE 1.** Connection diagram of an ammeter with a shunt

The current *Iu* passing through the shunt is related to the total current *I* as follows:

(2)

Where Ru is the internal resistance of the measuring mechanism.

The resistance of the shunt for extending the measurement range is:

(3)

is determined as follows, where *n=I/Iu* is the shunt coefficient.

For small current values (≤30 A), internal shunts were used, while for large current values (≥1000 A), external shunts were employed. External shunts are made of copper contacts and manganin plates, with an accuracy of ±0.5%.

**A**

**+**

**-**

*Ammeter*

**A**

**B**

**C**

**D**

***Output***

***Input***

**FIGURE 2.** External shunt diagram for 2000 A

Operating principle of the current transformer.

A current transformer was used for measuring high-value currents. It converts the primary current into a secondary current. This provides a safety protection environment for the system. Under normal conditions, it converts the output current back to the primary current.

**POWER SUPPLY**

**A**

**A**

***U***

***I***

***IMEAS***

***RN***

**FIGURE 3.** Connection diagram of the current transformer

Its primary winding is connected in series with the circuit, while the secondary winding is connected to the measuring devices.

The current transformation ratio of the current transformer is determined as follows:

(4)

Here, *Ia* and *Ib* are the nominal values of the primary and secondary currents, respectively.

Current deviations are expressed as follows:

(5)

The accuracy classes of the transformer range from 0.2, 0.5, 1, 3 to 10, determining the measurement accuracy within the 50-120% range. In the mini-module, the transformer output is connected to a resistor, and a voltmeter is connected in parallel.

Thermocouple mini-module for temperature measurement.

A thermocouple consisting of two different metal conductors was used for temperature measurement. It generates a thermoelectric voltage (thermoelectric converter) as a result of the temperature difference:

(6)

This voltage is proportional to the temperature difference between the two ends of the thermocouple. The thermocouple mini-module was connected to the measurement system, and its output signal was recorded using a voltmeter and a multimeter. The presence of temperature changes was visually monitored through an LED indicator.

*t*0

*t*

A

C

**FIGURE 4.** Connection diagram of the thermocouple temperature sensor

Conducting experiments using IA laboratory equipment.

The experiments were carried out using IA (Instrumentation and Automation) laboratory equipment. Each mini-module has IN (input) and OUT (output) terminals. In this setup, the employed mini-modules were connected to a function generator, voltmeter, and ammeter in various modes. The shunt mini-module was operated in AC mode, with the voltmeter connected to the OUT (output) and the function generator connected to the IN (input). Its real-time U(I) graph was plotted.

**FG**

**A**

**V**

**SHUNT**

CHANNEL

IN1

IN2

OUT1

OUT2

**FIGURE 5.** Connection diagram of the shunt mini-module to the function generator.  
FG-function generator; A-ammeter; V-voltmeter

The current transformer and thermocouple mini-modules were tested in alternating current (AC) mode. Its real-time U(I) graph was plotted.

**FG**

**A**

**V**

**CT**

CHANNEL

IN1

IN2

OUT1

OUT2

**FIGURE 6.** Connection diagram of the current transformer mini-module.   
FG-function generator; CT-current transformer; A-ammeter; V-voltmeter

During the temperature measurement process, a thermocouple mini-module was used. Measurements were carried out at intervals of every 5 °C. The results were recorded using a voltmeter and a multimeter. Temperature variations were visually monitored through an LED indicator. The LED indicated the variation ranges of the process. The obtained data were aimed at ensuring the stability of the thermocouple output signals.

IN1

IN2

OUT1

OUT2

**LED**

**MT**

+15V

**PM**

**FIGURE 7.** Connection diagram of the thermocouple mini-module to the IA system.   
MT-measuring transducer; PM-power module; LED-indicator showing the presence or status of various physical quantities.

**RESULTS AND DISCUSSIONS**

In this study, laboratory equipment of the IA (Instrumentation and Automation) brand was used. Mini-modules designed for measuring shunt, temperature, and current parameters were installed on it. During the experiment, shunt, current transformer, and temperature measurement mini-modules were connected to the technological data sensors module. A frequency signal with an amplitude of 5 V and a range of 10…120 Hz was transmitted to it via a function generator.

During the measurement process, the output signals of each module were recorded using a voltmeter, ammeter, and function generator. In this case, when the shunt mini-module was connected to the technological sensors module, an electrical signal with an amplitude of 5 V and a frequency of 120 Hz was transmitted via the function generator. As a result, the IA system recorded the maximum current value as 74 A. This result, corresponding to the current flowing through the electrical circuit via the shunt module, demonstrated the dynamic stability of the mini-module at high frequencies (Fig. 8).

0.0000 0.0025 0.0050 0.0075 0.0100

74

-74

0

**FIGURE 8.** Real-time measurement graph of the shunt mini-module

In the experiment conducted with the current transformer mini-module, a signal with an amplitude of 5 V and a frequency of 100 Hz was transmitted to the IA system. The measurement system used in the experiment recorded an alternating current value of up to 209 A. In this situation, the current transformer operated in AC mode. This generated an output signal through induction by means of a varying magnetic field.

According to its graphical analysis, the current transformer mini-module demonstrated stability within the signal range up to 100 Hz (Fig. 9). In this case, the dynamic performance of the modules was successfully tested under conditions close to the AC network frequency.

0.0000 0.0025 0.0050 0.0075 0.0100

209

-209

0

**FIGURE 9.** Real-time measurement graph of the current transformer mini-module

In the experiment, a system capable of simultaneously measuring electrical and thermal parameters through shunt, current transformer, and thermocouple mini-modules was studied. When the shunt mini-module was adjusted for a voltage source within the range of 0…25 V, a current within the range of 4…20 mA was obtained. By supplying a signal with an amplitude of 5 V and a frequency of 100 Hz to the current transformer, a current of up to 219 A was generated. The thermocouple mini-module sensor measured a temperature of 29 °C in real time within a range of ±0.5 °C. Each mini-module was connected through separate channels with galvanic isolation. Their output signals were converted through the ADC system. According to its graphical analysis, it demonstrated the capability of measuring electrical and thermal parameters through the mini-modules used in the experiment (Fig. 10). This enables the application of the experimental results in practical processes.

0.0000 0.0025 0.0050 0.0075 0.0100

219

-219

0

**FIGURE 10.** Real-time combined measurement graph of the shunt, current transformer, and thermocouple mini-modules

**CONCLUSION**

According to the results of the experiments, it is possible to use the shunt, current transformer, and thermocouple mini-modules together in the IA brand laboratory equipment. The use of these modules made it possible to measure electrical and thermal parameters. A linear relationship between current and voltage was observed. This process demonstrated the stability of the system under various frequencies and electromagnetic interferences. Through the thermocouple mini-module, the system’s ability to respond rapidly to real-time temperature variations was observed. The combined use of all mini-modules transformed the measurement system into a multichannel configuration. As a result, an automatic and adaptive control mechanism was formed within the system. This serves to apply the results aimed at automating measurement processes to real systems.

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