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STUDY ON MEASUREMENT OF LIQUID FLOW RATE USING AE SENSOR

Yi Quin ZHENG*, Takeshi NAKADA*, Moritaka OHTA*, Gang WANG* and Yasuo SAKURAI**

*School of Information Environment, Tokyo Denki University,
2-1200 Muzai Gakuenfai, Chiba, 270-1382 Japan
(E-mail: nakada@sie.dendai.ac.jp)
**Department of Mechanical Engineering, Ashikaga Institute of Technology,
268-1 Oomaecho, Ashikaga, Tochigi, 326－8558 Japan

ABSTRACT

This study deals with a computer system for measuring flow rate of tap water flowing in a rigid pipeline in a non-contact method by using an acoustic emission (AE) sensor placed on a surface of a pipeline. The acoustic emission generated by tap water flowing at a constant flow rate in a pipeline is caught by the AE sensor experimentally, and the corresponding output of the AE sensor is converted to a root mean square (RMS) value. It became clear that the relation between flow rate and the corresponding RMS value can be expressed as a quadratic curve with good approximation. This quadratic curve is used as the calibration date for measurement of flow rate. A prototype of a flow rate measuring system based on a computer was constructed by taking account of the calibration data. It is shown in the experiment that the flow rate more than 3.2 l/min can be measured by using the measuring system proposed in this study.

KEY WORDS

Flow Rate Measurement, Pipeline, AE Sensor, Signal Processing, RMS Value

INTRODUCTION

A measurement of a fluid flow rate is very important to get necessary data for designing or manufacturing a process system and a fluid mechanical system. In this study a method to measure a fluid flow rate in a pipeline using AE sensor is proposed. A measuring system based on this method has advantages to be cheap and be able to measure with noncontact. In this method an AE sensor is installed on the outer wall of a pipeline. The AE sensor detects the acoustic vibration generated by tap water flowing in the pipeline and it outputs the AE signal corresponding to the flow rate of tap water in the pipeline. A signal processing method of the AE signal is developed to measure the flow rate and an automatic measurement system of the flow rate is constructed. The flow rate more than 3.2l/min can be measured in this system. The effectiveness of a prototype flow rate measuring system based on the method proposed in this study is confirmed in the experiment.

PROPOSAL OF MEASUREMENT METHOD USING AE SENSOR

Figure 1 shows a concept of a fluid flow rate measurement method proposed in this study. An AE sensor, which is used to detect acoustic vibration to occur by breaking of materials in general, is installed on the outer surface of a steel pipe as shown in Figure 2. This AE sensor detects acoustic vibration to occur by tap water flowing in the pipeline, and we use Root-Mean-Square (RMS) method as a signal processing to obtain the corresponding flow rate from the AE output signal.

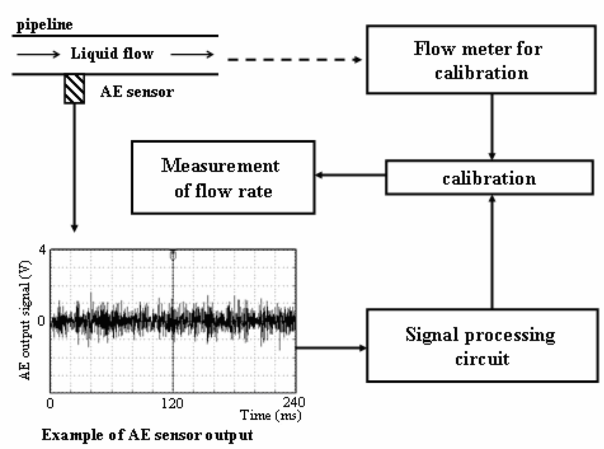

Figure 1 Concept of flow rate measurement

EXPERIMENT

Experimental Apparatus

Figure 3 shows the outline of the experimental apparatus used in this study. This experimental apparatus consists of a fluid source, a steel pipeline, a flowmeter for flow rate calibration, an AE sensor, some amplifiers, a high pass filter, a RMS circuit and a PC for collecting date and a data analysis. The fluid used here is a tap water, and the flow rate is temporally constant. The proposed measurement method can be considered an indirect measurement method, because an AE sensor has an inherent frequency characteristics, and the output signal of the AE sensor are effected by the mounting conditions between the AE sensor and the pipe, and the transmission characteristics of sound. Accordingly, the result of the measurement in our proposed measurement system must be calibrated by a precise flowmeter for flow rate calibration.

Experiment and results

Figure 4 shows an output waveform of the AE sensor at the flow rate Q of 7.3l/min, and it is found that various frequency components are included in it. The output waveform of the RMS circuit is shown in Figure 5, when the output waveform of the AE sensor is given to the RMS circuit, and the RMS value is almost constant during measurement time. This experimental result that a constant RMS value corresponding to a constant flow rate can be gotten shows the possibility of the flow rate measurement by using the AE sensor. Then, the corresponding RMS value was obtained experimentally

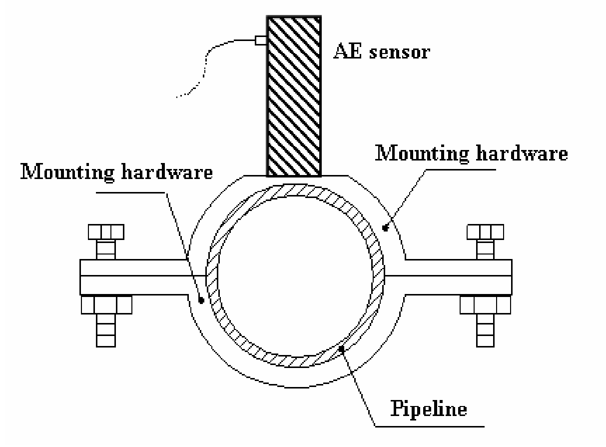

Figure 2 Installation of AE sensor

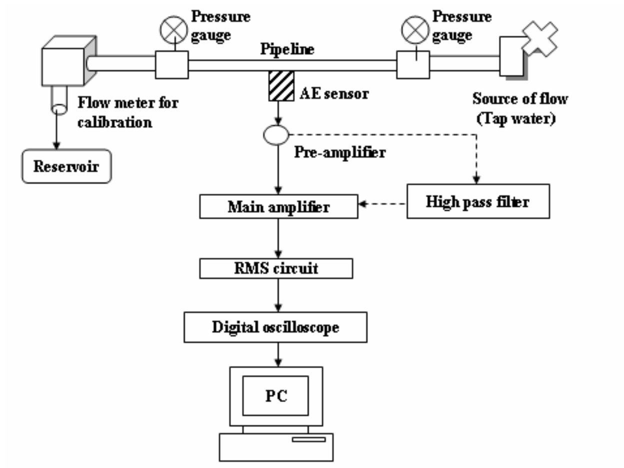

Figure 3 Experimental system of flow rate measurement

at each constant flow rate Q. The high pass filter in Figure 3 is removed in this experiment, and the signal processing system shown in Figure 6 is used. The experimental result is shown in Figure 7, and it is found that the RMS value increases almost in a quadratic function corresponding to the increase of the flow rate in the flow rate Q>5l/min. On the other hand the change of the RMS value corresponding to the change of the flow rate can not be found in the flow rate Q<5l/min, and it can be considered that the electric noise with the frequency of 50 Hz is this cause. So, the high pass filter with the cut off frequency of 80 Hz was inserted as shown in Figure 8 in order to remove the electric noise, and the gain of the main amplifier was readjusted twice. Under these conditions the relation between the flow rate and the RMS value in the flow rate Q<5l/min was obtained experimentally. The experimental result is shown in Figure 9 and its relation shows almost the same tendency as that in Figure 7. The following matters became clear from these experimental results.

(1) The RMS value of the output AE signal increase in a quadratic function, corresponding to the increase of the flow rate in the flow rate Q>3l/min, and the possibility that the flow rate can be obtained from the RMS value was found.
(2) The measurement of the flow rate is currently difficult in the flow rate Q<3l/min.

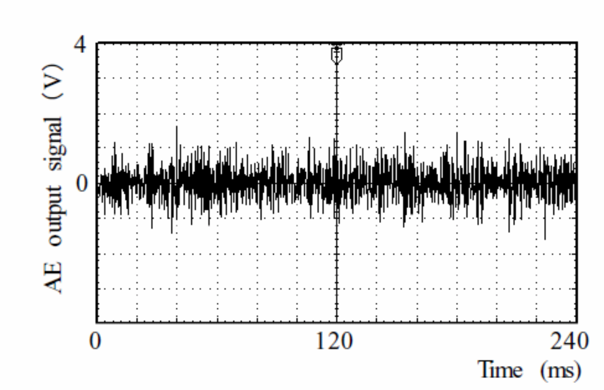

Figure 4 Output signal of AE sensor in Q=7.3[l/min]

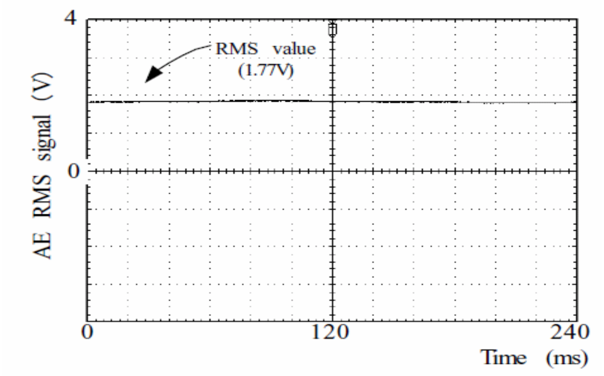

Figure 5 Output signal of RMS circuit in Q=7.3[l/min]

Frequency Analysis of AE signal

The frequency analysis of the AE signal caused by the fluid flow in the pipe was performed by using FFT in order to find the possibility of the flow rate measurement in the flow rate Q<3l/min. The conditions on the FFT analysis are as follows.

Frequency range : 20 kHz
Sampling frequency : 51.25 kHz
Window function : Rectangular window
Flow rate Q : 0l/min, 3l/min, 7l/min

Figure 10 shows the analytical results, and it became clear that the frequency components from 1 kHz to 3 kHz centering around 2 kHz are dominant. When focusing on the amplitudes at the frequency of around 2 kHz in the flow rate Q=3l/min and Q=7l/min, the

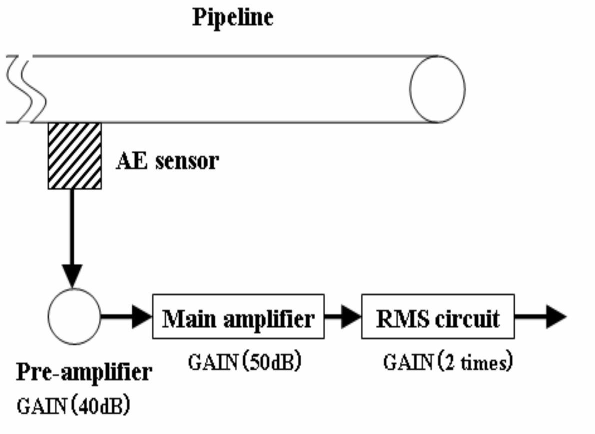

Figure 6 Basic signal processing system of measurement

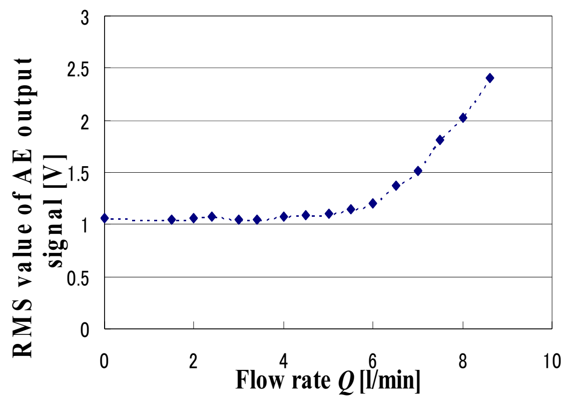

Figure 7 Relation of flow rate and RMS value in use of basic signal processing system

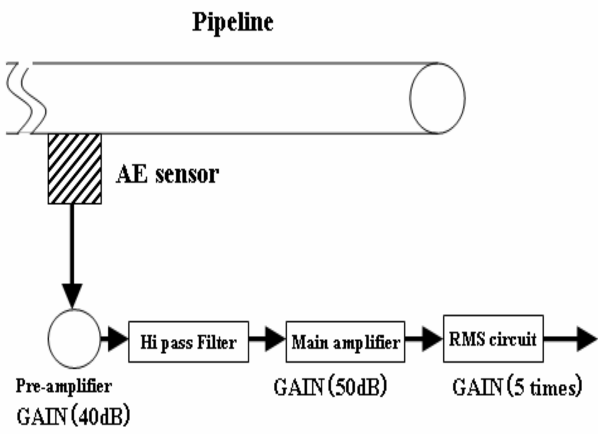

Figure 8 Modified signal processing system (High-pass filter insertion)

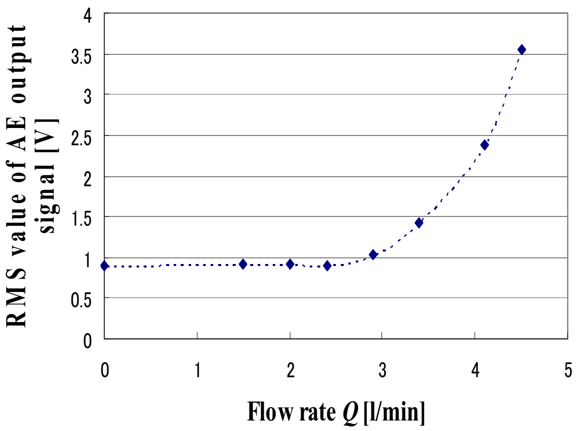

Figure 9 Relation of flow rate and RMS value of AE output signal in medium flow rate region

focusing on the amplitudes at the frequency of around 2 kHz in the flow rate Q=3l/min and Q=7l/min, the amplitude in Q=3l/min reduces to 1/10 of the amplitude in Q=7l/min. Since the amplitude reduces rapidly as the focusing on the amplitudes at the frequency of around 2 kHz in the flow rate Q=3l/min and Q=7l/min, the amplitude in Q=3l/min reduces to 1/10 of the amplitude in Q=7l/min. Since the amplitude reduces rapidly as the flow rate reduces as stated above, S/N of the AE signal reduces so small in Q<3l/min, and this makes the measurement of flow rate in Q<3l/min difficult. A solution to make the measurement in Q<3l/min possible may be to reduce the disused frequency components except 1 kHz to 3 kHz by using band pass filter.

CONSTRUCTION OF FLOW RATE MEASUREMENT SYSTEM

A flow rate measurement system based on a computer to measure automatically a flow rate by using the method proposed in this study was constructed.

Derivation of Calibration Curve of Flow Rate

The flow rate is classified in the large flow rate region (Q>5l/min), the medium flow rate region (5l/min>Q>3l/min) and the small flow rate region (Q<3l/min) in our measurement system. The relation between flow rate and RMS value in large flow rate region was shown in Figure7, and the relation in the medium flow rate region in Figure 9. The flow rate measurement in the small flow rate region is difficult presently. For constructing an automatic measurement system the flow rate has to be determined from the measured RMS value. In this study the relation between the RMS values and the corresponding flow rates was approximated by a quadratic curve, using least square method. The obtained quadratic curves express as follows.

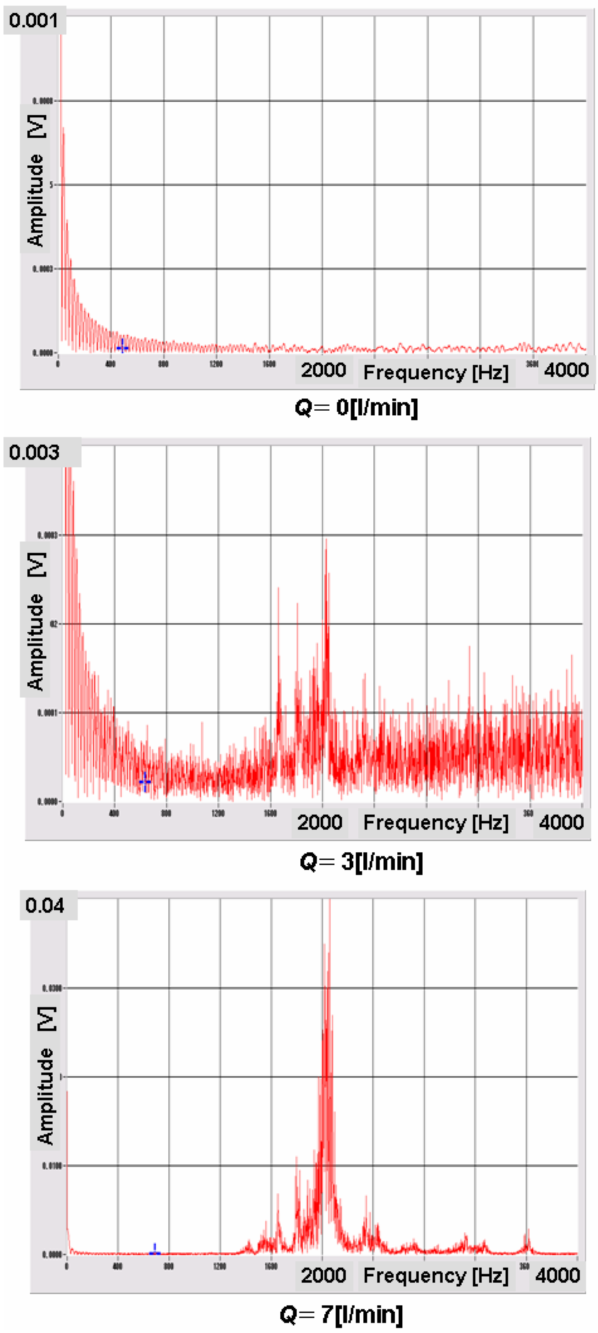

Figure 10 Power spectrum of AE (Q=0, Q=3, Q=7)

Large flow rate region :

$$V_{RMS} = 0.09Q^2 - 0.86Q + 3.15 \quad (1)$$

Medium flow rate region :

$$V_{RMS} = 0.69Q^2 - 3.57Q + 5.52 \quad (2)$$

The experimental results and the quadratic curves in the large flow rate region and the medium flow rate region are shown in Figures 11 and 12, respectively. The quadratic curve in the large flow rate region coincides well in the flow rate ranges more than 5l/min with the experimental results. Similarly, the quadratic curve in the medium flow rate region coincides well in the flow rate ranges more than 3l/min with the experimental results. Therefore, the flow rate can be obtained from the measured RMS value (V_{RMS}) as follows.

Large flow rate region :

$$\boldsymbol{Q} = \frac{\sqrt{0.36(V_{RMS} - 3.15) + 0.74}}{0.18} + 4.78 \qquad (3)$$

Medium flow rate region :

$$\boldsymbol{Q} = \frac{\sqrt{2.76(V_{RMS} - 5.52) + 12.74}}{1.38} + 2.59 \qquad (4)$$

Prototype of Flow Rate Measurement System

The flow rate measurement system includes the three kinds of processes as follows. Basically, in our system the flow rate is obtained from the measured V_{RMS} and Eq. (3) or Eq. (4), and the measured V_{RMS} and the flow rate are displayed on a screen.

(1)Process in large flow rate region :

The signal processing system shown in Figure 6 is used, and this process becomes the initial state in this measurement system.

As the flow rate belongs to the large flow rate region, as shown in Figure 11, when V_{RMS} >1.10, the flow rate can be obtained from Eq. (3).

(2) Process in medium flow rate region :

As the flow rate belongs to the medium flow rate region, when V_{RMS} <1.10 in the above process (1),the signal processing system is changed to flow rate in medium flow rate region from Figure 6 to Figure 8 automatically, and the flow rate can be obtained from measured V_{RMS} and Eq. (4).

(3) Process in small flow rate region :

As the flow rate belongs to the small flow rate region, when V_{RMS} <0.91 in the above process (2), the flow rate can not be measured in this state, and "Unmeasurable" is displayed on the screen.

The basic flow chart for the prototype of the flow rate measurement system is shown in Figure 13. Figure 14 shows the signal processing system which switches over from the process of the large flow rate region to the process of the medium flow rate region. The electric relay in Figure 14 is connected to point of contact [1] the initial state for measurement. When the measured V_{RMS} <1.10, the electric relay is connected to point of contact [2] by the operating voltage of 5 V generated from PC, and the process in large flow rate region shifts to process in the medium flow rate. Figure 15 shows an

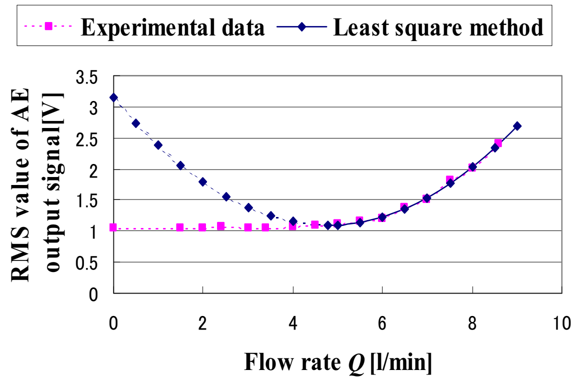

Figure11 Calibration curve of RMS value of AE output to flow rate in large flow rate region

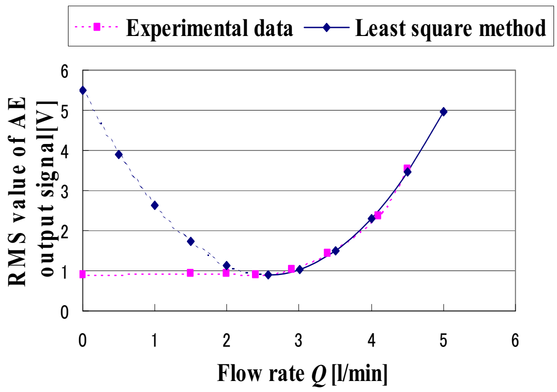

Figure 12 Calibration curve of RMS value of AE output

indication screen of the flow rate in the flow rate measurement system. The measured V_{RMS} is displayed on a part of "Input voltage" on the left of the screen, and the flow rate obtained from V_{RMS} is displayed on a part of "Flow rate" in the lower right of the screen. The insertion state of 80 Hz high –pass filter is displayed on a part of "Filter" of the right side of "Input voltage" by on/off lamp. In case of small flow rate region "Unmeasurable" is displayed on a part of "Error" in the lower left of the screen.

CONCLUSIONS

In this study a flow rate measurement method using AE sensor is proposed and a prototype of the flow rate measuring system based on the method is constructed. It is found that the flow rate measurement is possible in the flow rate region of 3.2l/min〜7l/min in this system.

However, the improvement of S/N is necessary to measure the flow rate in the small flow rate region less than 3l/min.

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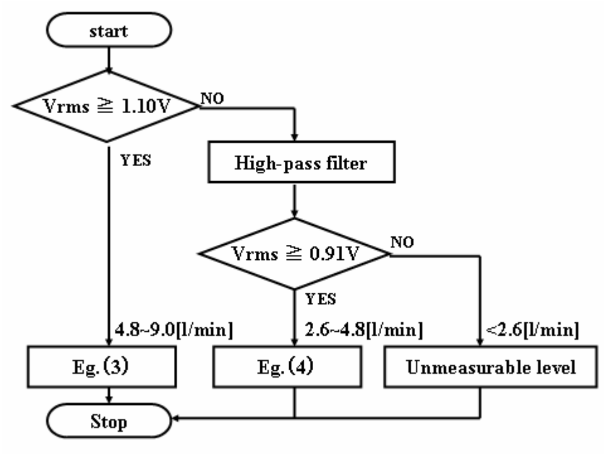

Figure 13 Flow chart of AE output and flow rate collation

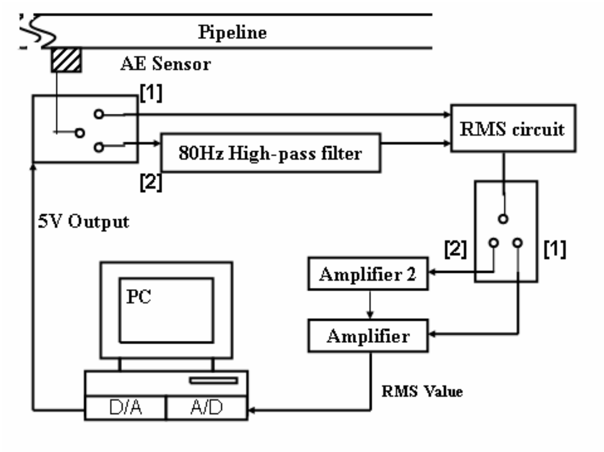

Figure 14 Flow rate process system in stationary flow rate

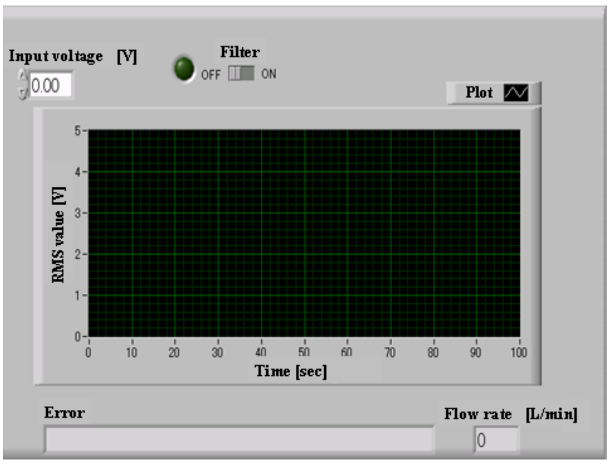

Figure 15 PC screen of flow rate process system

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