Measurement Accuracy of Raman lidar system to detect leakage of hydrogen gas in nuclear containment building

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1. Introduction

Hydrogen gas can be generated by oxidizing the nuclear fuel cladding during the critical accident and it lead to serious secondary damages in the containment building of the nuclear power plant. Therefore, hydrogen gas detection is very important for safety of the nuclear power plant.

In this research, based on the Raman spectroscopic technique by laser pulses, a hydrogen Raman signal was acquired and a fundamental experiment was carried out to measure the hydrogen gas concentration at a distance of several tens of meters from the measurement system. In the process of measuring and monitoring the concentration of hydrogen gas, there is an appropriate value in the relationship between the time required for signal processing and the monitoring cycle. We divided the Raman signals obtained by the experiment into several time intervals and analyzed the result values by applying different number of signal processing in each section.

2. Hydrogen Raman lidar system

2.1 System configuration

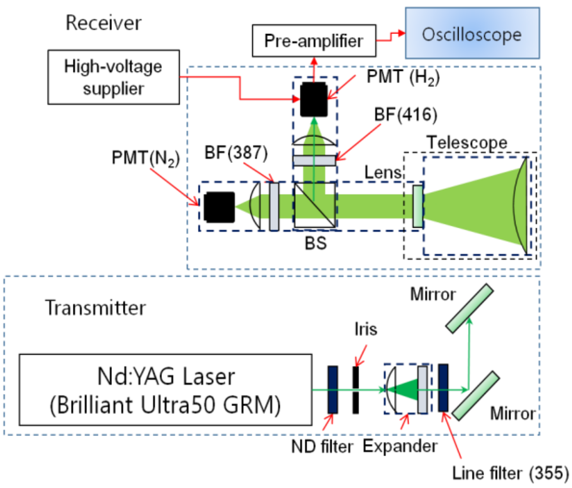

Fig. 1. Schematic diagram of Raman lidar system for hydrogen gas detection

As shown in Fig. 1, our experimental set-up is divided into three major parts. One is the transmitter, which is composed of an Nd:YAG laser and transmitting optics. The transmitted beam passes through the beam expander, and the expanded and collimated beam is sent to an mirror and the reflected beam at the mirror is sent into the target gas. Another is the acquisition part, which is separated into two paths. The Raman signals scattered from the target is collected by a telescope and passes through a beam splitter (BS). The scattered Raman signal passes through the band pass filter of 416nm and focused on a PMT (Photo Multiplier Tube) for hydrogen gas detection. [1-3] At the same time, the scattered Raman signal passes through the band pass filter of 387nm and focused on a PMT for nitrogen gas detection. [4-6] The third is electrical part, which consists of high voltage supplier, pre-amplifier, DAQ board and control computer.

2.2 Signal analysis

For detection of hydrogen gas leakage and remote measurement of quantitative concentration, change of Raman signal by hydrogen gas was measured while changing hydrogen concentration by using a gas chamber capable of adjusting hydrogen concentration. 6000 data of hydrogen Raman raw signals were collected at each concentration.

Table 1 shows the signal processing conditions. Subset of 60 sections was generated based on 100 data of 6000 hydrogen Raman signals. The intensity of the average hydrogen Raman signal was obtained by summarizing the data of each section by 40, 60, and 100 units. Using the average data of the hydrogen Raman signal of 60 sections, the values of the intensity, standard deviation and measurement error of hydrogen Raman signal were obtained and compared according to the number of each average data.

Table 1. The hydrogen Raman signal data processing condition

	Subset 40	Subset 60	Subset 100
Number of data	40	60	100

2.3 Experimental results

Fig. 2, 3, and 4 are experimental results of hydrogen gas concentration when the average number in each section is 40, 60, 100, respectively. As shown in Fig. 2, 3 and 4, the measurement results of hydrogen gas concentration shows better linearity as the averages are increased. Table 2 shows the determination coefficient (R^2) showing the similarity with the linear trend line, the result of comparing the average value of the measurement errors and the standard deviation error values of the hydrogen Raman signals shown in Figs. 2, 3 and 4. As the average number of hydrogen Raman signals increases, the value of the decision coefficient (R^2) showing the similarity with the linear trend line gradually increases, and the average of the errors and standard deviation decreased as the average number increased.

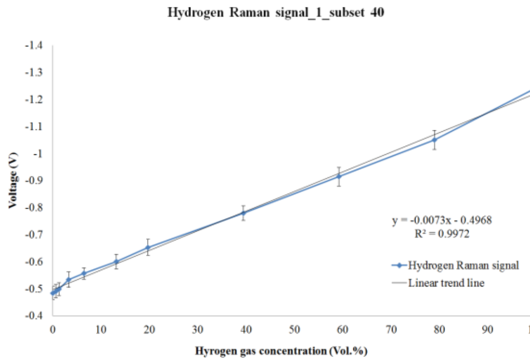

Fig. 2. Hydrogen Raman signal distribution for 40 averaging values

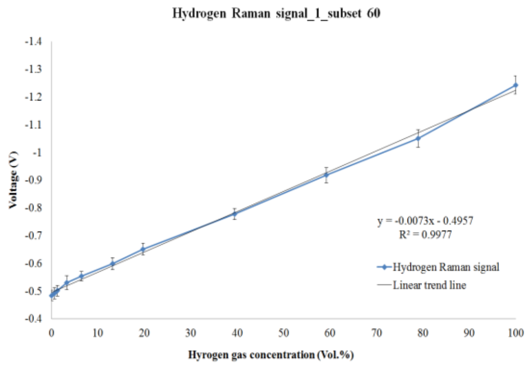

Fig. 3. Hydrogen Raman signal distribution for 60 averaging values

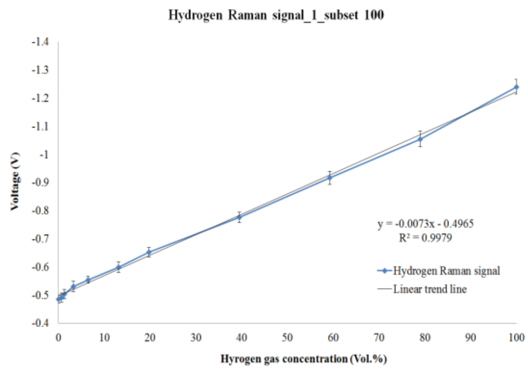

Fig. 4. Hydrogen Raman signal distribution for 100 averaging values

Table 2 Problem Description

Average number	40	60	100
Coefficient of determination (R^2)	0.9972	0.9977	0.9976
Average errors (%)	1.6796	1.4865	1.4648
Standard deviation (%)	3.8482	3.1963	2.5804

3. Conclusions

In this study, basic experiments were performed to measure and monitor the concentration of hydrogen gas using Raman lidar and efficient value between the signal processing time and the monitoring period to reduce the error of the acquired signal and to increase the measurement resolution of the system. As long as the measurement conditions and monitoring cycle are allowed, it is desirable to perform averaging including a large number of signals.

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