

Development of an Ultra-high Temperature Distributed Vibration Sensing (DVS) System for Supercritical Geothermal Wells

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ABSTRACT

“Supercritical Geothermal Power Generation”, in which subduction-origin ultra-high temperature (400-500 deg-C) geothermal resources are used as a thermal source, is considered as one of the few methods which has ability to drastically reduce emission of CO₂ around in 2050 in Japan. The Japanese Government has initiated national projects to investigate feasibility of the supercritical geothermal power generation. Downhole monitoring of acoustic signals is of critical importance for management of naturally existing/artificially created fracture system inside the supercritical rock body, because we expect a presence of fracture network with a grain scale in the supercritical rock body and energy of acoustic signals from seismic activity would be very small and have wideband nature. The authors designed and developed an ultra-high temperature distributed vibration sensing (DVS) system in a METI project and successfully demonstrated that the system has an ability to detect vibration applied to fiber optic under 550 deg-C conditions in laboratory.

1. INTRODUCTION

Development of supercritical geothermal resources in Japan, which have origin in subduction of oceanic plate, has been identified as one of the most promising means to drastically reduce emission of CO₂ around/after 2050 to establish COP-21 Agreement (CAO of Japan, http://www8.cao.go.jp/cstp/nesti/gaiyo_e.pdf, 2017). Target of supercritical geothermal development (SCGD) is rock bodies in ductile/plastic zones and contain fluid in supercritical conditions. Furthermore, the authors expect that these natures of the supercritical geothermal systems (SCGS) has ability to solve many of the obstructive factors in development of hydrothermal resources in Japan, including possible effect to hot springs, induced seismicity and thermal capacity (Muraoka et al., 2014).

Prof. Watanabe, Tohoku University, one of the members of the Supercritical Geothermal Development Project (SCGP), has inferred that permeability remains in the order of 10⁻¹⁵-10⁻¹⁴m² around at the top of the SCGS (Watanabe et al., 2017a), which is enough permeability for production of HT steam, although in some cases we need enhancement of permeability by hydraulic stimulation. Results from laboratory test of injection of supercritical water to granite sample demonstrated that “cloud-type” fracture network is created at the grain boundary in mixture mode of opening and shearing (Watanabe et al., 2017b), suggesting that seismic/acoustic signals with relatively small energy and wideband nature. The observations show that we need highly sensitive and wideband seismic detector which can be operated near the fracture system, for the monitoring of fracture cloud in the SCGS. The authors have concluded through feasibility studies of SCGD that high temperature passive fiber optic downhole monitoring system is one of the few solutions for this purpose, because we need no active electric component in borehole and size of the sensing unit should not disturb “multiple use” of a borehole that penetrated into the SCGS.

Distributed fiber optic sensing system which uses various kinds of scattering phenomenon to detect change of conditions (i.e. temperature, pressure etc.) has been originally developed for health monitoring of optical communication line, and currently distributed temperature sensing (DTS) system, distributed strain sensing etc., are commercially available (Miguel Lopez-Higuera, J. Ed., 2002). Application of distributed acoustic sensing (DAS) system (same as distributed vibration sensing (DVS) system) to borehole monitoring was made by service company in oil/gas industry, but improvement in thermal durability, sensitivity, bandwidth. The authors tried to improve performance of the DVS to be applicable to SCGD and manufactured prototype as described in this paper.

2. OUTLINE OF DVS FOR SCGD

Propagation characteristics of lightwave in optical fiber is determined by distribution of refractive index inside the fiber. Basically, refractive index on a core of fiber is homogeneous and constant along a fiber, and this brings low loss and distortion nature to the fiber signal transmission. However, some part of energy of the lightwave will be converted into scattered wave once change in the refractive index is induced. Temperature on the fiber and stress are typical cause of the scattering, suggesting that phenomena relate to local change in temperature and stress on the fiber can be detected by measuring scattered lightwave.

DVS uses “Rayleigh scattering” for incident short pulse to detect distribution of dynamic stress working along the fiber. Phase sensitive “Coherent- Optical Time Domain Reflectometer (OTDR)” (Divakaruni and Sander, 2006) has advantages to sensitivity, stability and resolution, has been introduced in the DVS, which has been developed by the authors. Major specifications and photo of the DVS is shown in Table-1 and Figure-1.

3. PERFORMANCE OF DVS

The energy of the returning lightwave by the Rayleigh scattering is very small and, therefore, level of scattered lightwave along a fiber causes heterogeneous signal to noise ration and sensitivity of the DVS. An example of spatio-temporal distribution of the noise along a fiber is shown in Figure 2. It is seen in the figure that the noise level is homogeneous and stable for the developed DVS. Figure 3 shows an example of frequency characteristics of the DVS. Here vibration was applied to a part of test fiber by piezoelectric element which is oscillated by a 2kHz sinusoidal signal. Frequency spectrum of the detected signal show that input vibration was correctly detected by the DVS with negligible distortion.

Spatial resolution of the DVS is determined by a length of time window in phase estimation in the processing unit of DVS. We have experimentally confirmed the spatial resolution of the DVS by applying a semi pin-point sinusoidal vibration to a test fiber at a length of 5015m. An example from the experiment is shown in Figure 4, where we can see that the DVS has a resolution around 5m as designed.

Test of the DVS for measurement under high temperature conditions was carried out using dry electric oven. The authors designed high temperature metal tube fiber and ordered manufacture to AFL (Jacobsen et al., 2017) for the test. The temperature inside the oven was increased up to 550 deg-C and we monitored the output from the DVS by hitting the oven as a vibration source. Outputs from the fiber at room temperature and 550 deg-C are shown in Figure 5. Vibration to the fiber was successfully detected under 550 deg-C conditions demonstrating feasibility of a combination of DVS and metal tube fiber.

Table 1: Major specifications of DVS.

Item	Spec.
Dynamic range	>60dB
Bandwidth	DC-2 kHz
Spatial resolution	<5 m
Max. temperature	550 deg-C



Figure 1: Photo of DVS.

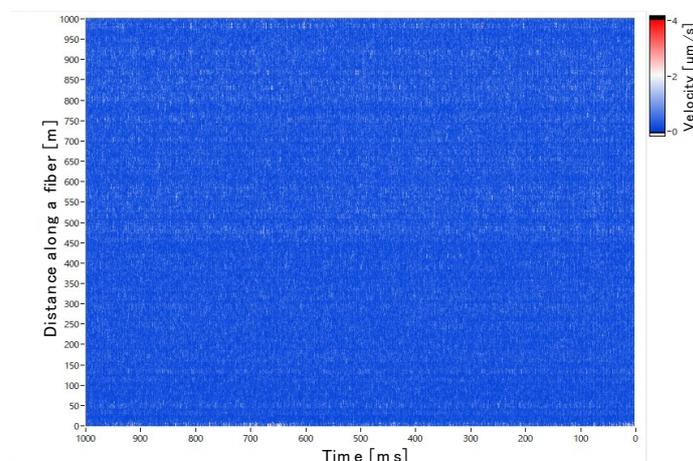


Figure 2: Noise of DVS.

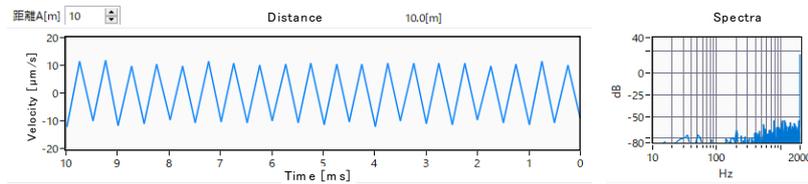


Figure 3: Waveform and spectra of output from DVS.

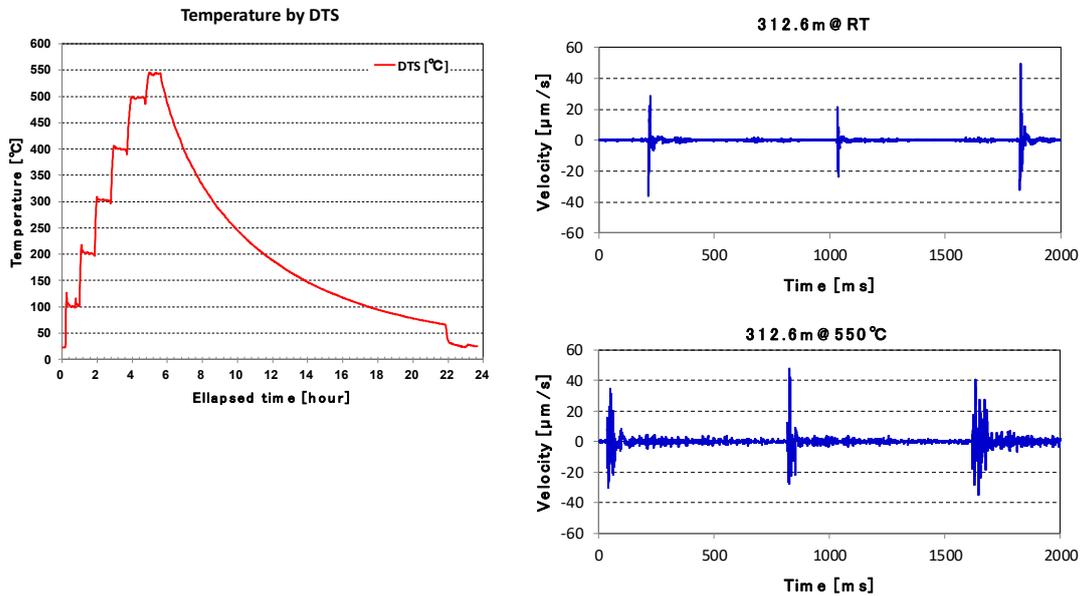


Figure 4: Waveform and spectra of output from DVS at different locations on a fiber.

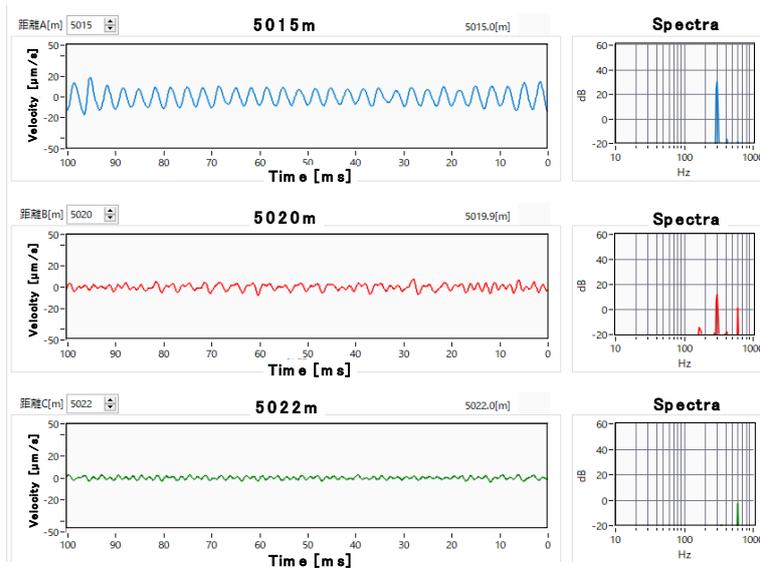


Figure 5: Result from a test in dry oven.

SUMMARY

It has been demonstrated that the DVS for SCGD, which the authors have been developing, has satisfactory performance for microseismic monitoring in “supercritical geothermal borehole” in both spatial resolution and bandwidth viewpoints. Further enhancement of dynamic range/sensitivity would increase practicality of the system. Test of the DVS in 250 deg-C geothermal well is planned in the beginning 2020 and the authors expect that points that need to be developed is clearly identified. Test of the metal-tubed HT optical fiber under HT, HP and corrosive environment is also expected in near future.

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