CORROSION DETECTION BY FIBER OPTIC AE SENSOR

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ABSTRACT

CUI (corrosion under insulation) of the piping at the industrial plant gathers more attention than ever. Currently, plant owners need to shut down their operation, scaffold, disassemble insulation, carry out Ultrasonic Testing mostly, and reassemble insulation for an extensive distance of piping. In-service-inspection (ISI), or on-line monitoring is one of the keys to improve economics. To evaluate CUI without plant shutdown, the authors group has carried out a preliminary research on AE detection occurred by corrosion progress. Fiber optic AE sensor was tested due to its anti-explosiveness, fitting to petrochemical plants. Experiment was successful, and one sensor could detect approx. 4,000mm-away corrosion. We report herein on its experimental results and fiber-optical AE sensor with calibration data (frequency response etc).

KEY WORDS

CUI (corrosion under insulation), ISI (in-service inspection), Fiber Optic AE Sensor

INTRODUCTION

Our study is how to detect and evaluate outer piping corrosion under insulation material, which is said to occur and accelerate by humidity and temperature correlation. To ensure that whole piping is corrosion-free or -allowable for safe operation, plant-owners currently have to shutdown its operation periodically. Then, in order for the precise inspection such as ultrasonic thickness measurement, they scaffold to elevated piping level (in Sumitomo Ehime factory, majority of piping runs 7-8 meters high in vast area), disassemble and reassemble insulation. To mitigate this work, our research focuses on utilizing AE methods as ISI tool and on enabling to screen/choose where among the long distance of piping to be precisely inspected.

Another point of research is utilization of fiber optic sensor. Fiber optic sensor is advantageous of its anti-explosiveness, due to its non-electrically driven principle. Majority area of petrochemical plant requires anti-explosiveness. Short-time AE monitoring does not need to be anti-explosive, but assuming continual monitoring at a corrosion-fast or inflammable gaseous area, sensor needs be anti-explosiveness.

This paper reports on the outline of experiment which used piping mock-up. Corrosion was accelerated by Sodium Chloride (NaCl). Fiber optical AE sensor was installed from 300mm to 3900mm away from corroded region and obtained AE signals.

FIBER OPTICAL AE SENSOR - PRINCIPLE

When the object vibrates with some elastic motion, the attached fiber optic on the objective surface elongates and shortens simultaneously. Light wave frequency f_o is modulated by such change in length of fiber optic, because the number of light waves in that vibrating region is constant in a moment. This is called “Laser Doppler effect” given as “f_o - f_d”. The frequency modulation f_d is proportional to the changing velocity of fiber optical length. Doppler effect is described as formula (1), f_d as modulated frequency, λ as light wavelength, and dL/dt as velocity [1).

$$f_d = -\frac{1}{\lambda}\frac{dL}{dt} \qquad (1)$$

The frequency modulation f_d is detected using the machzender/heterodyne interferometry as shown in Fig.1. The laser with frequency f_o is emitted and divided into the sensing optical path and detecting optical path. At detecting optical path, frequency f_M (80 MHz) is added by AOM (acousto optical modulator) to create the frequency “$f_o + f_M$”. The difference in frequency given as “$f_M + f_d$” is converted into the voltage. Hereinafter, we call this sensor “Fiber Optical Doppler” sensor or “FOD” sensor.

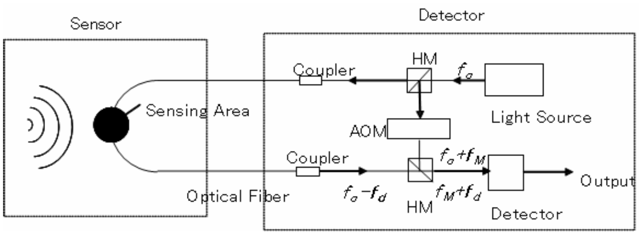


Fig.1 Optical interferometry by machzender/heterodyne system

FIBER OPTICAL AE SENSOR - CALIBRATION DATA

For this experiment, 65m long/multi-layered FOD sensor was employed as shown in Fig.2 and Table1. This sensor was originally purposed for micro seismic monitoring at field, and embedded into borehole near the excavated tunnel. The sensor was targeted at below 200kHz frequency. To reconfirm acceptance to corrosion monitor, we have calibrated the frequency response of FOD sensor.

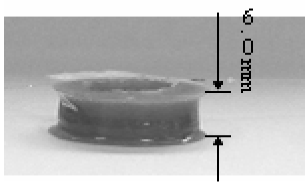
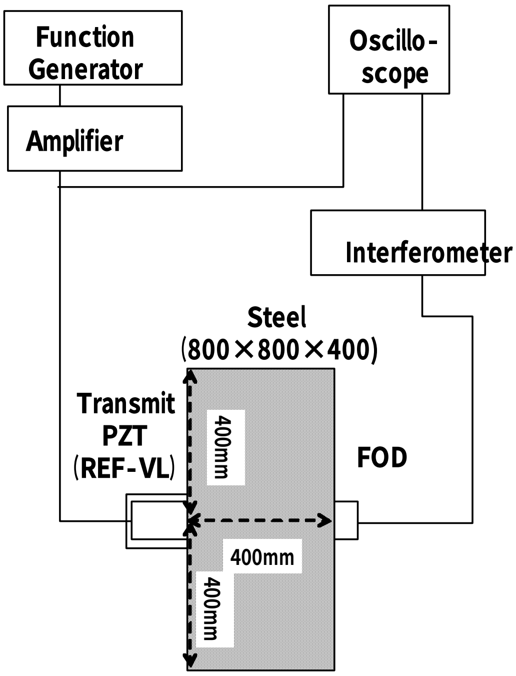


Fig.2 FOD sensor element

Table1 Used FOD sensor spec

Fiber optic	Polyimide coated
Fiber length (m)	65
Height (mm)	6.00
Inner diameter (mm)	8.00
Outer diameter (mm)	22.00

Calibration was in accordance with NDIS 2109-1991, particularly for longitudinal wave guidance. System and transmitting signal spec are shown in Fig.3. Three PZT sensors were employed to calibrate transmitting PZT sensor initially and then replaced receiving PZT sensor by FOD sensor. Due to restricted 400mm thickness of steel cube, elimination of reflected wave (80μsec delayed at shortest distance) was carefully examined. Accordingly, frequency response from 60kHz to 300kHz was calibrated at the same number of transmitted waves (5 waves).



waves	transmit freq (kHz)	duration (usec)	waves	transmit freq (kHz)	duration (usec)
5	30	167	5	170	29
5	35	143	5	175	29
5	40	125	5	180	28
5	45	111	5	185	27
5	50	100	5	190	26
5	55	91	5	195	26
5	60	83	5	200	25
5	65	77	5	205	24
5	70	71	5	210	24
5	75	67	5	215	23
5	80	63	5	220	23
5	85	59	5	225	22
5	90	56	5	230	22
5	95	53	5	235	21
5	100	50	5	240	21
5	105	48	5	245	20
5	110	45	5	250	20
5	115	43	5	255	20
5	120	42	5	260	19
5	125	40	5	265	19
5	130	38	5	270	19
5	135	37	5	275	18
5	140	36	5	280	18
5	145	34	5	285	18
5	150	33	5	290	17
5	155	32	5	295	17
5	160	31	5	300	17
5	165	30			

Fig.3 System and transmitted signal data for FOD Calibration

Calibrated frequency response is shown in Fig.4. As reference, 70kHz-resonant PZT (40dB amplified) sensor was also shown. 65m long/multi-layered FOD sensor has superior response to PZT sensor from 70kHz upto 140kHz. This was thought to be good for corrosion monitor [2].

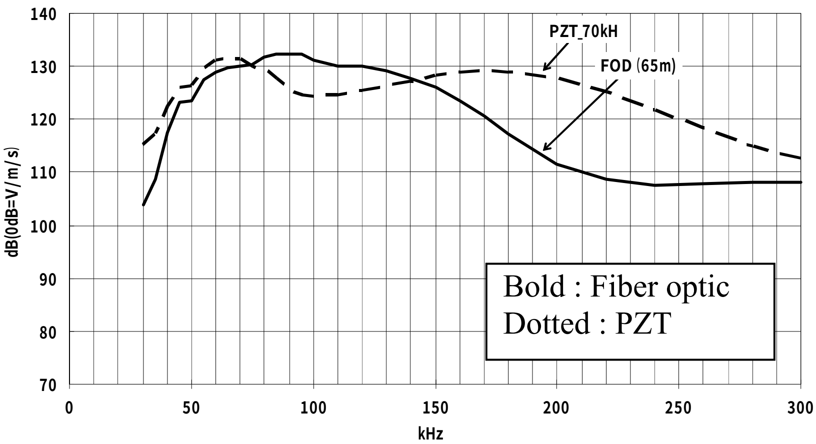


Fig.4 Frequency response data

(Below 50kHz, reference only, as the number of transmitted waves is only 3)

EXPERIMENTAL SETUP

Piping mock-up is shown in Fig.5. It is carbon-steel made, 5000mm long, outer diameter 60.5mm, thickness 3.9mm (STPG-370-50A-sch.40) and has inner flow of silicon oil for heating by circulation pump. Artificial corrosion area was located 1000mm from the right edge (in Fig.5) and was accelerated by NaCl solution and cyclic heating (max. approx. 80 degrees C.). FOD sensors were located 300, 2000, 3000 each on pipe, and 3900mm away both on pipe and on welded flange. FOD sensor was installed on pipe by U-shape bolt, while directly attached on welded flange, as shown in Fig.6.

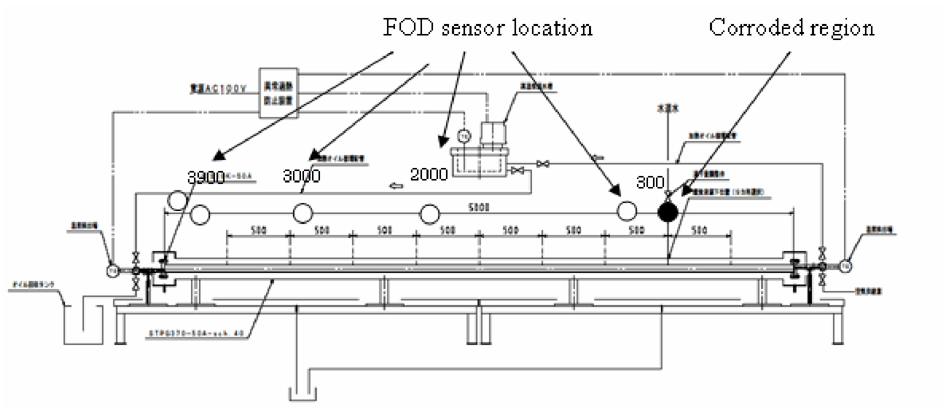


Fig 5 Experimental mock-up

Fig.6 Sensor installation (left: on-pipe image, center: on-pipe, right: on flange)

CORROSION AE MONITOR

AE monitor was implemented with approx. 2 month interval for 3 times. 1st data was obtained 1 month after the start of continual NaCl drop-off. Till then, corrosion spread on surface, but peeling was not observed by eyesight. At 3rd monitor, corrosion progressed aggressively, and peeling crack was confirmed even by eyesight. Fig.7 shows corrosion of 1st and 3rd.

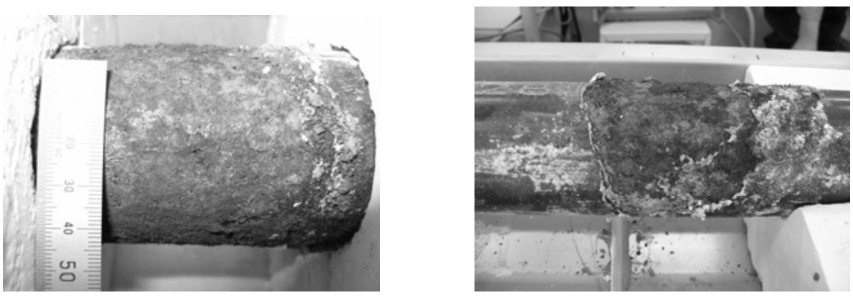


Fig. 7 Corrosion of pipe (left : 1st monitor, right : 3rd monitor)

DETECTED AE WAVEFORM AND FFT DATA

Fig 8 shows a sample of AE waves and FFT data at 1st experiment, which was obtained at 300mm away from corroded region.

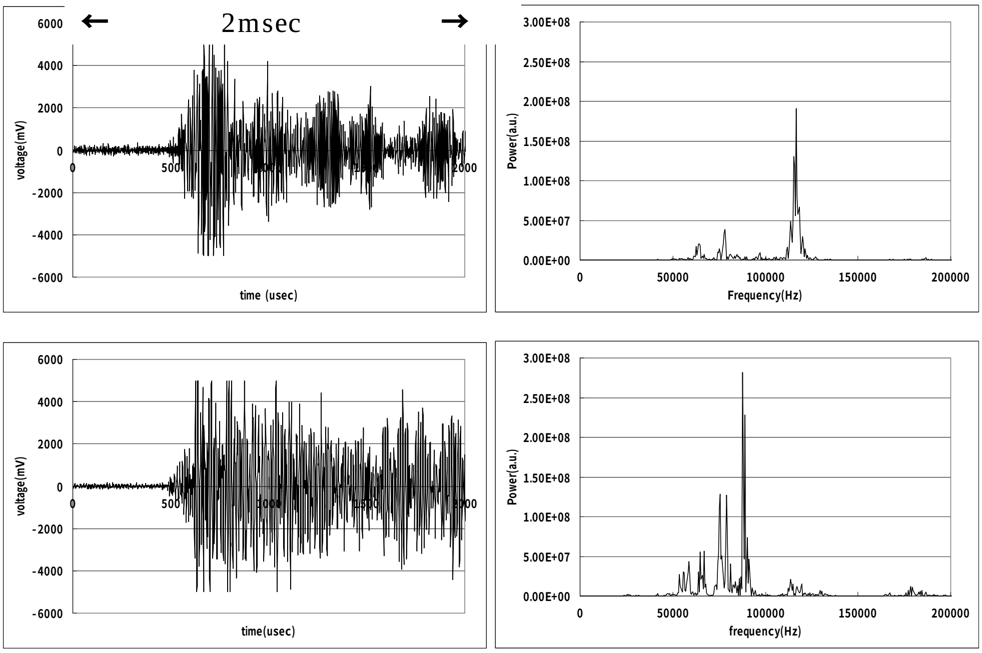


Fig.8 AE waves and FFT data

AE DATA ANALYSIS

AE was detected by FOD sensor successfully at 3900mm away from corroded region, with enough SNR(signal to noise ratio) margin. From those data, we made a sample analysis, 1) AE activity and corrosion status, 2) AE difference by sensor location between on-pipe and on-welded-flange, 3) AE frequency-amplitude histogram.

Fig.9 shows AE hits in half hour at 2nd monitor and at 3rd monitor at the same location (3900mm). Corrosion was largely activated clearly at 3rd, as confirmed by sight observation.

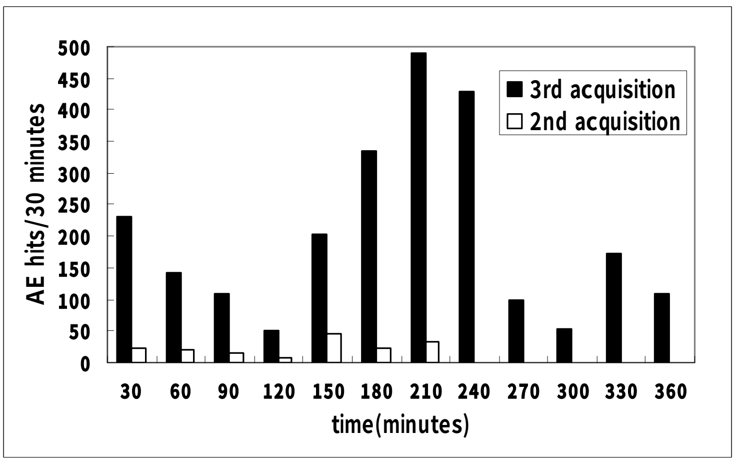


Fig.9 AE hits by corrosion progress at 3900mm

Fig.10 shows AE hits in half hour, describing whether AE data differs by sensor location between on-pipe and on-welded-flange, both are approx 3900mm away. Data clarified welded flange was relatively less in AE hits than on-pipe. This is thought to be attenuation of AE, being unable to fly over the welded joints. However, we do not see serious affect, that can give us more flexibility to install a sensor at anywhere location on piping structure.

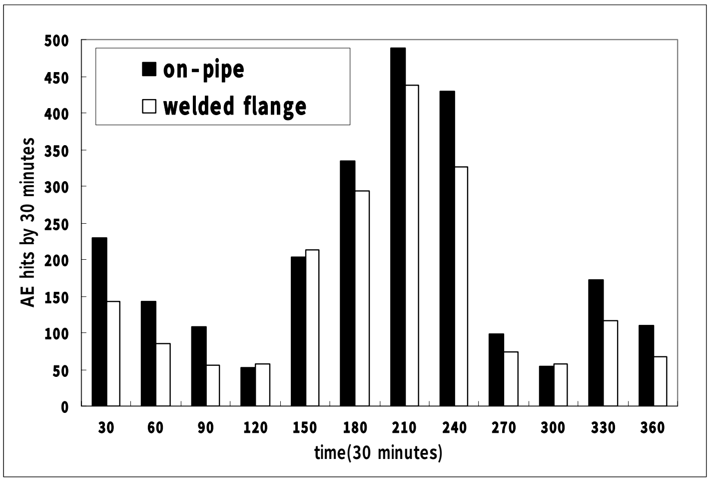


Fig.10 AE hits by sensor location at 4000mm

Fig.11 shows histogram of AE peak frequency / peak amplitude by sensor location. As monitoring duration of time is different from each other, the density of AE hits is not discussable here. However, it is clear that 60-70kHz peak frequency is more observed in any location, and larger amplitude is having lower frequency.

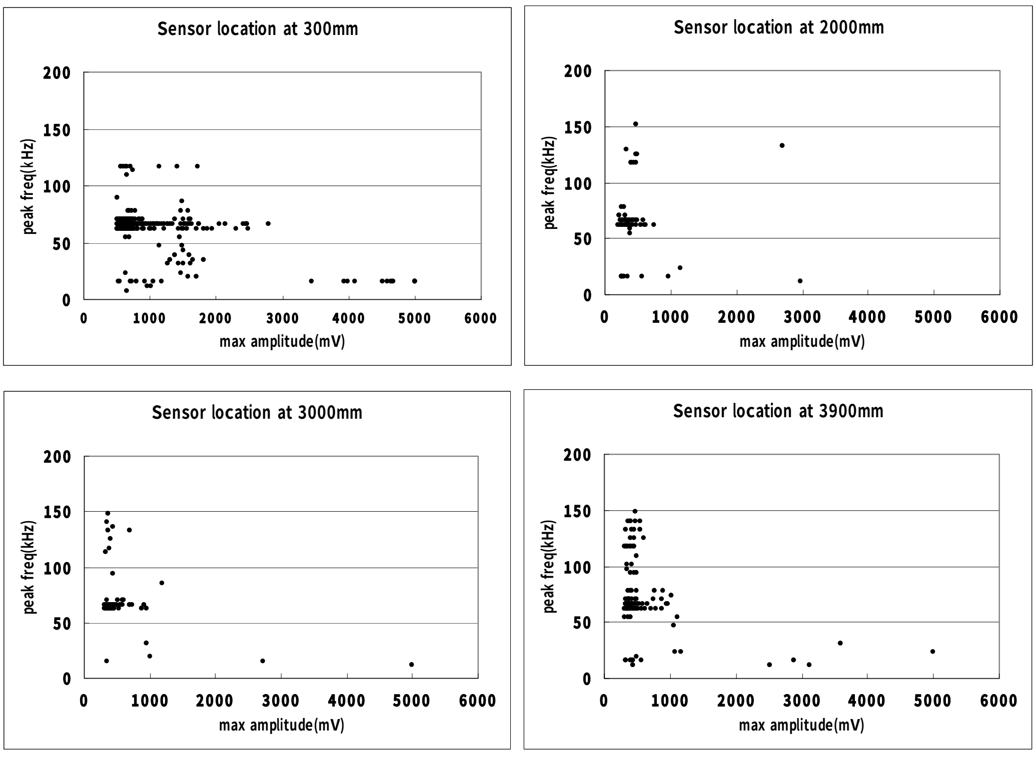


Fig.11 Peak frequency – amplitude histogram

CONCLUSIONS

We have successfully detected and evaluated AE, caused by corrosion progress by fiber optic AE sensor. Assuming one pipe length is approx 10m, one sensor can cover 1 pipe in order to screen CUI presence. Fiber optic AE sensor is naturally anti-explosive, that can be of advantage in petro/petrochemical plants.

Next challenge is to discriminate operation noise of piping flow. This will be difficult enough to tackle, having assumed internal steam flow and its cavitation particularly. We will continue to investigate and report at a next conference.

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