E-Journal of Advanced Maintenance Vol. 11 No. 2 (2019) 86-91
Japan Society of Maintenology

Operation and Maintenance experience of Sodium Leak Detector in Monju

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ABSTRACT

Gas sampling type sodium small leak detector, SID (Sodium Ionization Detector), a gas sampling detector installed to monitor small sodium leak in the Prototype Fast Breeder Reactor Monju, had been operated since its system start-up test through to the 40% reactor's output test. It's use was terminated in April, 2018. SID showed some indication variations during its operation period, and necessary measures were implemented.

As a result, the SID system maintained its functions without any critical malfunction until the end of its operation.

KEYWORDS

proto type fast breeder reactor, Monju, sodium leak detector, sodium ionization detector, SID, DPD, gas sampling

ARTICLE INFORMATION

Article history:
Received 23 October 2018
Accepted 26 June 2019

1. Introduction

In the Prototype Fast Breeder Reactor Monju, the small sodium leak detectors are placed in the cooling system which contains liquid sodium as a coolant. Because of the characteristic of FBR that the coolant pressure is low, a small leak happens from a crack on pipe before it breaks. So it is possible to shut down the reactor safely before coolant piping rupture by detecting a small sodium leak.

Sodium Ionization Detector (SID) is a type of a small sodium leak detector for the reactor vessel and primary cooling system. The scope of the sodium leak Detector, SID is shown in Fig. 1.

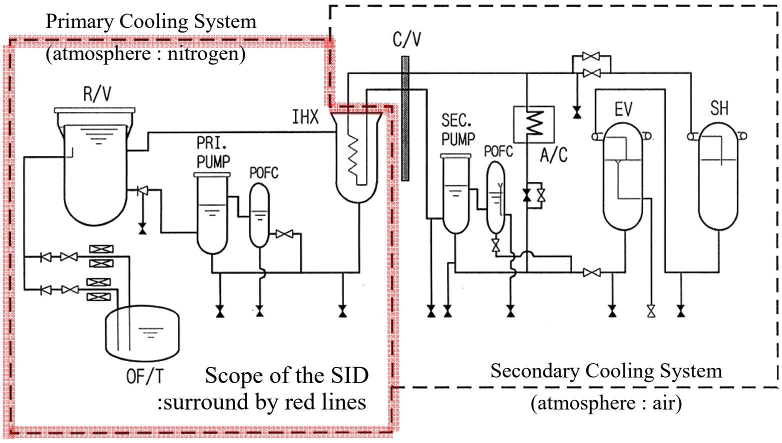

Fig. 1. Scope of the sodium leak detector, SID system in Monju

The SID system samples the gas from the nitrogen atmosphere around the cooling pipes, machines and rooms by sampling pump.

The sampling lines have many sampling nozzles and sampling flow rate of each nozzles are adjusted to be constant. The sampled gas flow into the detector and detects sodium. Then, the sampled gas is returned to the sampled room again. The outline of the sampling system is shown in Fig. 2.

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The SID system was designed and manufactured by two companies (MHI, Ltd, around the rector; Hitachi, Ltd, around the primary cooling system) to obtain diversified technical expertise.

The SID ionizes the gas with the filament kept at a high temperature of about 1000°C. The ion current increase depending on the ionized aerosol concentration, so SID can detect a sodium leak. The SID can detect 10^{-10} g/Na cm^3 of the aerosol concentration in the sampling gas. The outline of the SID is shown in Fig. 3.

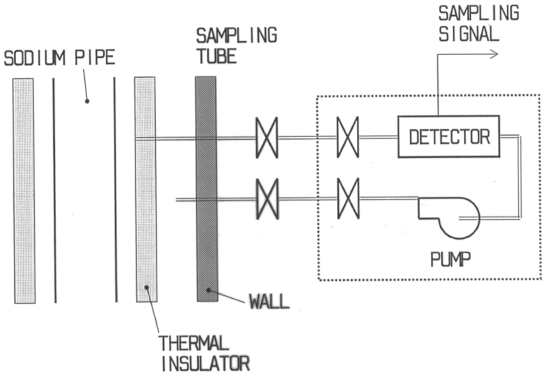

Fig. 2. Outline of the gas sampling system

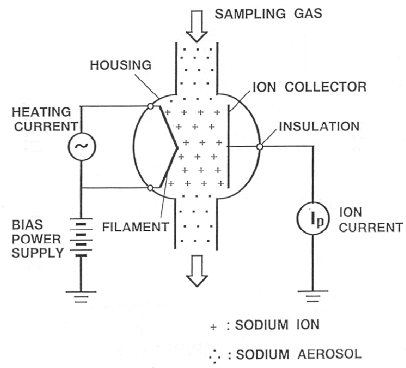

Fig. 3. Outline of the SID

SID is placed in parallel with Differential Pressure Detector (DPD). DPD traps sodium aerosol by the filter, and detects a small sodium leak by measuring the differential pressure of the filter. Also DPD's filter is used to judge a sodium leak by chemical analysis when a sodium leak is suspected.

2. Operation and Maintenance Experience of Sodium Leak Detector(SID)

2.1. Failure contents of sodium ionization detector (SID)

SID was operated between 1995 and 2018, beginning from the test run of Monju until its decommissioning. Regular maintenance, reviews of alarm set point, updating and remodeling of the system were carried out after the 40% output test.

Table 1 shows the maintenance reports issued during the operation period in the maintenance management of the SID detector, classified according to failure contents and causes. Table 2 shows the fault classification of Table 1 applied to the machines constituting the SID system.

Table 1. SID - Issued Maintenance Reports - (Failure Contents and Causes)

No.	Failure contents	Causes	Number of reports
1	Abnormal sound	Aged deterioration	1
2	Black out	External factor（Lightning)	1
3	Criteria deviation	Aged deterioration , Instrument drift	10
4	Decline in sensitivity	Aging	1
5	Dent on the bellows	Human error	2
6	Disconnection	Deterioration	4
7	High suction pressure	Filter Clogging	2
8	Indication variation	Aged deterioration, Design problems, External factor（dust, static electricity, Temperature change, etc.）, Initial variation	10
9	Malfunction	Aged deterioration, Initial variation	14
10	Misalignment (switch)	Aging	3
11	Pump trip	Aged deterioration, wear	8
12	Seat leak	Aged deterioration	1
		Total	57

Table 2. Fault classification of Table 1. According to Machines

Machines	Parts (Failure contents Table 1. No.)	Number of reports	Number of reports (SID unmonitored*)
Control equipment	Internal parts (***3,8***), Relay (***9***), Logic unit (***9***), Logic program (***8***)	7	1
Control switch	Internal parts (***9***)	2	None
Detector	SID Filament (***6***,***8***), Internal parts (***4,8***)	12	7
Filter	Depth filter (*7*)	2	None
Power supply	Power supply unit (***2***), Internal parts (***8***), NFB (***9***)	3	1
Preamplifier	Internal parts (***3***)	2	None
Pressure indicator	Internal parts (***3***), Micro switch (***9***)	3	None
Recorder	Internal parts (***3***,***9***), motor (***9***)	9	None
Sampling pump	Bearing (***11***), Carbon vane (***11***), Internal parts (***1***,***9***)	10	8
Valve	Bellows for solenoid valve (***5***), Limit switch (***10***), Lubricant (***9***), Seat parts (***12***)	7	None
Total	—	57	17

* SID unmonitored: Including the occurrence of a short time (a few seconds) unmonitored condition

From Table 1, 57 maintenance reports on the SID system occurred during the operation period. Among them, there were 17 events were unmonitored by the SID detector (underlined in Table 2.). Of these 17 cases, disconnection of SID filament (4 cases) and trip of sampling pump (7 cases) were included and occurred during the period of 1993-2000.

After the new maintenance programs were applied in 2008, regular parts replacement and equipment inspection based on the maintenance schedule started. Since the continuous improvement of facilities and the introduction of the maintenance programs, the SID unmonitored failure due to internal component failures was not occurred.

2.2. SID problems and countermeasures

SID detects sodium leakage by sensing a fine current increase (0.01～100nA). Therefore, the SID system is susceptible to external factors (thermal, dust, moisture, and so on). The ion current by the SID fluctuated during its operation period, and necessary measures were implemented.

2.2.1. Filament material affecting SID indication values

On October 25th, 2004, after replacing the SID sensors installed to primary cooling system, the SID ion current increased from 0.5 nA, under normal conditions to 6 nA, exceeded the alarm setting value of 5 nA. We immediately confirmed that a sodium leak did not actually occur by analyzing the DPD filter.

After flushing the SID sampling line, the SID was restarted, after that, the SID ion current increased to maximum 20 nA after 13.5 hours from the restart of measurement. Therefore, we replaced the SID sensor with spare parts of old stock (made before 1998). As a result, we confirmed that the SID ion current was stable. Thus, we investigated to identify the cause of the ion current increased.

We analyzed the SID sampling gas (sample No. 1, No. 2) to identify the cause of the increase in the ion current values. The sampled gas was dissolved in pure water or hydrogen peroxide solution and analyzed to measure impurities concentration by ion chromatography. We found that the gas included chlorine, NH_3, NOx and SOx, which is shown Fig. 4, 5.

For the reproduction test, the test gas containing the identified substance was reproduced. However, the test gas did not increase SID ion current significantly.

Based on previous sampling gas experiments, it was presumed that the characteristic of the sensor causes the indication variation. Both SID sensors (made before 1998 and made 2004) were made with same manufacturing and speciation, although there are different years.

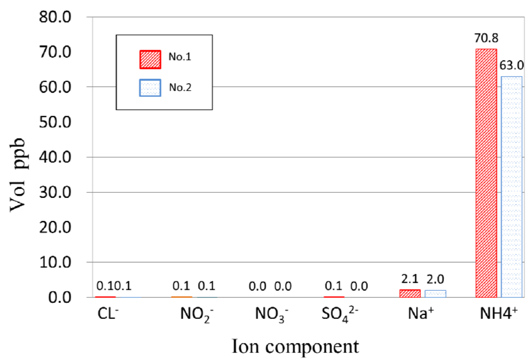

Fig. 4 Analysis of SID sampling gas by ion chromatography (pure water)

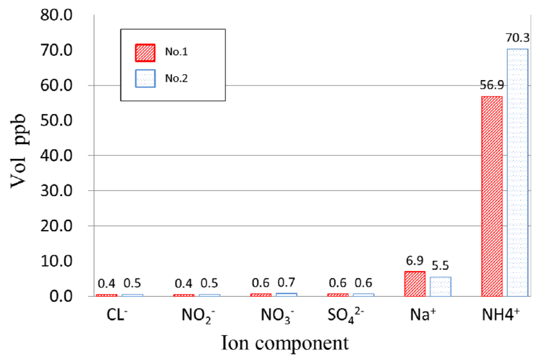

Fig. 5 Analysis of SID sampling gas by ion Chromatography (hydrogen peroxide solution)

The SID sensors have filament using high purity platinum (99.99%). We investigated whether there is any difference in impurities in these filaments. We analyzed the impurities in the SID filaments using ICP-MS (high frequency inductively coupled plasma mass spectrometry). The results are shown in Table 3. From Table 3, it was confirmed that the SID sensor made in 2004 contains more iron and aluminum in comparison to the sensor made before 1998. The purity of the platinum portion of both SID filaments was specified as 99.99%, but the products manufactured before 1998 were in fact purity close to 99.999%.

Table 3. Impurities contained in the SID filaments. (ICP-MS)

	SID sensor with spare parts of old stock (Made 1998)	SID sensor with ion current increasing (Made 2004)	test SID sensor (improved sensor) (Made 2006)
Filament purity	99.99%	99.99%	99.999%
Impurities	Evaluation value wtppb	Evaluation value wtppb	Evaluation value wtppb
Na	1350	93	66
K	1830	20	82
Ca	2850	23	37
Mg	152	204	46
Fe	5670	27600	1630
Cu	1230	1330	386
Ni	2210	1100	686
Cr	323	441	103
Zn	213	486	70
Mn	66	445	20
Al	301	12300	247
Ti	136	78	30
Mo	28	39	24
Co	178	26	6
Sn	61	117	49
Ce	<1	4	<1
W	17	65	2
Pb	742	925	663
Total	17457	45926	4147

The gas sampled by the SID from the nitrogen atmosphere included 0.5% oxygen and moisture equivalent to dew point -10°C. In this condition, no significant correlation between low oxygen concentration variation and SID ion current has been confirmed. Therefore, we investigated the influence of moisture on SID sensitivity. The nitrogen atmosphere was added to moisture and measured by SID to confirm the change of SID ion current. The results are shown in Table 4.

The SID sensor made 2004 had the characteristic that the SID ion current increased when it was passed through an atmosphere containing moisture.

Table 4. Dew point and SID ion current in N_2 atmosphere

Dew point (Td/°C) Measurement condition (N_2 atmosphere)	Ion current (nA) SID sensor with ion current increasing (Made 2004)	Ion current (nA) test SID sensor (improved sensor) (Made 2006)
-55 (dry)	0.30	0.06
-10 (SID sampling gas)	0.38	0.07
0	0.44	0.07
10	0.52	0.08

A sensor containing a large amount of aluminum or iron as an impurity is more sensitive to moisture than a normal sensor, and it is inferred that compounds on the sensor surface react with aerosols more than platinum, resulting in increased ion current.

Based on these results, we then examined countermeasures for SID ion current increase. In the plant environment, it is difficult to reduce moisture, so we tried to reduce impurities of aluminum and iron in the SID sensor.

However, it was difficult to get rid of those impurities selectively, Therefore, high purity platinum sensors and the test SID sensor made for evaluation (made 2006: Pt 99.999%) were adopted. From Table 3, we confirmed that impurities of iron and aluminum contained in the test SID filament were significantly smaller.

From Table 4, the test SID sensor was not significantly affected by the moisture. Therefore, we reduced impurities by setting the filament purity specification to 99.999%. As a result, we achieved reducing indicator value variation.

2.2.2. SID ion current increased by temperature change

The liquid sodium is controlled by heaters and kept stable at about 200°C in the piping even when the reactor is stopped. When sodium is drained for maintenance, these heaters are turned off.

On December, 25th, 2015, the maintenance of machines was completed and the piping around the reactor was heated to 200°C to fill the liquid sodium. Then, the SID ion current increased and exceeded the alarm set value of 1 nA, and a SID leakage alarm was issued. At this time, we analyzed the DPD filter installed together with SID and confirmed that sodium leakage had not occurred. The cause of this SID ion current increased was assumed to be similar to the case in 2.2.1.

It was confirmed that the increase in the SID ion current correlated with the temperature change, so we adjusted the set voltage of the pipe preheating heater as s provisional countermeasure.

After this countermeasure, the SID indication never exceeded the alarm set value of 1 nA, and the false alarms was suppressed.

2.2.3. SID ion current variation due to door operation

On September 20th, 2012, it was found that the SID ion current decreased. In the investigation, we checked the accuracy of the related instruments, and we found looseness of the screws, poor contact of the coaxial cable connector, but no abnormality was found. After that, we confirmed the variation of SID indication occurred at the time of the opening and closing of the panel door in the on-site console panel for SID system.

Placing the electrostatically charged plastic plate close to the coaxial cable, the SID ion current decreased. The reduced amount of ion current was in the range of leakage current (10 ~ 44 pA) of the preamplifier circuit. Therefore, it was presumed that the leakage current of the substrate decreased due to charging of the preamplifier circuit.

As a result of the investigation, the on-site console panel was installed on grating, the pressure variation inside the on-site console panel was generated by opening and closing the door, and the structure was such that the air entered and exited from the grating bottom shown in Fig. 6.
It was suspected that the wind generated by the entrance and exit of this air came into contact with the surface of the coaxial cable and affected the coaxial cable for instance the air stream generates static electricity (electric charge) on the surface of the coaxial cable due to the friction between the air and the sheath (skin), so the weak current flows to the signal path. Static electricity caused by wind

friction affects the core material through which weak current flows with the following mechanism.
(1) Wind contacts the surface of the sheath of nonconductor, induced polarization occurs due to friction
(2) Electrostatic induction occurs with the outer conductor
(3) Inductive polarization occurs in insulator
(4) Electrostatic induction occurs in the inner conductor, which affects the minute current of the SID

Following the occurrence of these issues, the following countermeasures were implemented shown in Fig. 7.
(1) In order to suppress static electricity on the cable surface from affecting the cable core material, it was exchanged for a cable with a semiconductor layer between the insulating layer and the conductive layer.
(2) In order to be able to check the influence of indicator fluctuation, we raised the zero point (15→50 pA) and added the alarm set value for decreasing SID ion current.
(3) Vibration was generated due to contact with the coaxial cable, and there was a possibility of indicator fluctuation. Therefore, a cover was attached to the detector which fixed this problem.

As a result of facility improvement, we succeeded in suppressing SID indication fluctuation.

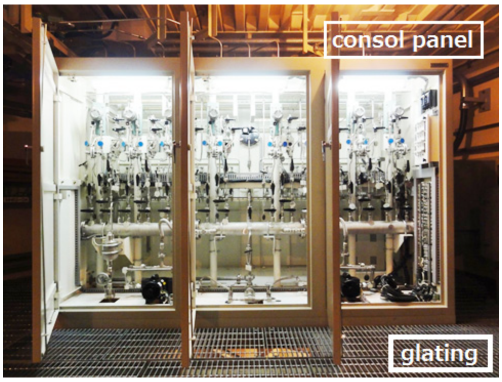

Fig. 6 SID console panel

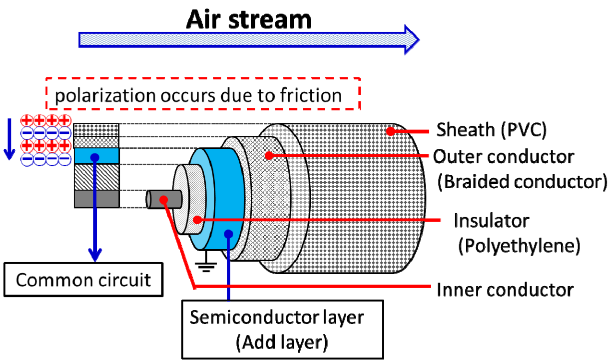

Fig. 7 SID improvement cable

3. Conclusion

We have implemented measures and modifications to the SID system, as the system detects fine currents and is influenced by impurities in filaments and electrification caused by draft friction. The SID system was stably maintained. Any critical malfunctions did not occur in the measuring instruments, and we were able to obtain valuable technical expertise in operating the SID system in the actual plant stably for a long time.

In order to operate SID system stably, it is necessary to introduce mechanisms to exclude unstable elements for fine currents. Also, we need to develop and demonstrate SID system which is able to detect sodium selectively and does not respond to moisture in the future.

Acknowledgement

The authors would like to thank Yoshihisa Kaneko (JAEA), Shin Usami (JAEA), Tsutomu Irie (JAEA), Shuichi Takeda (Hitachi, Ltd) and Naoto Motooka (MHI ,Ltd) for useful discussion and advice.

References

[1] K. Morizono:, "Studies on applicability of smoke sensors as a sodium leak monitoring system", ICONE-10 (2002/04).