Development of Failed Fuel Detection System for HANARO Fuel Test Loop

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1. Introduction

FTL (Fuel Test Loop) is a test facility which could conduct fuel irradiation test at HANARO reactor [1][2]. The FFDS (Failed Fuel Detection System) is installed in the FTL for detection of test fuel failure. The signals from the FFDS are interconnected with HANARO reactor protection system via FTL protection panels for reactor trip. In this paper, a design, manufacturing and functional test results of the FFDS are introduced.

2. Development of FFDS

The FTL is composed of an IPS (In-Pile test Section) and an OPS (Out Pile system) [1][2][3][4]. The IPS is to be loaded into the IR-1 position in the HANARO core. This implies that the environment around the IPS is subjected to a high neutron flux (Thermal neutron flux : 1.2×10^{14} n/cm^2·sec, Fast neutron flux : 1.6×10^{14} n/cm^2·sec). The OPS contains pressurizer, cooler, pump, heater and purification system which are necessary to maintain the proper fluid conditions. In addition, the OPS contain an engineered safety system that could safely shutdown both HANARO and the FTL if an accident occurs. The FTL simulates the irradiation conditions of the commercial power plants such as pressure, temperature and neutron flux levels to conduct for the irradiation and thermo hydraulic tests. The FTL coolant is supplied to the IPS at the required temperature, pressure and flow conditions that are consistent with the test fuel.

2.1 Design and manufacturing of FFDS

The FFDS is used for detecting of the delayed neutron emitted from the fission products released into the main cooling water system caused by test fuel failure. [5]. The FFDS channel is implemented by three (3) BF3 detectors and required electronics such as amplifiers and rate meters. The FFDS is designed as nuclear safety grade, quality class "Q", and seismic category "I". The FFDS is accomplished by monitoring delayed neutron level on the main cooling water pipe in an effective manner. Whenever the delayed neutron levels due to the fission products concentration in the main cooling water system reach a predetermined value, this system will be used to trip the reactor. This FFDS signal (high-high) will be used to trip the reactor protection system via FTL protection system.

Some of the typical delayed neutron precursors to be released from the failed fuel are: Br-87, I-137, I-138, I-139, etc. The main cooling water pipe area where the BF3 detectors are to be installed will be in a very high gamma background. The maximum N-16 background is expected to be 7.61×10^{-3} rad/sec at the pipe surface. The BF3 detector will be mounted on a 4-inch diameter main cooling water line of IPS outlet.

Amplifier consists of a pre-amplifier circuit module and a single channel pulse height analyzer. The system is designed for;

- High-energy resolution
- Low drift of zero or gain over the long term
- Easy set-up and adjustment
- Provision to take out a raw signal to be used as an input to an external device like multi-channel analyzer

The pre-amplifier is compatible with the requirements of the detector and rate meter. The rate meter shall display the pulse rate in count per second with a logarithmic scale, spanning at least five decades. The rate meter has the following displays:

- Measured neutron level in cps – logarithmic digital
- High and high-high alarm set point
- Status for high, high-high and equipment failure alarm

If no neutron pulse is detected for a fixed time period, the fail alarm is initiated and both visual and audible alarms are energized. The rate meter shall have following outputs:

- Range: 1 x 10^{-1} ~ 1 x 10^{5} cps
- 0~10VDC, 4~20 mADC outputs for the delayed neutron

This output covers full range of the system, which will be fed to the control computer system (for a recording purpose) via FTL safety indicator panel (for monitoring purpose). The following signals are transmitted to the computer system.

- High and high-high alarm relays for each signal
- Equipment failure alarm relay

The high and high-high alarm relays are de-energized when each signal reaches/exceeds the alarm set point. Also, the equipment failure alarm relay is de-energized on failure of the delayed neutron channel. Fig. 1 shows the signal flow diagram for FFDS.

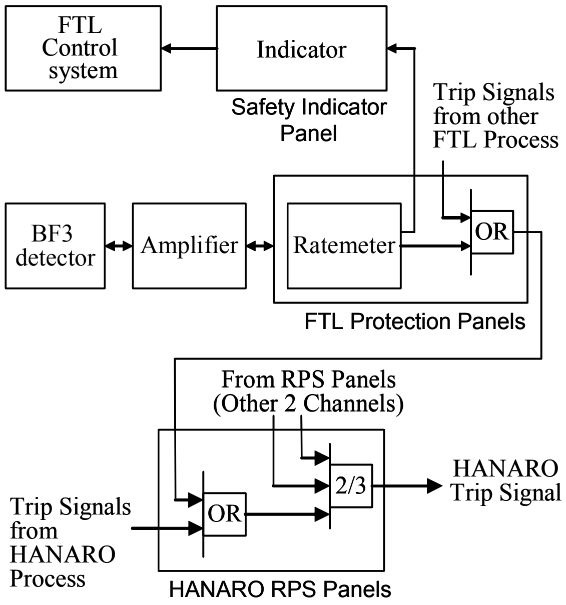

Fig. 1. Signal flow diagram.

2.2 Functional test

The following functional tests were performed to verify the design performance.

- High voltage setting
- Discriminator threshold setting
- Real time clock setup
- Lamp test
- Analog output check
- High (High-High) alarm setpoint adjustment
- High (High-High) alarm
- Alert alarm adjustment
- No count failure testing, etc.

The analog outputs for the 0 ~ 10VDC and the 4 ~ 20mA were tested. The log output is calculated from the following equations,

$$True\ voltage[VDC] = 1.667\log(Observed\ cps/0.1)\ , \quad (1)$$

$$True\ current[mADC] = 2.667\log(Observed\ cps/0.1) + 4\ , \quad (2)$$

$$\%\,error = \frac{Observed\ OUTPUT - True\ Output}{True\ Output} \times 100\ . \quad (3)$$

Table 1. Test results for analog outputs.

	Output 1	Output 2	Output 3
Observed cps	$2.30\times10^{+0}$	$2.50\times10^{+0}$	$2.30\times10^{+0}$
Observed output	2.280VDC	2.334VDC	7.657mADC
True output	2.270VDC	2.330VDC	7.632mADC
% error	0.44%	0.17%	0.328%

Table 2. Test results for current outputs.

Observed rate (CPS)	Observed output (mA)	Expected output (mA)	% Error
1.00×10^{-1}	4.014	4.000	0.350
$1.00\times10^{+0}$	6.691	6.667	0.360
$1.00\times10^{+1}$	9.368	9.334	0.364
$1.00\times10^{+2}$	12.040	12.000	0.333
$1.00\times10^{+3}$	14.720	14.670	0.341
$1.00\times10^{+4}$	17.390	17.340	0.288
$1.00\times10^{+5}$	20.050	20.000	0.250

Each output provides a signal corresponding to the specified measurement rate of 1.00×10^{-1} to $1.00\times10^{+5}$ cps. The functional test results for analog output are given by Table 1 and 2. The test results show that the % error is within ±0.5%. And all performances are satisfied through the functional tests.

3. Conclusion

A design, manufacturing and functional test results for the FTL FFDS were introduced. The FFDS was designed as nuclear safety grade, quality class "Q", and seismic category "I", and qualified by the safety regulation of the IEEE Standard-603 and qualified by IEEE std-323 and IEEE std-344. The performance of the FFDS was qualified by the functional tests. The FFDS will be applied to HANARO FTL system after installation and hot functional test.

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