Thermal Transient Test Facility for Structures


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Abstract

Power Reactor and Nuclear Fuel Development Corporation (PNC) has constructed a new test facility "Thermal Transient Test Facility for Structures" (TTS). The major objectives of the testing are to validate or establish structural design criteria for FBR components, and to develop various structures for thermal mitigation. TTS is capable of imposing repetitive severe thermal loadings and mechanical loadings independently or simultaneously on complex, medium-sized models at high temperatures. The test is continued until failures occur in a model. TTS is made up of hot and cold sodium loops of 6 in. in diameter, a mechanical unit of two 20 ton-actuators, a test section for accommodating models, and data acquisition system.

1. Introduction

To establish well-qualified and reliable high temperature structural design rules, a great deal of material tests are needed for investigating deformation behaviors and strength at high temperature. The development of design analysis methods is also required for predicting the behaviors of structural components of complicated geometry under various loading conditions. The high temperature design criteria for FBR components have been based on the results of such material tests and analyses, and structural component tests described below, and the existing design criteria in non-creep and creep regime, and also experiences of usage of FBR components.

Structural component tests for simple geometry such as beams and tubes play an important role for validating and modifying the design analysis methods and the design criteria. Considerable amounts of structural component tests at high temperatures have been conducted under mechanical loadings at O-arai Engineering Center of PNC. Thermal loadings are, in general, predominant in FBR components. As for component tests under thermal loadings, tests for simple structures such as straight pipes, curved pipes and cylindrical shells have been performed at PNC and elsewhere. In FBR components, structures including a variety of structural discontinuities such as nozzles, Y junctions, tapering structures and various kinds of welded joints are widely used, and combined thermal and mechanical loadings are applied to structures. Complicated stress states are generated by the interaction of primary, secondary and peak stresses, including elastic follow-up effects. Such stress states are realized in rather complicated structural models. Strength of structures are effected by fabrication methods including forming, welding and surface conditions. Thus,
medium-sized structural models with typical structural discontinuities are required for realizing such stress states in service and simulating fabrication procedure of actual components.

The design criteria intend to guard structural components against failures. To validate the design criteria, failure tests of components are requisite because inherent design margin for failure incorporated into the design criteria can only be clarified by the results of such tests.

Thermal loadings in FBR plants are very severe and various types of structures are adopted for mitigating thermal loadings. The effectiveness and structural integrity of such structures should be demonstrated by thermo-hydraulic and strength tests, since special structures are generally used for thermal mitigation.

Furthermore, it is often required to demonstrate the structural integrity or excellent function of specific critical components even under more severe loading conditions than those encountered in actual FBR components.

When components happen to experience troubles in service, the structural integrity of such components and effectiveness of repairing methods for them should be evaluated by applying loadings simulating actual ones to a model representing the real components.

Based on the above background, the testing satisfying the following requirements is needed.

(a) Testing at high temperature
(b) Testing under combined repetitive severe thermal and mechanical loadings
(c) Testing using medium sized complex structures representing real components
(d) Failure test

TTS has been designed to meet all the requirements above. The objectives of the testing by TTS are summarized as follows.

(1) Validate current structural design criteria
(2) Develop improved design criteria for future FBR plants
(3) Develop more reliable and cheaper structures of FBR components
(4) Demonstrate structural integrity of critical structures
(5) Evaluate structural integrity of specific components in service or develop reliable methods for repairing components

2. Constitution and Capability of TTS

TTS is made up of sodium loops and their control system, a mechanical force unit, a test section and data acquisition system. The bird’s-eye view of TTS is shown in Fig. 1.

(1) Sodium loops and their control system

Sodium loops supply sodium to a test article and impose thermal transients necessary for testing. A flow diagram of sodium loops is shown in Fig. 2. Sodium loops are made up of a hot loop, a cold loop, a purification system, drainage-charge lines and gas lines.

The hot loop supplies hot sodium to a test article. Hot sodium circulates through the hot sodium head tank (V-1), the test article (T), the hot sodium dump tank (V-3), and the head tank (V-1). Hot sodium flows through a by-pass line having the switch valve (SV-105), when cold sodium flows through the test article. The cold loop is made up nearly symmetrically with the hot loop. Cold sodium circulates through the cold sodium head tank (V-2), the test article (T), the cold sodium dump tank (V-4), and the head tank (V-2). Hot and
cold sodium supplied to the test article is switched repetitively by switch valves. At hot shock, EV-101 and EV-103 are opened and EV-102 and EV-104 are closed. At cold shock, these valve conditions are reverse. Flow rate of sodium are controlled automatically by the flow control valve FCV-101 and FCV-102 using signals from flow meters FRC-101 and FRC-102, respectively. The temperatures of sodium in hot and cold loops are kept constant by the hot and cold sodium heaters ((H-1) and (H-2)) and the cold sodium cooler (C-1). Each hot and cold loop has respectively five and three expansion joints to absorb thermal expansion of pipes, and to reduce the piping length. The purification system is designed so that hot and cold sodium may be purified independently or simultaneously. Sodium purity is measured by the plugging meter (PL). The loops are controlled automatically by a computer and monitored and operated concentrically using color CRT and keyboard in the central control room.

(2) Mechanical force unit

Two electro-hydraulic actuators are used to impose the mechanical load on the test article. Each actuator controlled independently has the capacity of 20 ton. The maximum stroke and cyclic speed are respectively ±100 mm and 0.4 Hz/±100 mm when one unit works and 0.2 Hz/±100 mm when two units work. The actuator can apply load to the test article from any desired direction using the appropriate attachments.

(3) Test section

The test section consists of a test bed and a semi-air-tight test cell accommodating the test article and the mechanical force units. The test bed is 1.2 m in height, 5.4 m in width and 9.6 m in length and is rigid frame structure. The stainless steel liners are laid on the test bed so that leaked sodium may not spread out from this cell. The test cell has fire-proof walls and three hatches at the ceiling which enable to exchange the test article and sodium components.

(4) Data acquisition system

The signals of temperatures, strains and displacements obtained from the test article are sent to a mini-computer in the central control room, converted to digital signals and transferred to a disk unit. These data can be monitored at the graphic display. The maximum sampling speed is 30 ch/30 msec.

3. Specification of TSG

The design life of this facility is 15 years, but that for some specific components subjected to severe thermal loadings is 1 to 5 years.

(1) Sodium loops

<table>
<thead>
<tr>
<th>Hot loop</th>
<th>Cold loop</th>
</tr>
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<tbody>
<tr>
<td>Design temperature</td>
<td>670 °C</td>
</tr>
<tr>
<td>Design pressure</td>
<td>5 kg/cm²C</td>
</tr>
<tr>
<td>Maximum operating temperature</td>
<td>650 °C</td>
</tr>
<tr>
<td>Most severe thermal transient condition up ramp</td>
<td>from 250 °C to 650 °C in 10 sec.,</td>
</tr>
<tr>
<td>down ramp</td>
<td>from 650 °C to 250 °C in 10 sec.</td>
</tr>
<tr>
<td>Time for one cycle of transient</td>
<td>approximately 60 min/cycle for a thick walled (≤50 mm), medium-sized (≤1 m in diameter and 3 m in length) vessel model</td>
</tr>
<tr>
<td>Main loop pipe diameter</td>
<td>6 inches</td>
</tr>
<tr>
<td>Sodium inventory</td>
<td>approximately 40 m³</td>
</tr>
</tbody>
</table>

Materials: type 304 stainless steel
(2) Test section
   test cell size: 9.2 m in length, 5 m in width and 8.5 m in height
   test cell structure: semi-air-tight
(3) Data acquisition system
   Maximum numbers of data acquisition channel: 240

4. Design Standard for TTS Sodium Loops
   Some components of TTS sodium loops are subjected to severe thermal loadings.
   Appropriate design standard is needed for the design of the TTS sodium loops. The design
   standard used for nuclear reactor plants containing radioactive substance has too much safety
   margin for the TTS sodium loops which are test facility containing non-radioactive substance.
   Then, the design standard for TTS sodium loops was established by aiming at reducing reason-
   ably the design margin of "Monju" Design Guide. That was made by examining again the
   coefficients of creep strain equations, creep rupture curves and design fatigue curves based
   on the strength data of SUS304 and calculation methods of strain range and creep damage rule.
   The comparison between the life obtained from creep-fatigue tests of the Japanese type
   304 S.S. and the predicted life by the TTS design standard is shown in Fig. 3. It is clear
   that the TTS design standard is conservative. The similar comparison is depicted in Fig. 4
   for the strength data of pipe specimen subjected to thermal loadings. It is concluded that
   the life of piping structure under thermal loading can be predicted with adequate safety
   margin by this standard. From these results, TTS standard appears to be appropriate for the
   test facility.

5. Examples of Design of Components
   Some components near the test article are subjected to nearly as severe thermal loadings
   as the test article. Therefore, the measures to mitigate the thermal loadings, were adopted
   for the components of TTS loops. The typical examples are shown in this chapter. Expansion
   joints were used to reduce the thermal expansion stresses of piping system. The sectional
   plan of it is shown in Fig. 5. The expansion joint has double convolutions. Between the
   boundary and back-up bellows, inert gas were enclosed and a leakage detector was attached to
   detect the sodium leakage quickly. A flow sleeve was provided inside the inner convolution
   to straighten the sodium flow and to mitigate the thermal loadings.
   An example of counter-plan for hot sodium dump tank is shown in Fig. 6. Mixing pipes
   were installed inside the tank to avoid the initiation of thermal stratification by cold
   sodium flowing through inlet nozzles. These mixing pipes are made up of a circular pipe and
   a straight pipe having many holes. Cold sodium through these holes is mixed fully in this
   tank. A thermal liner installs at the bottom of the tank for cold sodium not to flow
   directly to the vessel wall.

6. Plan of Test
   The schedule of the tests is shown in Table 1.
   (1) Thermal transient test of "Monju" vessel model
   This is a test to obtain the strength data of various structure of "Monju". The test
   article is shown in Fig. 7. This model incorporates typical structural discontinuities of
   FBR components such as inlet and outlet nozzles a Y piece, a tapering structure and welded

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joints of thick walled vessel. The configuration was decided to have nearly the same lives for such structural discontinuities by means of preliminary thermo-hydraulic and stress analyses and strength evaluation. The strength data obtained in this test will be compared with the life predicted by "Hokuryu" Design Guide and validates the Design Guide by confirming inherent design margin to failure.

(2) Thermal transient test of expansion joint

This test will be carried out as a feasibility study of the expansion joints used in future LMFBFRs. Especially the strength of the hardware of the joint under thermal loadings is the main objective. The concept of the test article is shown in Fig. 8.

(3) Thermal transient test of thermal mitigation model

In the future large LMFBFRs, the size and thickness of various components will become larger and will become more severe for structural strength. Aiming at further reduction of construction cost of plants, it is required to develop more reasonable thermal mitigation structures. The objective of this test is to confirm the thermal mitigation characteristics and structural integrity of thermal mitigation structures.

(4) Others

Various thermal transient tests will be carried out for components and structures for developing more improved design evaluation procedures and design criteria for future large LMFBFR plants which will be subjected to more severe loading conditions.

Acknowledgements

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Fig. 3 Verified result of TOS design standard by Jeppe material data

Fig. 4 Verified result by thermal transient strength data of pipes

Fig. 5 Sectional plan of expansion joint

Fig. 6 Example of cross-plan for hot sodium dome tank

Fig. 7 "Marugo" vessel model

Table 1 Test schedule

<table>
<thead>
<tr>
<th>Test Article</th>
<th>FY 1984</th>
<th>FY 1985</th>
<th>FY 1986</th>
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<tbody>
<tr>
<td>Trial Test</td>
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<tr>
<td>Vessel Model for &quot;Marugo&quot;</td>
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<td></td>
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<tr>
<td>Expansion Joint Model</td>
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<tr>
<td>Thermal Insulation Model</td>
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Fig. 8 Expansion joint model