RESEARCH AND DEVELOPMENT OF BELLOWS FOR LMFBR IN JAPAN

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Abstract

The bellows is employed as a useful mechanical element with its flexibility and imperviousness to liquid and gas in the system in which such chemically active substance as sodium is handled.

Since the early time of development of Japanese LMFBR, bellows have been used e.g. for the shaft seal of small sodium valves.

Bellows are employed in the fast experimental reactor JOYO which is now in operation and the fast prototype reactor MONJU whose desing program is in final stage at the following parts:

- control rod drive mechanism,
- intermediate heat exchanger,
- small valve,
- mechanical penetration assembly of the containment boundary,
- outer piping of the double-walled primary system (for JOYO only).

In addition, the application of bellows as thermal expansion joint to the main piping system is under consideration for future FBRs.

This paper outlines the research and development work on bellows for the FBR use in Japan.

1. Introduction

Development of Japanese LMFBR started as a national project in 1967. PNC which takes charge of actualization of this program has constructed the experimental reactor JOYO of 100 MWt of ultimate power output and designed the prototype reactor MONJU of 300 MWe. A demonstration reactor of about 1000 MWe is expected to follow them. Figure 1 shows the master schedule of the LMFBR development program in Japan.

JOYO has accomplished the second stage of nominal power of 75 MWt in July 1979 and will be operated with 100 MWt of power level for the fuel irradiation use in a few years, while MONJU is now in the final stage of the preparatory design.

The bellows, that is a mechanical element widely used in various fields of industry, is used as well in high-temperature sodium or cover gas environment in the cooling system of an LMFBR.

Various kinds of bellows, in size and in type (formed or welded), are applied to the sodium system of JOYO and to other sodium test facilities with successful operational experiences.

Besides, experimental and theoretical studies are in progress on some types of bellows mainly for the MONJU design.

2. Application of bellows in the LMFBR systems

Bellows are used in general for the following purposes:

(1) flexible sealing device,
(2) thermal expansion absorber.

In the field of LMFBR as well, bellows are used for both the above purposes.

In the cooling systems of JOYO, bellows are applied to the control rod drive mechanisms (CRDMs) and to small valves as sealing devices and to the intermediate heat exchangers (IHXs) as expansion absorber.

Bellows expansion joints are also used out of the sodium system, i.e. in the outer piping of the double-walled primary system and in the mechanical penetration assemblies of the containment boundary.

The application of bellows in MONJU is for same parts as in JOYO with exception of absence of the double-walled primary piping.

In some conceptional designs of the demonstration reactor, application of bellows expansion joint for main cooling system piping was investigated but it is not applied to the present reference design.

Figure 2 illustratively shows the location of bellows in JOYO and MONJU.

3. History and Current Status of Research and Development Work

The application of bellows to sodium system started with laboratory-scale apparatuses in the early stage of sodium technology development in Japan.

It is since sodium test facilities equipped with bellows-seal sodium valves were built in O-arai Engineering Center, PNC, that a number of bellows have come into regular service.

The accumulation of operation experiences and improvements on bellows in sodium valves has largely contributed to the design, fabrication and handling of various bellows for sodium systems.

In the research and development work for JOYO, performance test and endurance test were carried out in sodium on the prototypes of stroke bellows and latch bellows for CRDM prior to the fabrication of the CRDM assembly.

A preliminary performance test has once been carried out on a model of bellows expansion joint in order to look for the possibility of applying to JOYO main piping system. This concept is, however, not applied to the present JOYO design.

Bellows used as expansion absorbers for the IHXs and the outer piping of the double-walled primary system of JOYO were judged by Kellogg's formula.

These components have successfully brought about operational results in the JOYO plant for more than three years.

Research and development of bellows to be used the MONJU components are being performed in almost same manner as in that of JOYO.

In parallel with the performance test and endurance test of some kind of prototype of CRDM assemblies, carried out were experimental study on dynamic behavior and fatigue strength of the CRDM bellows and theoretical presumption on stress distribution and creep failure by using inelastic analysis.

Metallurgical and fatigue tests are being performed on the full-size prototypes of the MONJU IHXs' bellows and elastic analysis on them is in progress using the finite element method for various mode of load.

Strength evaluation was made by using Kellogg's formula for the bellows which are to be applied to the mechanical penetration assemblies at the containment boundary in MONJU as well as JOYO.

Bellows as thermal expansion absorber, on which the research and development had made little progress after the above-mentioned preliminary test, was again investigated in the conceptional design of the demonstration reactor.

Figure 3 and Table 1 show a drawing and a specification proposed on that occasion respectively.

A test is in progress for providing the feasibility of application of bellows as a dilatation compensating device. For this purpose, a test section for bellows of 12 inch in diameter was attached to one of the existing sodium loops in O-arai Engineering Center.

An investigation is made on the reliability of bellows for piping system by means of the theory of probability.

A test loop named Small Bellows Test Loop (SBTL) was built in O-arai Engineering Center in 1978 for the purpose of fundamental research and development on small bellows to be applied mainly to valves.

This apparatus permits a number of bellows to be exposed to sodium under common condition and tested in sodium on fatigue behavior at a time.

Large numbers of bellows seal valves with various sizes of 1/2 in. to 8 in. are now in service in the sodium test loops in O-arai Engineering Center.

In order to take out information as much as possible of numbers of service experiences of the bellows seal valves a team is organized for making inquiries about failed valves.

In this activity, more precise evaluation of the reliability of bellows will be possible by statistically treating the information on valve troubles.

Tables 2 and 3 show the test items of above-mentioned R and D work on bellows and the test facilities for bellows respectively.

4. Prospect of Application and Development of Bellows

As mentioned hitherto, the research and development work on the bellows in Japan has been performed with the intention of applying mainly to sodium valves, CRDMs and IHXs.

The development of bellows will continue to be done for same parts of components and in same manner as the above toward the demonstration reactor and further ones. Few difficult problems on scale-up appear to remain to be solved.

The most important subject for the future seems to be the application of bellows to the main piping system as a thermal expansion absorber. This will bring in a large economical merit of plant simplification.

Constant effort of research and accumulation of service experiences are needed to accomplish the practical use of bellows for the main piping systems of LMFBRs with adequate reliability.

Table 1. Main Features of Bellows Expansion Joints Proposed for a Demenstration Fast Breeder Reactor

	Seal Bellows (Outer Bellows)	Backup Bellows (Inner Bellows)
Working stroke	50 mm	ditto
Inner dia. × Outer dia.	425 mm × 485 mm	365 mm × 415 mm
Thickness of disc	0.6 mm	ditto
Number of disc	100	80
Material of bellows	SUS 304L Stainless steel	ditto
Material of casing and piping	SUS 304 Stainless steel	ditto
Free length	350 mm	256 mm
Spring constant	1.4 kg/mm	2.5 kg/mm
Effective area	1,625 cm²	1,194 cm²
Fluid outer side	Liquid sodium	Argon gas
inner	Argon gas	Air
Pressure in service	2 kg/cm²	0.5 kg/cm²
Design pressure	5 kg/cm²	ditto
Test pressure	8 kg/cm²	ditto

Table 2 Test Items of R & D Work on Bellows

		CRDM	VALVE	I HX	PIPING	BOUNDARY
JOYO	TEST	Mock-up (function, endurance)	Experience at OEC			
	ANALYSIS	Evaluation by K eq.	Evaluation by K eq.	Evaluation by K eq.	Evaluation by K eq.	
MONJU	TEST	Mock-up (function, fatigue)	Material Mock-up (corrosion, fatigue, endurance)	Mock-up (static, fatigue)		
	ANALYSIS	Inelastic (max. stress, creep damage)	Evaluation by K eq.	Elastic (stress distr., contact)		Evaluation by K eq.

K eq. =KELLOGG's equation

Table 3 Test Facilities for R & D on Bellows

	FACILITY		TEST ON BELLOWS	
	NAME	MAIN FEATURES	COMPONENT TO WHICH BELLOWS IS APPLIED	TEST ITEMS
1	Small Bellows Test Loop	In-sodium, 12 fatigue test rigs Static test rig.	Valve (Formed and Welded bellows)	Fatigue test, Corrosion test
2	Large Bellows Test Facility	In-sodium, One fatigue test rig	IHX (Formed bellows)	Functional test, Fatigue test
3	Dynamic Test Equipment	In-air, In-water	CRDM (Welded bellows)	Dynamic behavior test
4	Cyclic Endurance Test Apparatus	In-sodium	CRDM (Welded bellows)	Endurance test
5	Pump Test Loop (by-pass loop)	In-sodium	Expansion Joint	Function test

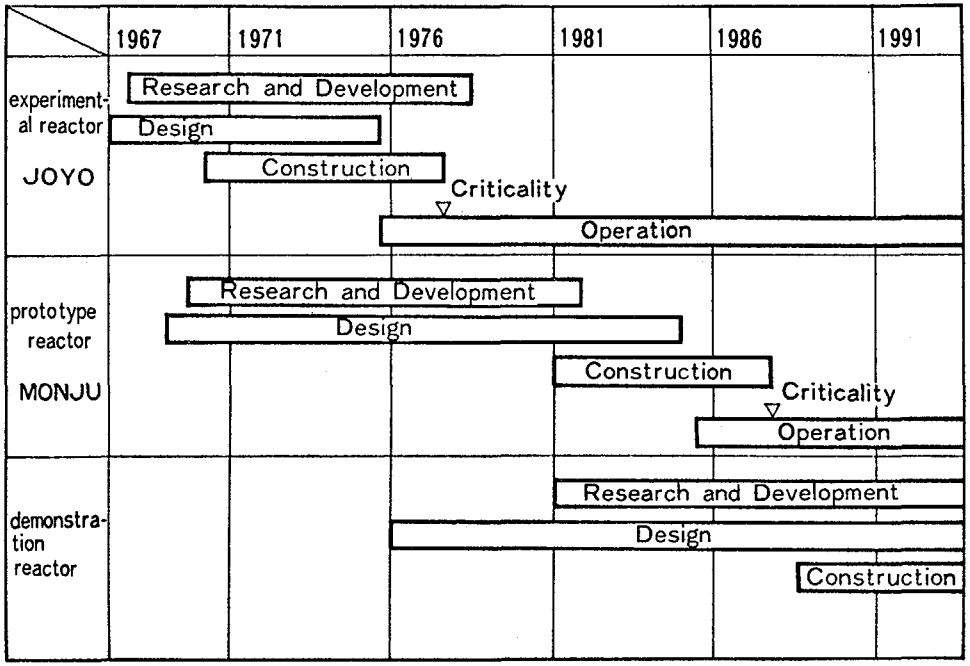

Figure 1 LMFBR Development Program in Japan

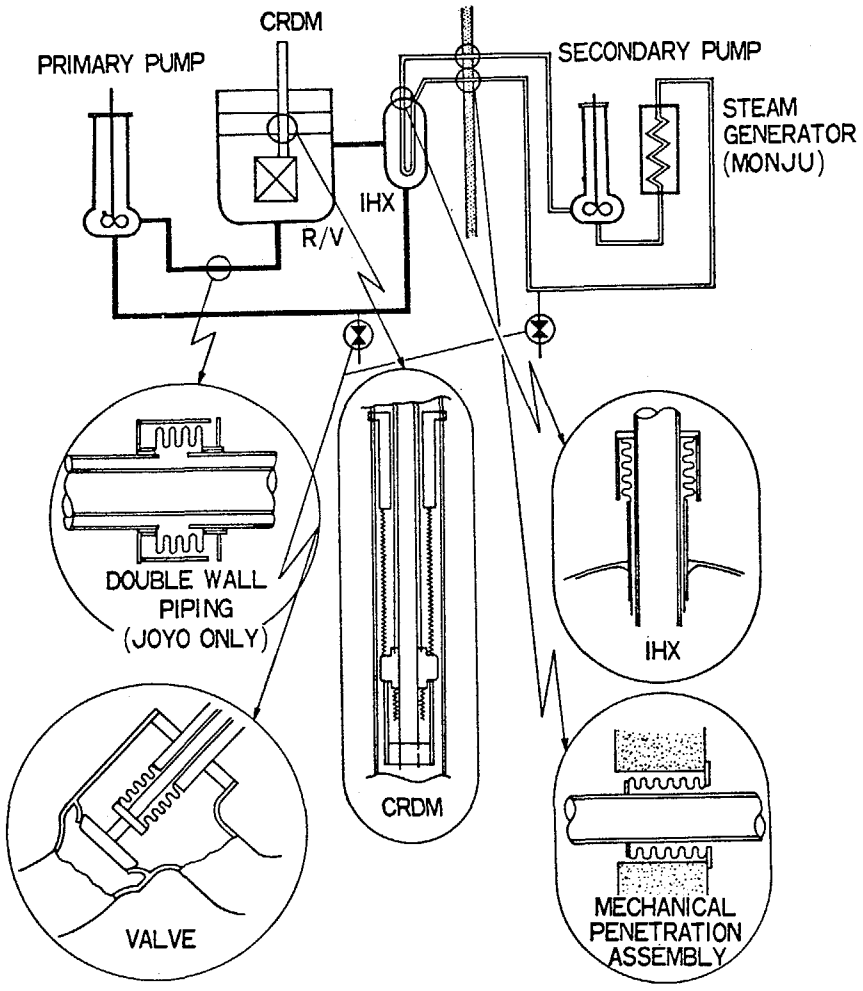

Figure 2 Illustration of Application of Bellows for JOYO and MONJU

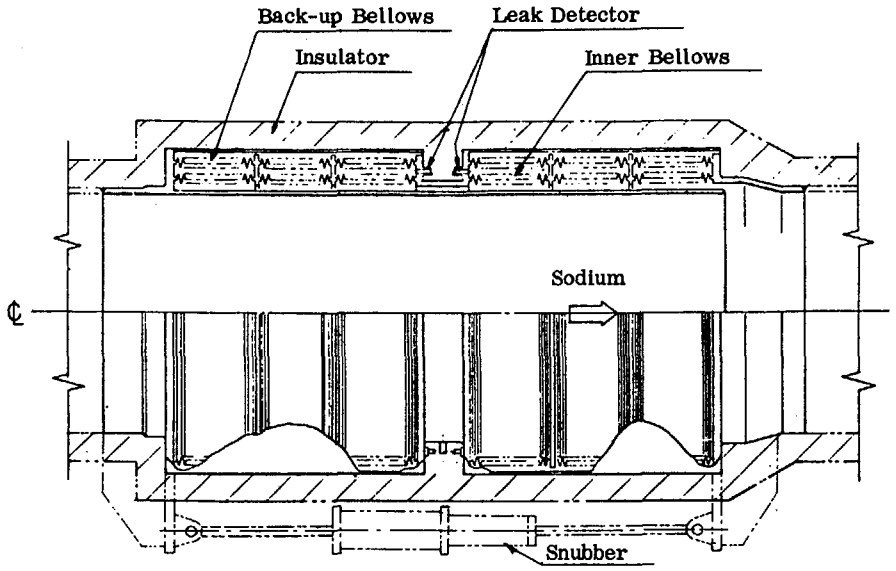

Figure 3-(1) Inner Pressure Type Bellows Expansion Joint

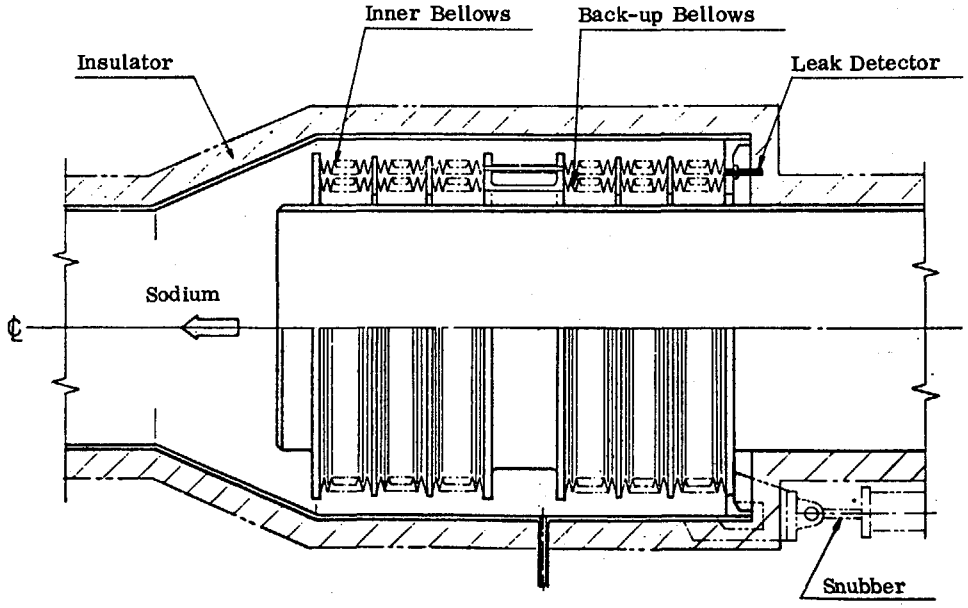

Figure 3-(2) Outer Pressure Type Bellows Expansion Joint

BELLOWS FOR CONTROL ROD DRIVE MECHANISMS OF "MONJU"

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Abstract

The full mock-up operation test of Control Rod Drive Mechanism (CRDM) for "MONJU" have been carried on since 1972 in OEC of PNC.

Welded type bellows were adopted for CRDM as the boundary between sodium and atmosphere.

In design, two different locations were considered for bellows, one in sodium and the other in argon gas with sodium vapor and some experiences on the bellows have been obtained.

Besides the prototype tests of CRDM, several R & D on CRDM bellows, such as environment effect test and endurance test are conducted.

1. Design

1.1 Introduction

The design work for control rod drive mechanism (CRDM) of "MONJU" is entrusted separately to three Japanese manufacturers by PNC. PNC plays the role of finalizing the design of CRDM by the contribution of the R & D work in which PNC strongly participates and also the experience gained from the construction and operation of "JOYO".

In the present "MONJU" design, two types of bellows are considered for the primary seal of the CRDM; namely, the stroke bellows for sealing between upper guide tube and drive shaft and the gripper bellows for sealing between drive shaft and gripper actuator rod. They are all nesting type welded bellows, but have several different design points in their details.

This chapter deals with the design philosophy and two typical design examples of bellows for CRDM of "MONJU".

1.2 Design Philosophy

One of the most interested thing for the design of the bellows is to decide the position where the bellows should be installed. The following three positions for the bellows