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Manufacture and test of seismic bellows for ITER magnet feeder

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HIGHLIGHTS

- The design of the double bellows was iterated with the results of analysis based on the Expansion Joint Manufacturers Association (EJMA) standard.
- The seismic bellows was tested with cyclic pressurization of the interlayer space to 2 bars absolute pressure for 5 cycles.
- 200 cycles of tensile fatigue test with 90 mm of stretching from the nominal design length.
- A full tensile test with 315 mm of stretching from its nominal length was conducted.
- The prototype bellows was qualified for its leak tightness (less than 1×10^{-9} Pam^3/s of helium) at all time during the qualification test.

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ABSTRACT

This paper presents the key manufacturing and testing processes of the prototype ITER feeder seismic bellows. The design of the double bellows was iterated with the results of analysis based on the Expansion Joint Manufacturers Association (EJMA) standard. Each inner and outer bellows was supported in dedicated molds and formed by a hydraulic pressure machine rated at 800 tons. The double bellows were constructed by welding individual collars to the end flanges. The seismic bellows was tested with cyclic pressurization of the interlayer space to 2 bars absolute pressure for 5 cycles. This was followed by 200 cycles of tensile fatigue test with 90 mm of stretching from the nominal design length. After the mechanical fatigue test, a full tensile test with 315 mm of stretching from its nominal length was conducted. Helium leak tests, with the sensitivity of the helium leak detector set to 1×10^{-9} Pa m^3/s of helium, were performed at different stages of pressure and mechanical tests. The prototype bellows was qualified for its leak tightness at all time during the qualification test.

1. Introduction

The ITER magnet feeder system, which is the life-line to support and control the superconducting magnet system operated at liquid helium temperature inside the cryostat, supplies electrical currents and supercritical helium from the Tokamak gallery to the magnets, and transmits magnet diagnostic signals to the operators. The feeder cryostat feedthrough (CFT) as one of the major feeder subsystems, penetrates the Tokamak cryostat. The gap is sealed with an interface seismic bellows which is sandwiched by cryostat window flange and CFT terminal flange (Fig. 1) to maintain the main vacuum for the superconducting magnet system. The seismic bellows is constructed with a double bellows structure (Fig. 2) with the intermediate space charged with partial pressure of tracer gas such as argon, neon, krypton, hydrogen, etc. The material of the bellows is stainless steel 304L which should follow special requirement of ITER.

The bellows is designed to isolate the seismic acceleration of the cryostat, which is anchored to the Tokamak foundation, from that of the feeder CFT, which is supported by the floor embedment plates in the Tokamak gallery. The acceptance criteria for the seismic durability of the bellows is vacuum leak tightness before and after the dynamic mechanical loads simulating Seismic Level 2 accelerations of 78 m/s^2 in the axial direction and 89 m/s^2 in the lateral direction. The bellows also serves as a length compensator for the thermal contraction in the CFT vacuum duct in case of helium leak accident. The leak tightness requirement needs to be met after tensile fatigue cycles followed by an extensive stretching.

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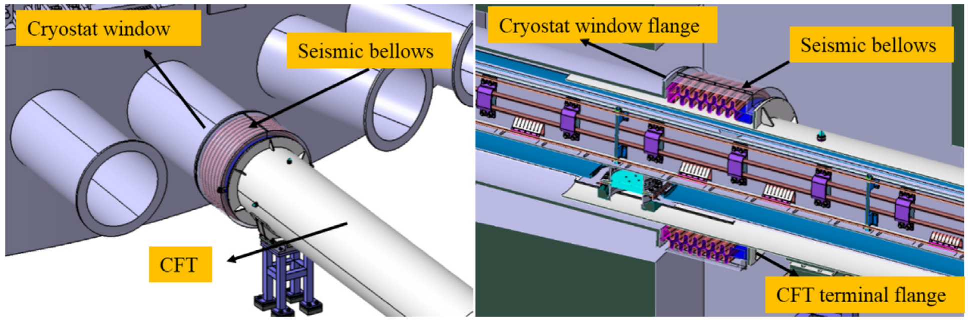

Fig. 1. Connection configuration of seismic bellows.

Table 1
Working conditions of feeder seismic bellows.

	Condition 1	Condition 2	Condition 3	Condition 4
Temperature	300 K	300 K	External: 300 KInternal 4–200 K	External: 300 KInternal 4–200 K
Pressure	External: 0.1 MPa Internal: vacuum	External: 0.1 MPa Internal: 0.11 MPa	External: 0.1 MPa Internal: 0.2 MPa	External: 0.1 MPa Internal: 0.2 MPa
Tensile displacement	5 mm (Assembly)	5 mm (Assembly)	<90 mm	<90 mm
Compressive displacement	5 mm (Assembly)	5 mm (Assembly)	5 mm (Assembly)	5 mm (Assembly)
Lateral displacement	5 mm (Assembly)	5 mm (Assembly)	25 mm	25 mm
Angular displacement	<1° (Assembly)	<1° (Assembly)	<1° (Assembly)	<1° (Assembly)
Maximum number of cycles	0 (Static)	<5 (Static)	<5	<5

2. Seismic bellows shaping design

2.1. Working condition introduction

Base on the technical specification from ITER, feeder seismic bellows have four different working conditions. Condition 1: normal operation; Condition 2: assembly/break cryostat vacuum; Condition 3: helium leaks in cryostat and in CFT; Condition 4: seismic event + helium leaks in cryostat and in CFT, which is an extremely unlikely rare event. The details are shown in Table 1 (refer to the technical specifications for feeder seismic bellows from ITER [1]).

2.2. Calculation analysis based on EJMA standard

EJMA standard is an internationally recognized advanced standard, which is used for almost all bellows standard [2–4]. AEROSUN-TOLA Expansion Joint Co. Ltd., has their own proprietary software (the software interface as shown in Fig. 3) to do the quick design calculation, which follows EJMA 9th standard.

The design of the double bellows was iterated with the results of analysis based on EJMA. The calculation results showed that under normal operation condition, the design fatigue life is nearly 40 million cycles. That means during normal operation period, the seismic bellows is impossible destroyed.

2.3. Safety assessment of the bellows under working condition 4

As above, working condition 4 is seismic event + helium leaks in cryostat and in CFT which is the worst condition for seismic bellows. In this condition, the lateral displacement is too big to make the wave shaping of the bellows will “yield” or “will be deformed plastically”, so the EJMA calculation cannot be used because it works

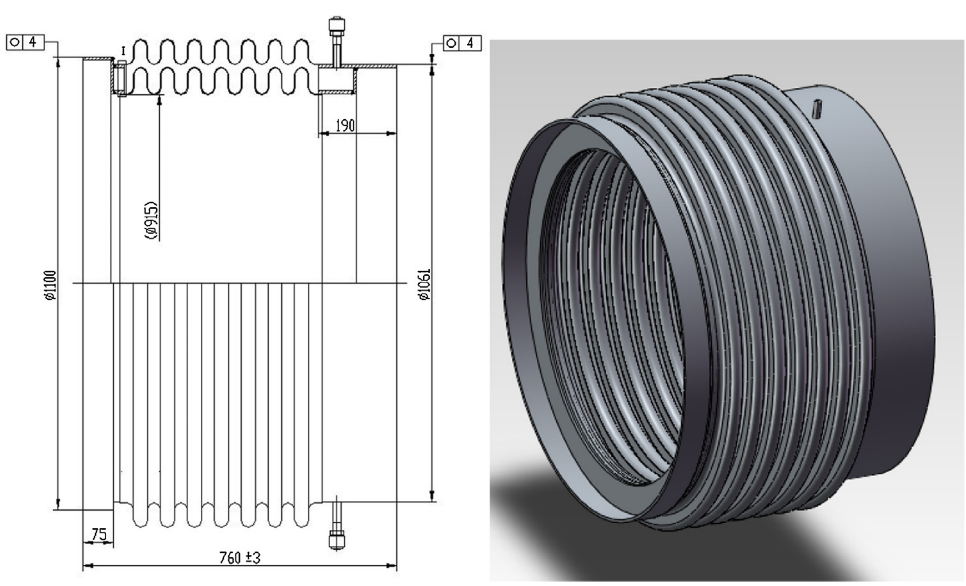

Fig. 2. Feeder seismic bellows.