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Appendix 9 Bellows

This Appendix is written as a guide for the manufacture and supply of vacuum bellows and flexibles for use on ITER vacuum systems. It is intended that the suppliers of vacuum bellows and flexibles should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

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ITER Vacuum Handbook
Appendix 9

Guide to the Supply of Bellows for use on ITER Vacuum Systems

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9 Guide to the Supply of Double Wall Vacuum Bellows for use on ITER Vacuum Systems

9.1 Scope

This Appendix is written as a guide for the manufacture and supply of vacuum bellows and flexibles for use on ITER vacuum systems. It is intended that the *suppliers* of vacuum bellows and flexibles should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components manufactured comply with the requirements of the ITER Vacuum Handbook.

“Supply” includes the design, manufacture, testing and delivery of bellows and flexibles as described in the specifications

9.2 General

Bellows are considered as inherently vulnerable components due to their method of construction and because they are designed to facilitate movement.

Circular bellows are to be designed to the Expansion Joint Manufacturers Association (EJMA) code or to another *accepted* design code. Where design codes do not apply, design shall be by analysis and proven by testing.

Care shall be taken to ensure that the operational loading parameters are fully considered including all design loads and combinations. Precautions need to be taken against rupture and other failure modes where there is a pressure difference in either direction between the inner and outer surfaces of the unit.

In all test situations and after installation, the bellows should be protected against all abnormal load conditions.

9.3 Design of bellows

All bellows for use on VQC 1 and 2 systems should be of double wall construction unless they are accessible for maintenance and fitted behind an *accepted*, interlocked, isolating valve. For VQC 1A bellows separating torus vacuum from air, double wall bellows are a mandatory safety design requirement as specified in the ITER Vacuum HAndbook. For VQC 2A where regular and significant movement is to be compensated by a bellows that is not required to be double walled by safety rules, the use of double wall bellows is to be determined by considerations of reliability, maintainability, maintainability and ALARA. Bellows which are of edge-welded construction shall be *accepted* provided that they comply with the ITER Vacuum Handbook Section 7.1.

The interspace between the two walls of the bellows assembly will normally be filled with a suitable tracer gas and the pressure in the interspace will be monitored continuously. The interspace will be connected to the Service Vacuum System in accordance with the ITER Vacuum Handbook Section 11.

9.4 Materials

9.4.1 General

All vacuum facing materials for use in the manufacture of bellows should comply with the requirements of the ITER Vacuum Handbook. In particular materials should be selected from the ITER Vacuum *Accepepted* Materials list (ITER Vacuum Handbook Appendix 3) and be consistent with the outgassing requirements of the ITER Vacuum Handbook section 5.4.

9.4.2 Metallic Machined Components and Fittings

All VQC 1A components which are machined from steel, austenitic steel or superalloys and which are of final thickness less than 5 mm, should be made from cross-forged material which is Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR) in accordance with the ITER Vacuum Handbook. The use of plate is prohibited. Alternative processes for achieving the required inclusion limits may be *accepted* if successfully validated.

The rate of inclusions in such steels should be checked in accordance with ASTM E-45 Method D (or equivalent) to be within the following inclusion limits:

- Inclusion Type A ≤ 1.0
- Inclusion Type B ≤ 1.0
- Inclusion Type C ≤ 1.0
- Inclusion Type D ≤ 1.5

Both halves of demountable flanges using metal seals are to be manufactured from cross or upset forged material.

Stainless steel knife-edge sealed flanges of any thickness for all vacuum classifications should be manufactured from cross-forged ESR grade material blanks.

All VQC 1A and 2A demountable vacuum flanges shall be made from cross-forged upset forged material.

9.5 Manufacture

9.5.1 General

Hydrostatic, rolling or elastomeric formation of bellows is *accepted* for all vacuum classes

Non circular bellows of non edge welded construction are to be welded then formed rather that formed in parts then joined. Cross welds are to be avoided. This does not necessarily apply to the post-forming welding of bellows sections to collars where these are required.

Bellows which are of edge-welded construction may be *accepted* provided that they comply with the requirements of the ITER Vacuum Handbook Section 7.1.

9.5.2 Welding of bellows assemblies

The qualification, production and testing of welds should be in accordance with the Vacuum Handbook Attachment 1.

In particular:

1. Before fabrication can commence the *supplier* should prepare for approval a weld plan in accordance with the Vacuum Handbook Attachment 1. The weld plan is a drawing which cross references each welded joint to a supporting Weld Procedure Specification (WPS).
2. Welding procedures and the Procedure Qualification Records are to be qualified in accordance with Attachment 1.
3. 100% visual examination of production welds should be performed.
4. 100% volumetric examination of production welds should be performed, unless a method of pre-production proof sampling is *accepted*.
5. Dye-Penetrant examination of production welds is only permitted in accordance with the ITER Vacuum Handbook.

9.6 Qualification of Bellows (type testing)

Prior to the manufacture of bellows assemblies the manufacturer should qualify the bellows design. The supplier should submit for *acceptance* a qualification plan (as part of the quality plan) detailing the tests to be performed on bellows assemblies. After the completion of all manufacturing processes the bellows assemblies should undergo the following qualification tests.

- Pressure test
- Mechanical shock test
- Fatigue life test
- Helium leak test
- ITER-specific tests as prescribed in the procurement specification documentation

In each case, the method of testing should be *accepted* before manufacture begins..

9.6.1 Pressure testing

Prior to leak testing it should be demonstrated that with the bellows assemblies displaced axially and radially to the maximum design values, and subjected to a 0.2 MPa pressure differential applied internally or externally to the assembly, that the bellows can survive and remain unaltered when the bellows interspace is at the following pressures

- $< 10^{-3}$ MPa (evacuated interspace)
- 0.05 MPa (interspace normal operation)
- 0.2 MPa (Interspace over pressure)

In all cases pressure testing should be followed by leak testing.

9.6.2 Mechanical shock testing

Type testing of the bellows assemblies should show no failures at 15 g acceleration after 1000 cycles under the conditions specified in 9.6.1

9.6.3 Fatigue life tests

The *supplier* should demonstrate that the bellows assemblies will remain mechanically unaltered over the expected life of the ITER machine. Fatigue life tests should be performed under load conditions similar to the ITER loading conditions.

9.6.4 Leak Testing

The supplier should perform leak testing of the bellows assemblies in accordance with the ITER Vacuum Handbook. Guides to helium leak testing can be found in the ITER Vacuum Handbook Appendix 12.

Bellows assemblies for use on VQC1 systems should be baked and hot leak tested at the maximum operating temperature as follows:

- Global test of bellows assembly
- Leak test of bellows interspace (to vacuum and to atmosphere)
- Leak test of water cooling circuits (if applicable)

VQC 1A or VQC 3A components which include joints of dissimilar materials should be subjected to a minimum of three thermal cycles from ambient to the maximum possible operating temperature prior to leak testing. Normally, the time taken for any component to reach the specified bake temperature from ambient should be less than 100 hours.

Immediately after bake-out, the above tests should be repeated at ambient temperature. In both cases, the acceptance leak rate should be met with the background reading on the leak detector being at least one order of magnitude below the acceptance leak rate without electronic correction. In each case, the leak test procedure should include three operating cycles of the bellows assembly at each test temperature before leak testing.

Bellows for use on systems with VQC 2, & 4 should be subjected to the same leak testing requirements as for VQC 1 & 3, but there is no requirement to test at temperatures above ambient.

Leak rates for bellows assemblies are summarised in Table 9-1.

	Acceptance Leak Rate ($Pa.m^3.s^{-1}$ air equivalent) at maximum operating temperature			
	VQC			
	1	**2**	**3**	**4**
Global leak rate	1×10^{-10}	1×10^{-9}	1×10^{-9}	1×10^{-7}
Bellows interspace to atmosphere	1×10^{-10}	1×10^{-9}	1×10^{-9}	1×10^{-7}
Bellows interspace to vacuum	1×10^{-10}			

Cooling channels (if applicable)	1×10^{-10}

Table 9-1 Maximum acceptance leak rates for bellows assemblies

9.7 Testing and Inspection of Bellows

Prior to the manufacture of bellows assemblies the *supplier* should provide for *acceptance* a test plan and test procedures detailing the tests to be performed on bellows assemblies before delivery to the ITER site.

After the completion of all manufacturing processes and before delivery to the ITER site the bellows assemblies should undergo a vacuum baking cycle to their operating temperature and the following tests should then be carried out

9.7.1 Leak testing

The bellows should be subject to helium leak testing in accordance with 9.6.4.

9.7.2 Dimensional inspection

The supplier shall perform a survey of the bellows convolutions to confirm compliance with the bellows technical specification. The survey results will be supplied to ITER and any non-conformance may lead to rejection of the bellows.

9.8 Cleaning

Great care has to be exercised when cleaning thin walled metal bellows, particularly those of edge-welded, nested construction. If any cleaning residues are trapped between the convolutions, either inside or outside, these can result in corrosion which can rapidly cause leaks to develop. Similarly, if any particulates are deposited in the convolutions, mechanical puncturing can take place. Alkaline degreasing solutions such as Almeco are prone to particulate precipitation and therefore must not be used for bellows assemblies.

9.8.1 Procedure for Bellows for Class VQC 1 use

The bellows should be fixed in an extended position if at all possible.

1. Any traces of visible, loose contamination should be removed with a gentle jet of clean, dry air or nitrogen.
2. The bellows should be immersed in an ultrasonically agitated bath of isopropyl alcohol (IPA) or ethyl alcohol (ethanol).
3. The bellows should be vapour washed immediately in vapour of the same solvent.
4. The bellows, including the interspace where appropriate, should be thoroughly dried inside and out using a gentle jet of clean, dry, particulate free air or nitrogen.
5. The bellows should be placed in a dry air oven at 100 °C for at least 1 hour with the interspace vented and open to atmosphere.

6. The bellows should be baked in a clean vacuum oven at a pressure $<10^{-4}$ Pa for 24 hours at 250 °C with the bellows interspace pumped or open to the vacuum environment of the oven.
7. The bellows should be sealed under dry nitrogen in a polyethylene bag.

This procedure can be used for bellows used on VQC 2, 3 & 4 systems with the vacuum bake requirement waived.

9.9 Proprietary bellows

Proprietary bellows fully meeting the ITER specification of the item and the requirements of each VQC may be allowable.

For VQC 1, 2 and 3, proprietary bellows should be supplied with an individual certificate of conformity, stating that the item is suitable for the design, operation and test conditions as stipulated in the technical specification,.

For VQC 4, proprietary bellows should be supplied with a certificate of conformity as above, but this may be in the form of generic or type conformance certificates to the catalogue specification.

9.10 Bellows Protection

Normally accessible bellows assemblies and bellows assemblies which become accessible during machine maintenance should be supplied with mechanical protection (such as the use of metal braiding or removable cover plates) to prevent accidental damage and ingress of matter to the bellows convolutions.

9.11 Marking

Surfaces which are to be exposed to vacuum should only be marked or identified if absolutely necessary, and should be marked by scribing with a clean sharp point. Seal faces should not be used. Chemical etching is an acceptable alternative for all VQC except VQC 1

Dyes, marker pens, paints, etc. should not be used on surfaces which will be exposed to vacuum. Furthermore, their use should be avoided on other surfaces to eliminate the potential for cross-contamination during subsequent cleaning operations. The use of such substances may block porosity in material and result in leaks which are initially undetectable but may open up after some time.

9.12 Packaging & delivery

Where practical, bellows assemblies should be entirely enclosed in heat sealed polyethylene and backfilled with a suitable dry gas. Bellows interspaces should be backfilled to 0.1 MPa with the connections sealed by a closed valve. Nitrogen is preferred but other gasses may be *accepted*. All bellows assemblies must be shipped dry internally and externally irrespective of final acceptance testing at the manufacturer's site.

The use of adhesive tape for the protection and packaging of components should be limited to prevent the risk of contamination from the tape. In particular tape used on

austenitic stainless steel shall meet leachable chloride and fluoride limits of 15 ppm and 10 ppm, respectively. Where used tape must be fully removable, without residue, using isopropyl alcohol or acetone as the solvent

Where practical all bellows assemblies should be transported in rigid packing cases or containers which are lined with waterproof material. Components should be packed with adequate protection from thermal and mechanical stresses (particularly shock loads resulting from dropping and mal-handling) which may adversely affect the operation of the bellows. All packing case joints should be sealed and cases marked with bellows specific identification. Handling instructions should also be clearly marked on the outside of the packaging. Any chemical or radiological hazards, etc., must be identified on the packaging. All packaging markings should be in English and French and should include the VQC of the bellows.

9.13 Incoming inspection at ITER Site

In addition to the inspection detailed in this Appendix, bellows assemblies will be subject to an incoming inspection on delivery to the ITER site. This will include, as a minimum, dimensional inspection for compliance with the technical specification and helium leak testing in accordance with the ITER Vacuum Handbook Appendix 12.

9.14 Documentation

The following documents should be *accepted* before pre-manufacture activities commence:

- Weld Plan
- Quality Plan (including test plan /schedule)
- Welding Procedures and Welder Qualifications
- Dimensional Drawings

The following documents should be *accepted* before manufacture commences:

- Type testing report

On completion of manufacturing, two sets of the following documents should be supplied as data books:

- Signed-off Quality Plan
- Welding Procedures and Welder Qualifications
- Radiographic Reports (if applicable)
- Production Proof Sample Reports (if applicable)
- Material Certificates, traceable to assemblies, in accordance with EN 10204 2.2, 3.1 or 3.2
- Dimensional drawings identifying welds
- Type testing report
- Dimensional inspection report