



Accelerator Science and Technology Centre

CCLRC Daresbury Laboratory

Vacuum Science Group

Vacuum Systems

**General Specification for the Design, Construction and
Handling of Ultra High Vacuum Vessels, Components and
Assemblies for ASTeC**

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1. Definitions

Please refer to ASTEC-VAC-QCD-spc-001 *Definitions relevant to Quality Control Documentation* for definitions of various terms used in this document

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2. Introduction to UHV

Ultra High Vacuum is generally taken to refer to pressures below about 10^{-9} mbar (10^{-7} Pascal). At this pressure, there are about 36 million molecules of gas per cubic centimetre, each with a mean free path of about 6 km.

The attainment of UHV is not particularly difficult and there is little in the way of “black art” associated with it. However, it does require careful selection of materials and processes and meticulous attention to detail in design, constructional methods, handling and processing.

3. Design Practice

The basic design rule applied to UHV vessels and assemblies is to minimise the gas load and to maximise available pumping speed. This effectively means that the less gas you have to pump away and the greater the pumping capability of the installed pumps, the lower the pressure that will be achieved. In general terms it is possible, within limits, to reduce gas load – which arises from outgassing, diffusion and leaks – by orders of magnitude whereas it is difficult to increase pumping speed more than a factor of a few. Therefore it is obvious that attending to the former will pay handsome dividends.

Gas load is minimised by careful surface treatment, and by minimising the surface area exposed to vacuum. In general, the less one does to a vacuum surface the better. Treatments such as acid etching or polishing (either mechanically or by electropolishing) result in surfaces which cosmetically might appear very nice (i.e. smooth and shiny) but their outgassing rate can be very much enhanced over an as-received metal surface which has been carefully chemically cleaned.

The most common constructional material for vacuum vessels for UHV use is some form of stainless steel. It will often be found that a vessel made from stainless steel sheet which has been hot-rolled and the oxide scale stripped with an air knife gives the best performance. If a polished surface is required for cosmetic reasons, then the use of electropolishing followed by a vacuum bake at a temperature of at least 450°C for a minimum of 24 hours may result in a similar performance.

An important design criterion is the elimination of trapped volumes. These are volumes which connect to the main vacuum volume through very small orifices, capillaries, etc. They tend to crop up in the most unexpected places, and any design should be carefully reviewed for such features. For example, a bush spot-welded to a flat surface will inevitably leave trapped volumes in the machining marks and microscopic surface roughness in the two contacting surfaces. A fixing screw in a blind hole in a bush will trap a volume at the bottom of the hole (and also between the screw head and fixture and fixture and bush! Clearly, washers will only compound the problem.) Problems can generally be minimised by drilling strategically placed venting holes (e.g. along the screw axis), milling a relieving slot or slots along one of two surfaces in close contact, and so on. Attention to detail here is important, and should be included in the engineering design process.

It is in order to minimise trapped volumes that vacuum sealing welds for UHV should generally be specified as internal welds. Where this is not possible, full penetration external welds may be specified. The aim in either case is to leave a smooth surface on the inside of the vessel. Similarly vacuum braze preparations should aim to leave a smooth run of braze material linking the piece parts on the inside of the vessel.

One thing that should never be done is to attempt to “seal in” a trapped volume with a sealing weld. This can be a recipe for disaster, since it is impossible to locate a leak in such a weld. All volumes should be vented, either to atmosphere or to vacuum. For the same reason a vacuum sealing weld should always be a single weld, never a double weld.

Clearly, the above criteria can give rise to design conflicts. Relieving a trapped surface reduces thermal transfer. Venting holes can reduce strength and stability. Pressure vessel regulations may call for double welds for safety. Such conflicts can only be resolved on an individual basis, where all the relevant criteria are taken into consideration and a suitable compromise reached.

If the above criteria for avoiding trapped volumes are adhered to - and it is always better to eliminate them rather than alleviate them - then the further criterion of minimising places in which solvents used in cleaning processes can be trapped, or into which dirt residues can be washed, may also be satisfied. However, this is not always the case, since it can be difficult to remove dirt from areas which can actually be satisfactorily pumped when clean. In general, this implies that a vacuum assembly should be stripped down as far as possible for cleaning, and then reassembled under clean conditions. For items which cannot be subsequently disassembled, e.g. a bush welded to a surface, it is imperative that each component be rigorously cleaned before such a welding process, and that the welding take place under clean conditions.

It is sometimes a requirement that vacuum surfaces be plated - e.g. a gold plating may be required to ensure a uniform work function over a surface, or a silver plating may be used to reduce "stiction". In such cases, extreme care should be taken so that there is no possibility of delamination or peeling of the plating. Likewise, the surface to be plated should be clean and free from defects which could give rise to trapped volumes under the plating. It is always a good idea to prove the plating by a high temperature (i.e. at least 250°C) vacuum bake. Evidence of peeling or bubbling is then just cause to reject the plating. If the plating is carried out by electroplating or any other process involving acids, then a 450°C vacuum bake is recommended to remove acid residues. An electroless process, vacuum evaporation, sputter coating or similar is recommended wherever practicable, although these too should normally be followed by a vacuum bake to at least 250°C. Chemical plating - e.g. electroless nickel - should also be followed by a vacuum bake.

Water-to-vacuum joints are always a problem. Cooling water circuits, or, indeed, pipes carrying any other liquid inside the vacuum system, should always be designed in such a way that joints are vented to atmosphere or to a secondary vacuum system.

Maximising pumping speed is not always achieved by simply increasing the nominal size of a vacuum pump. In UHV, pumping speed achievable in a system is limited by the transfer of gas molecules evolved in the system into the pump itself. As mentioned above, mean free paths are of the order of kilometres, so gas molecules in general strike internal surfaces many times before they reach a pump or trap. Hence, vacuum systems should be as "open" as possible, with clear lines of sight to the pump or pumps. It is frequently better to use a distributed form of pumping, rather than a single large pump. It is also important not to try to pump a vessel through long narrow tubes, since then the pump speed available will be very constrained.

4. Conditions and Handling

It is recognised that conditions in engineering workshops are often not ideal for the manufacture of UHV components. Nevertheless with some simple precautions, the possibility of storing up trouble for the future can be minimised. (See also Section 7 below.)

Cleanliness is important at all times. Frequent cleaning of items before, during and after manufacturing processes is required. Care should be taken not to cross-contaminate "clean" and "dirty" components. Clean components should be handled wearing clean, dry, lint-free gloves, and all tools, etc., should be cleaned before use (including the handles). It is sometimes observed that someone wearing gloves while working on a clean assembly will go off and rummage in a general-purpose toolbox for a particular tool without taking the gloves off. He will then carefully clean the tool before using it, blissfully unaware of the possibility of his gloves then being dirty.

The atmosphere in which clean *assembly* for UHV is being undertaken is important. The air should be clean and of low humidity, free from gases or oils exhausted by vacuum pumps, machine tools, stacker truck engines, etc. It should be dust and particulate free (Class 10000 is usually adequate). Local areas of cleanliness may be achieved using portable laminar flow filtration units. Operators should be dressed appropriately to prevent dust and particulate shedding.

Components should be stored under clean conditions, e.g. by wrapping in clean aluminium foil and sealing in clean dry polythene bags. Enclosures should have all apertures sealed, and preferably be filled with dry nitrogen before sealing.

Care must be taken in all handling processes to avoid damage, e.g. scratches or dents, to vacuum sealing faces, especially knife-edges. Knife-edges are best protected by a clean scrap gasket fixed in place. Flat flanges should be protected by a clean metal plate or hardboard sheet cut to match the outer flange profile

and fixed to the flange face by fasteners through the bolt holes. Either a rubber gasket or washers on the bolts between the plate and the flange face should be used to leave a gap to stop scratching by the plate itself.

The possibility of distortion of sealing flanges during lifting and slinging operations must also be borne in mind.

If it is necessary during any operation to use adhesive tape or a masking agent on any vacuum surface, then this should be applied for the minimum time possible. Immediately after removing it, any adhesive residue must be thoroughly removed with an appropriate solvent, e.g. acetone.

Suitable cleaning procedures are detailed in the Vacuum Specification ASTEC-VAC-QCD-spc-003 *Procedures for the Cleaning of Vacuum Items*.

5. Drawings

Any vacuum vessel, component or assembly should be manufactured to the manufacturing documents supplied by ASTeC and using the methods and procedures specified, except where alternatives are agreed or where a contract is placed which includes both design and manufacture.

A Contractor may propose alternative methods of construction, details of which must be submitted to ASTeC for approval before proceeding. If any such modifications are agreed between a Contractor and ASTeC, the relevant drawings will be modified and the agreement incorporated into the contract.

Except as agreed, no departure from approved drawings may be made without the express permission, in writing, of ASTeC.

All drawings for jigs, formers and tooling required to fulfil the terms of any contract shall be submitted to ASTeC for approval prior to commencement of manufacture. Such approval shall not relieve the contractor of his responsibilities under any contract.

All drawings shall contain the appropriate Vacuum Notes (See ASTEC-VAC-QCD-spc-008 *Standard Vacuum Notes for use on Engineering Drawings for Vacuum Systems*)

6. Materials

All materials used must be compatible with UHV. Materials shall normally be specified for any given contract, but Appendix 1 lists materials known to be satisfactory for UHV use. However, some materials may be excluded from any particular contract because of other properties, e.g. magnetic permeability, temperature limitations or radiation resistance.

Knife-edge vacuum flanges shall be manufactured from electroslag refined (ESR) hot forged austenitic stainless steel grade 304L, 304L+N, 316L or 316L+N as detailed in ASTEC-VAC-QCD-spc-007 *Material for Vacuum Flanges*. The material may be in the form of forged bar for diameters up to and including 70mm and forged blanks for larger flanges.

Within magnet apertures vacuum vessel walls are required to have very low magnetic permeability (≤ 1.005). Where the permeability is specified, the contractor shall supply a permeability test certificate for a sample taken from each batch of material used.

For any material not supplied by the ASTeC and exposed to UHV, material certificates may be required. These should state the material specification, ladle analysis, room temperature mechanical properties and surface finishing process used.

7. Machining and Fabrication

All machining work is to be carefully controlled to ensure that no foreign matter is embedded in the surface of the material.

The use of abrasive wheels or cloths (which can leave foreign matter embedded in the UHV surfaces), wire brushes, files, harsh abrasives, sand, shot or dry bead blasting, polishing pastes and the like is prohibited under normal circumstances and without the prior permission of ASTeC.

Scale removal, etc., shall be by careful hand brushing with a stainless steel brush. Other surface finishing techniques which are permitted include slurry blasting with alumina or glass beads in a water jet; gentle hand use of a dry fine stone or a fine stone lubricated with isopropyl alcohol or ethanol; hand polishing using fine mesh alumina in an isopropyl alcohol or ethanol carrier on a lint free cloth and hand polishing with ScotchBrite™ (Alumina loaded, Grade A).

All mechanical cold working operations must exclude the use of heavy organic lubricants since these can be retained to some extent in the surface after the process.

All parts to be welded must be thoroughly cleaned (degreased) to ensure UHV leak-tight welds. Prior to and during welding the cleaned surfaces must never be in contact with oily or greasy objects (including bare hands).

All welding will be to BS7475, Part 2 or equivalent. Conventional welding will be by the TIG process although electron beam welding, plasma welding and laser welding may be used as appropriate and by agreement with ASTeC.

To prevent undue oxidation all vacuum sealing welds are to be backed by an inert gas purge.

Where vacuum sealing welds are made externally there should be full penetration leaving a smooth surface inside, without any subsequent dressing operation.

The use of dye-penetrant is strictly forbidden at any stage of manufacture.

If at any stage of manufacture a weld is found to be faulty, no rectification is to be done without prior approval from ASTeC.

8. Marking and Labelling

At no time should any surface which is to be exposed to vacuum or immersed in vacuum (e.g. during a bake operation) be marked out, identified or the like except by scribing with a clean, dry sharp point or a vibrating engraver. Vacuum surfaces should only be marked if it is essential so to do. The use of dyes, marker pens, paints, etc. is to be avoided. It is good practice not to use these on external surfaces because of possible cross-contamination in subsequent cleaning operations. Similarly, it is possible to temporarily block porosity in material with such substances.

Labels for identification purposes should be tied to components or, in the case of small components, fixed to packing bags. Self adhesive labels, tapes, etc. if essential, may only be fixed to non-vacuum surfaces of components and care should be taken to ensure that the adhesive used is soluble in acetone.

Component identification markings should be laser engraved or dry-scribed at the position identified on the appropriate drawings. Where this is impractical, such markings should take the form of an engraved metal tag securely wired to the fixing point identified on the appropriate drawings.

9. Inspection and Testing

A visual inspection shall be carried out of all internal surfaces and vacuum sealing faces.

All vacuum surfaces shall be free from all visible defects such as pitting, scale, cracks and indentations.

All vacuum sealing faces shall be free from radial scratches.

Knife edges shall be free from scratches, indentations and any evidence of rolling, peeling, delamination or inclusions.

All vacuum braze regions shall be flush and free from voids, blow holes, etc and there should be no visible evidence of inclusions.

All weld regions shall be free from scale, voids, blow holes, etc, and there should be no visible evidence of inclusions. Some degree of discolouration of material in the weld area may be acceptable.

No weld repair shall be attempted without the agreement of ASTeC.

After manufacture the Contractor will measure all components to check the dimensions, finish and tolerances specified on the drawings. The contractor shall supply an inspection report, details of which will be agreed between ASTeC and the Contractor.

If any dimensions are not achieved no rectification is to be made without the prior approval of ASTeC.

After mechanical inspection, the vessels assemblies or components shall be cleaned to specification ASTEC-VAC-QCD-spc-003 *Procedures for the Cleaning of Vacuum Items* as appropriate. Vacuum leak testing shall be carried out in accordance with ASTEC-VAC-QCD-spc-004 *Leak Testing of Vacuum Vessels and Assemblies* and acceptance tests to ASTEC-VAC-QCD-spc-005 *Acceptance Tests for Vacuum Vessels, Components and Assemblies* carried out as appropriate. All gaskets used in such tests shall be of a type approved by ASTeC for the purpose. They will normally be of the type specified for use of the vessel, component or assembly in service. However, with the prior approval of ASTeC an

alternative type of seal presenting a similar bolt loading to that expected in service might be considered acceptable.

On receipt by ASTeC, vessels assemblies or components will, before acceptance, be visually inspected and then tested to ASTEC-VAC-QCD-spc-004 and ASTEC-VAC-QCD-spc-005 as appropriate in order to check that no deterioration has occurred in transit.

10. Carriage and Packing

Knife edge flanges and other vacuum sealing faces shall be protected to prevent damage during transit (see 4 above).

Where so specified, vessels assemblies shall be shipped either back-filled with dry nitrogen (dew point $< -50^{\circ}\text{C}$) or under vacuum ($< 1\text{mbar}$).

Individual components shall be shipped in clean, dry, sealed polyethylene bags backfilled with dry nitrogen.

Components must be properly supported and contained to prevent damage and contamination during transit. Details of the carriage and packing procedure will be discussed with the Contractor and incorporated into the contract

Appendix 1

Materials for UHV Use

This list does not pretend to be exhaustive. In any given contract, some of the materials listed here may not be suitable for other reasons, e.g. magnetic permeability, temperature limitations, radiation resistance, etc.

Vessels

Stainless steels - AISI 304L, 304L+N, 316L, 316L+N, 321, 347

Inconel 600, 625, 718, 750

Mumetal, Monel metal

Copper, OFHC and OFS grades

Titanium, Beryllium

Aluminium and alloys 5086, A-6061-T6, A-6063-T6, ISO AlMgSi6060, VAW 19/06 LVW Glass, high density Alumina, Beryllia

Flanges

Hot forged ESR grade stainless steel type 304L, 304L+N or 316L or 316L+N. For knife edges, a Brinell hardness of 160-200 is required. ASTEC-VAC-QCD-spc-007 *Material for Vacuum Flanges* gives further details for flanges for SRS machine use.

Interior

Most metals except Cadmium, Caesium, Mercury, Potassium, Magnesium, Sodium, Lead, Selenium, Strontium, Zinc.

Most alloys except those containing the above in such quantities or chemical state that they can segregate to the free surface.

Most high density ceramics.

PTFE, Mica