JOINT EUROPEAN TORUS

JET-P(89)57

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Preprint of a paper to be submitted for publication in
Vacuum Journal

Leak evaluation in JET and its consequences for future Fusion machines.

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During the assembly of the vacuum vessel and the subsequent operation of JET hundreds of vacuum leaks were found and repaired. Information on leaks has been collected and evaluated since 1981 in an attempt to reveal the causes. In this evaluation a clear distinction was made between leaks occurring during the installation and during the plasma operation phase. Most installation leaks on flanges appear to be caused by incompatible seals, damage or contamination of the sealing surfaces. Leaks in welded connections were mostly due to impurities, incompatible welding materials or inaccurate setting of the welding parameters. The difficulty of access to flanged or welded connections proved to be responsible for the occurrence of leaks during assembly. Operational leaks are in general the result of design errors, problems with bellows, in particular bellows in water cooling systems, and mechanical forces on the equipment due to uncontrolled plasma behaviour (disruptions). Recommendations will be made on leak prevention for the radioactive tritium phase of JET and for future machines.

1. Introduction

Leak detection[1] and repair of leaks in large fusion devices will become increasingly more difficult once these machines have been operated with deuterium/tritium plasmas. Access and hands-on operation will be severely restricted due to activation and tritium contamination. Hence leak detection and repair eventually have to be carried out by remote means.

Therefore the main aim is to minimise leak test and repair interventions by developing leak prevention techniques. Each individual leak on the JET machine was evaluated and the resulting data were stored on a computer database to enable analysis of the causes. A clear distinction was made between installation and operation leaks.

This data has been analysed and the conclusions and recommendations for JET and future fusion machines will be discussed in this paper. Leaks occurring during the manufacturing stage of the machine components have not been included in the study.

One common cause for both, leaks during installation and operation, were the lack of knowledge and experience for this large machine. Extrapolations for design and manufacture had to be made from smaller machines with the inherent under and over designs in many cases.

During the last three years JET has been operating far beyond the design limits for the plasma current and pulse duration causing a variation of operational leaks.

Due to the experience gained during the six years of operation we have been able to reduce or to eliminate various sources of leaks and are now able to share our experience.

2. Leak distribution

After every vacuum intervention and in particular after the planned major shutdowns the JET machine is leak tested. The leaks which are found during these periods are classified as "Installation Leaks".

As the analysis revealed most of the installation leaks were avoidable and generally easy to cure. A large number of these leaks could be attributed to lack of access. Vacuum connections often have to be made under difficult circumstances. Access restrictions therefore are a precursor to installation leaks.

During the operational periods leaks often occur due to directly or indirectly plasma operation related activities. They are classified as "Operational Leaks".

Curing this type of leak proved to be more difficult and time consuming.

3. The JET vacuum vessel and peripherals

The JET vacuum systems[2] consist of the main Torus Vacuum Vessel[3] (200 m^3), two Neutral Beam Injectors[4] (80 m^3 each), Pellet Injector (80 m^3) and several diagnostic systems.

Each of these systems are individually pumped by turbomolecular pumps with additional cryo condensation pumps for the Neutral beam[5] and Pellet injector[6].

The vacuum vessel is an all welded double walled Inconel vessel and forms the main plasma chamber. The vessel is built out of eight Octants each of which has been baked to 520 °C and then leak tested at 350 °C. After the repair of some initial leaks in single run welds, revealed during the hot leak tests, no more leaks have occurred in the Octant segments.

Each double walled Octant is made up of segments of 20 mm thickness. They were welded together with multi pass weld runs. After the internal root weld had been made the additional weld passes were added externally[3]. Some concerns existed as to the possibilities of trapped volumes and virtual leaks. This has proven to be unfounded and after baking the vessel to 350 °C and cool down vessel pressures of $<1.10^{-9}$ mbar have been reached.

During the last three years the machine has been operated regularly with vacuum vessel temperatures in excess of 300 °C without any leaks occurring in the vacuum vessel itself[7].

3.1 All metal valves

The main vacuum chamber is separated from the peripheral systems by all metal valves. Numerous leaks across valve seats and in the sealing actuators occurred. Debris lodged into the sealing surfaces was the mean cause for leaks in vent valves and the valves used during the initial pumpdown from atmosphere, the bypass valves.

Vent valve damage due to debris from the vent line was overcome by installing a particle filter in the vent line adjacent to the valve.

Bypass valve damage was caused by debris from the vacuum vessel being stirred up during the initial pump down. This necessitated the pumpdown procedure to be altered at the start of the pumpdown. The fore vacuum lines ~ 20 m^3 - 10% of the vessel volume- are now vented to atmospheric pressure before pumpdown commences. This prohibits the initial surge from the previously evacuated fore pump lines and has proven to be successful.

The second main cause for valve damage was out of sequence operation of the electronic and the pneumatic control of the pendulum gate valves. The JET valves needed two separate air lines i.e. one pneumatic actuator for sealing plate closure, the second one for the actual sealing action of the valve. Simultaneous operation of the actuators or operation in reverse order, after power or compressed air failure, did damage the seal and the sealing plate. Occasionally this also caused the pneumatic seal bellows to crack causing a leak.

To avoid out of sequence operation a new actuator was developed which prohibits by mechanical means the sealing actuation before the sealing plate has reached its final position.

Where possible -space permitting- pendulum gate valves have been replaced by single acting all metal gate valves.

3.2 Vacuum gauges

In most systems Penning gauges are used for vacuum measurement and to set high vacuum switching levels. Pirani's are used in the same way for fore pressure measurements and switching levels. For several reasons Penning gauge leaks have frequently occurred: the magnet was dislodged due to strong magnetic field during plasma operation damaging the electrical feedthrough; gauges left switched on at atmospheric pressure; Penning measuring chamber pole plate movement damaging electrical feedthrough.

The Penning magnet fixing has been improved which eliminated the occurrence of related leaks.

Penning gauges left switched on at atmospheric pressure caused arcing at the feedthrough between the central electrode and the casing. The metal seal between ceramic insulated electrical feedthroughs and the casing was destroyed by spark erosion or the ceramic had cracked.

As a concequence all the Pennings are now switched on and off depending on the pressure that is reached. JET pennings are switched on at 5.10^{-3}mbar and switched off at 1.10^{-2} mbar. The Penning gauge can also be used to switch itself off via the controller but needs another fore vacuum gauge like a Pirani to be switched on again.

The measuring chamber pole plate movement was caused by inadequate securing of the plate and the strong magnetic fields of the machine. The problem was solved by fitting a large internal circlip holding the plate in position.

The electrical feedthroughs of the JET Pirani's are very prone to mechanical damage and have caused several leaks.

Better mechanical protection of these feedthroughs have improved their reliability.

4. Vacuum connections

Although the vacuum vessel is an all welded structure the peripheral equipment is attached in a variety of ways. Several types of flanges, including weld flanges, are used. The Conflat type flange is the only one not remote handleable[8] and is only used sparingly without any major problems. The other types, the JET designed remote handling bolted flange, the V-band flange, the sleeve joints and the weld lip flange are all remote handleable.

4.1 The bolted flange

The bolted flange[8] (Fig.1) is based on the Helicoflex all metal seal and is used from 35 mm ID to 1200 mm ID. For UHV and bakeable systems a silver lining is used and for fore vacuum and ambient temperature applications an aluminium one. For remote handling purposes it is desirable to reduce the number of bolts per flange. Therefore the JET bolted flanges differ from the standard vacuum flanges in several ways. The bolts made of Nimonic are stronger than normal and the flange thickness is ~ 1.5 times the standard flanges to compensate for distortion. To ease remote handling operation the flanges have been designed with nut rings and captive bolt rings.

Initially ~5% of the flange connections were leaking. The main cause was due to : damaged sealing surfaces; to a lesser extent to uneven heating of flanges; damaged seals; debris falling in from the bolts (vertical flanges). The problems associated to sealing surfaces were caused by damage due to scratches and dents. Accidental electro polishing of some flange sealing surfaces caused incurable leaks in the of 10^{-6} - 10^{-7} mbarl/sec range. The concentric machining grooves in the surface seem to be essential for a proper sealing action.

Most of the damage problems have been overcome by protecting the sealing surfaces immediately after manufacturing, during transport and after removing a flanged component. Special aluminium protection rings have been made protecting only the sealing surface and leaving access through the centre for welding and cleaning purposes. The protecting rings are attached by nylon bolts.

Uneven heating of the 1200 mm JET main door seals resulted in leaks opening up mainly on cool down of the machine. A much improved heat distribution was obtained by installing a heat insulated door cover.

Before installing or re-installing a flange the seal and sealing surface is carefully inspected for damage. Damaged seals are rejected and surfaces "touched up" if required.

For ease of assembly Molycote paste has been applied to the bolts. Subsequent feeding through and tightening up of the bolts often caused some Molycote to fall onto the seal frequently causing leaks. Ultrasonic cleaning of the bolts and Molycote applied to the nut provided the answer.

4.2 Conflat type flanges

These flanges are occasionally used up to 150 mm ID in equipment without remote handling requirements . They are used invariably in diagnostic systems decoupled from the main vacuum system via an all metal valves and bellows. They have given minimal problems.

4.3 V-band flanges

V-band flanges[8], originally introduced for water connections, have found their way into the vacuum systems. The flanges have tapered edges and a chain clamp with wedged sections provides the clamping force for the metal Helicoflex seals. The wedged sections of the chain are wrapped around the tapered edges of the flange and tightened up by a single bolt. To reduce the friction Molycote paste is applied to the wedged sectors of the chain clamp and the bolt threads. The single tightening bolt is very useful for remote handling but leaves a lot of room for improvements in UHV applications.

The main "bone of contention" is the inherent uneven distribution of the clamping force which is mainly concentrated on the sealing area near the tightening bolt. An increasing amount of leaks in these flanges are being observed during installation and operation in particular after large mechanical forces have been applied due to uncontrolled plasma behaviour (disruptions).

Limits have to be set for the unsupported mass attached to these flanges. Further improvements in the clamping mechanism are still required before the V-band flange can be reliably used for UHV applications.

4.4 Weld lip connections

The weld lip design (Fig.2) is one of the most successful vacuum sealing applications in JET. Both sides of the vacuum interface are equipped with identical 2 mm weld lip flanges and after matching up welded together with an edge weld. The welding can be carried out by hand or with the remote handling welding trolley[8]. For disassembly a remote handling nibbler or a hand held grinding tool is used to remove the edge weld. This type of connection occasionally requires additional support in case comparative large components have to be carried.

The connection is very easy to make and to repair by remote handling. It does not suffer from sealing surface damage or damaged seals.

The only problems experienced initially were leaks at the connecting weld between the weld lip and the component. Since this weld will be internal as soon as the two flanges are welded up, repair is impossible without creating a relatively large trapped volume. For that reason -easy repair- the welds to the components were done externally wherever possible. Alternatively local test probes were used to leak test the internal welds in advance.

In these connections leaks were only found during installation on manually welded components.

4.5 Tube welds sleeves

A special weld sleeve[8] has been designed enabling automatic welding and cutting of tubes. The weld sleeve has a locating groove for the remote handling orbital welder/cutter and can be set up for either side of the sleeve. A fillet weld on either side completes the vacuum connection. For disassembly the fillet weld is removed again with the orbital machining arrangement. This type of sleeve joint can be used up to three times before replacement of the sleeve is required. It is only applied in cases of infrequent removal of components or connections.

4.6 Aluminium wire seals

Several aluminium wire seals have been used unsuccessfully in one particular application. The sealing arrangement was unable to withstand the mechanical loads in combination with bakeout temperature fluctuations and caused intermittent leaks. Since this component could not be isolated from the torus main vacuum vessel it took a lot of effort to pin-point the leak.
The problem has been cured by changing the sealing arrangement to a lip weld seal without further leak occurrence.

4.7 Ferro fluidic seals

In the same application as above ferro fluidic seals have been used to accomplish a rotary movement in vacuum. Probably due to the high external magnetic fields the seals started failing causing intermittent leaks. The leak indications in the machine disappeared after removal of the suspected equipment, which later proved to be the leaky component.

It is recommended that ferro fluidic seals are never used in large fusion machines.

The problem has been partly solved by an oil filled differentially pumped rotary feedthrough.

5. Optical windows

Optical windows necessary for spectrometers, CCD cameras, laser and other diagnostics have to stand bake out temperatures in excess of 400 °C. Gold or aluminium bonded quartz and sapphire windows are installed directly onto the vacuum vessel. Water, resulting from water leaks inside the vessel and deposited on the hot windows, cracked several whereas the aluminium bonded ones were often destroyed due to the demineralised water attacking the bonding. Gold seals did not suffer from this effect but were much less reliable due to bonding problems which manifested themselves during venting and pumping of the machine.

In the critical areas the gold sealed windows have been replaced by aluminium ones which are protected from water as well as can be achieved.

6. Water cooled components

Water cooled components leaking into the vacuum vessel at > 300 °C are of major concern. The reason for this type of leak is mainly due to arcing or particle beams penetrating insufficiently protected water channels.

This type of leak is very difficult to anticipate or prevent and the resulting damage is the most severe. Not only is access to the vessel needed for repair but more often than not the water has damaged the vacuum measuring equipment and cracked optical windows. Recovering from this sort of incident at the moment, even with 24 hours working, takes the best part of a week.

Other leaks of water cooled components have occurred with less catastrophic results and were mainly caused by bellows failing due to excess of vibration or weld failing under high stresses induced during the plasma shots. The stresses are a combination of high power loading, magnetic field induced mechanical loads and vacuum forces.

Efforts have to be made to improve the protection of water lines from penetrating particle beams by protective cladding, bellows have to be designed specifically for their purpose and structures strengthened to withstand the forces. In general a more stringent application of design codes and improved quality control have to be employed. Often equipment had to be removed for repair, redesign or remanufacturing in a continuous effort to still improve in these areas in spite of the already very high standards achieved initially.

The water cooled internal vessel components are the most controversial problem to be solved in the future. Several almost incompatible entities, vacuum, high temperature walls and water have been combined.

7. Bellows

Metal bellows subjected to high gas or water throughput are prone to sustain damage due to excessive vibration. Metal fatigue and subsequent failure occur even in a couple of days as in the case of edge welded bellows which are used for high throughput or are exposed to 50 Hz vibration as in JET's eddy current controlled dosing valves[9]. Special test efforts are necessary to avoid resonance in the system in particular in longitudinal direction. Although the bellows itself may stay within the limits of maximum expansion individual sections may be over stretched and crack.

When large displacements are not asked for and bellows are merely used for decoupling the vibration can be reduced considerably by enclosing the rolled or hydro formed bellows in a metal braiding.

Quality control on material and the fabrication is essential. Recently 10^{-7}-10^{-10} mbarl/s leaks have been found along the grain structure of machined components made from forged stainless steel[10]. Impurities are deemed to create this porosity and it is therefore important to check on the inclusion content of the original material. To avoid these problems on the machined end pieces of bellows it is suggested to use electro slag refined material (ESR).

Designs with double bellows and interspace pumping or ventilated double or triple ply bellows should be envisaged.

Bellows failures in JET have been the major single item causing most of the operational stoppage. Hence a major effort is needed to solve this problem for future machines.

8. Electrical feedthroughs

Early on it had been recognised that small leaks in electrical feedthrough arrays were almost inevitable. Therefore feedthroughs in JET are generally designed in such a way that a guard vacuum can be applied in case of a leak. This has frequently been proven to be the proper approach to overcome leak problems. A problem arises when a guard vacuum is applied in the pressure range of 10 - 10^{-2} mbar. A voltage of ~150 V can create a discharge or flash over which often damages the isolated conductor. High current discharges aggravated by magnetic fields from the magnetic field coils are the main cause of feedthrough destruction and subsequent leakage.

There seem to be only two solutions, either pumping down below 10^{-5} mbar, or back filling with a noble gas at 0.5 to 1 bar. Hydrogen or deuterium back filling could be contemplated as well.

In JET systems are often back-filled with nitrogen or a noble gas (argon or neon) to 600 mbar and the pressure is monitored regularly for leak indications. Monitoring the mass spectrum for these gases will indicate a possible feedthrough leak.

9. Discussion of results

Examination of the statistics of the leaks encountered on the JET machine and its peripheral equipment as presented in Table 1 and Figures 3 and 4 show the range and complexity of the problems of the leak integrity and component reliability.

Considerations of Table 1, which lists the number of installation and operational leaks in each category and shows the total as percentage of the installed connections and items, gives a range in this figure from 0.8% to 70.2% but taking each category in turn the following comments are valid.

For flanges it is self evident that the bolted type is more reliable than the single bolt V-band flange, particularly as the operational leaks on the bolted type occurred in the early periods of JET operation and the leaks on the V-band type were caused in the later periods when the machine performance was upgraded and were caused by vibration. No such bolted flange leaks occurred for this reason.

In general terms welds were found to be more reliable than seals. The figure of 13.2% for lip welds as against 2.8% for fillet welds does not itself give a true picture as the lip welds are more reliable as far as operation leaks are concerned and much more accessible for repair requiring much less machine downtime

The electron beam welds were part of the nickel limiters which after they failed during operation were removed from the machine.

As far as the non-standard seals are concerned two points are relevant. One is the high failure rate of aluminium wire seals (54.5%) caused by both variation in temperature and machine vibration and the ferro fluidic rotary seals whose leaks (33.3%) were caused by high magnetic fields. These items have been dealt with as mentioned before.

The water leaks apart from the particle beam show the need of stringent testing of components prior to installation and possible redesign where necessary as this has shown to be beneficial in reducing the number of this type of leak to a minimum.

For the most part windows were found to be reliable, no leaks having occurred in aluminium bonded windows apart from water damage. However the gold bonded windows at 37.5% leak rate mostly of diameters of 80 mm and above were eventually replaced.

Edge welded bellows at 13.3% leak rate and hydro-formed bellows at 5.5% leakage is not surprising as the duty required of edge welded bellows is much more arduous.

Feedthrough and gauge leaks (7.7%) have been mentioned already.

The valve leakage figure of 70.2% is very high, but as the majority of leaks across valves occurred in positions where the valve acted as a barrier between two systems under vacuum, the effect of these leaks is not significant.

With reference to Figures 3 and 4 which illustrates the leak distribution of the various categories several items stand out.

No leaks on welds are found less than 1.10^{-6} mbar.l/sec. during installation leak tests, due it is thought to water vapour blocking any leak below this level and in fact only on flanges are leaks found less than that figure. The larger leaks of magnitudes $>1.10^{0}$ mbar.l/sec found during installation on the JET machine can be explained by clamps misaligned on V-band flanges or wrong type seals used on bolted flanges, welds in the wrong place or valves accidentally left partially open. On a machine as large and complex as the JET machine the last item is easily done.

Looking at Figure 5 in operational leaks the general leak spread tends to be over a greater range with more leaks at the top and bottom end. At the top end it is obvious that this is due in part to the number of catastrophic water leaks present and that leaks due to plasma disruption forces tend not to be small due to the high forces involved.

Obviously in the next generation of fusion machines all these factors need to be taken into account during the design of such a machine.

10.– Conclusion

Leaks and other vacuum related delays accounted for more then 10%

of the total machine operation delay time and constitutes 2.5% of the actual operation time loss[11]. This figure may well increase in future due to access restrictions, i.e. increasing radiation levels.

It is therefore important to apply and even extend the recommended leak prevention techniques. It is essential to protect sealing surfaces, bellows, feedthroughs and other sensitive components against damage.

The type of vacuum connection should be well considered and where possible a welded connection should be chosen. The weld lip design is recommended in particular.

For most of the occurring leak problems solutions have been presented for introduction into the design parameters of future fusion machines. Some problems like edge welded bellows still exist with the main emphasis on cooling of invessel components and welds failing under stress.

Wherever possible pre-assembled components must be tested up to or even in excess of the machine operation parameters. Whatever tests are carried out however to prove the components in advance nothing resembles the combination of temperature, temperature gradients, mechanical forces, magnetic forces and vacuum in machines like JET. Only during the experiments with these devices is the true character of the components revealed. That is why JET should continue to be a test bed for all future fusion machines.

11. Acknowledgements

We are grateful to K. J. Dietz and E. Usselmann for the contributions and the helpful discussions. We thank D. Holland and T. Johnson for their technical assistance.

12 References

(1) Winkel, T.G.A. and Hemmerich, J.L., " Helium leak detection in JET in the presence of high deuterium partial pressures.", Proc. 10th International vacuum congress, Baltimore, U.S.A., Oct. 1986.

(2) Usselmann, E., et al., " Vacuum system and Wall conditioning in JET.", Proc. 13th SOFT, Varese, Italy, Sept. 1984.

(3) Walravens, M., " The fabrication of the Jet Vacuum Vessel.", EUR-JET-R12, Eurotom, June 1983.

(4) Duesing., G., et al., " Neutral Beam Injection System.", Fusion Technology, Jan. 1987.

(5) Obert., W., et al., " Operation and Performance of Large Scale JET Cryopump System.", Proc. 14th SOFT, Avignon, France, 1986.

(6) Kupschus., P., et al., " The JET Multi- Pellet Injector Launcher - Machine Interface.", 12th symp. on Fusion Engineering, Monterey, U.S.A., Oct. 1987.

(7) Dietz., K. J., " Modifications to the JET Vacuum Vessel as result of Plasma Operation.", Proc. of EVC-1, Vacuum vol. 38,

Pergamon Press, 1988.

(8) Dean., J. R. and Raimondi., T., " JET Remote Maintenance during Active Operation.", Fusion Technology, Jan. 1987.

(9) Boschi., A., Dietz., K. J. and Rebut., P. H., " The Gas Introduction System on JET.", Proc. 13th SOFT, Varese, Italy, Sept. 1984, Vol. 1, P.247, Pergamon Press, (1984).

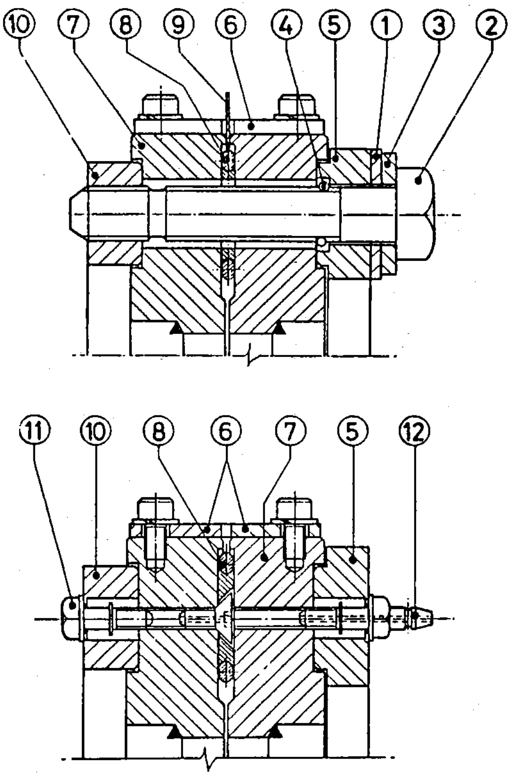
(10) Meriguet., P., To be published.

(11) Green., B. J., et al., " Machine utilisation and operation experiences with JET from 1983.", SOFT, Utrecht, The Netherlands, Sept. 1988.

Category	Type	Leak Frequency Assembly		Leak Frequency Operation		Installed Items	
		No	%	No	%	No	Leak %
Flanges	Bolted	31	22.5	4	2.9	185	18.9
	V Band	36	26.1	6	4.4	137	30.7
Welds	Lip Weld	14	10.1	1	0.7	114	13.2
	Butt Weld	3	2.2	1	0.7	375	0.8
	Fillet Weld	17	12.3	15	10.9	1235	2.8
	EB Weld	0	-	5	3.6	48	10.4
Non-Standard Seals	Al. Wire	0	-	6	4.4	11	54.5
	Ferrofluidic	0	-	2	1.5	6	33.3
	Conflat	2	1.4	1	0.7	115	2.6
	Miscellaneous	18	13.8	1	0.7	85	22.4
Windows	Water Damage	1	0.7	6	4.4	25	32.0
	Gold Sealed	2	1.4	4	2.9	16	37.5
	Accidental	0	-	1	0.7		
Bellows	Edge Welded	0	-	10	7.3	75	13.3
	Hydroformed	1	0.7	14	10.2	273	5.5
Feedthroughs and Gauges		3	2.2	15	10.9	196	7.7
Valves		10	7.2	30	21.9	57	70.2
Water Circuits	Beam Damage	0	-	3	2.2	62	24.2
	Component Leak	0	-	12	8.8		

Table 1.Leak Frequency Distribution by Categories

FIG 1



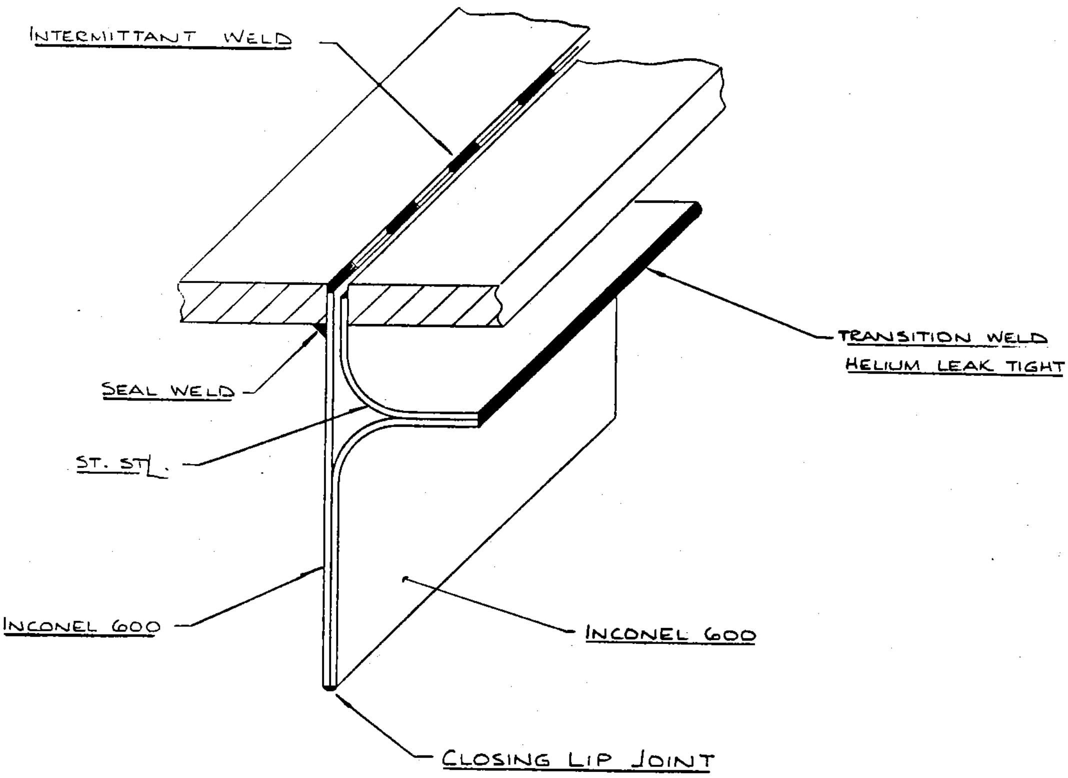
1. PLAIN WASHER
2. CAPTIVE BOLT POSITIVELY RETRACTED
3. BELVILLE WASHER.
4. CAPTURING CLIP.
5. HALF CAPTIVE RING.
6. LOCATING GUIDES.
7. FLANGE.*
8. HELICOFLEX SEAL (SINGLE OR DOUBLE**).
9. TAB FOR FIXING AND HANDLING SEAL.
10. HALF NUT-RING.
11. HALF NUT RING LOCKING BOLT.
12. HALF CAPTIVE-RING LOCKING BOLT (TWO WITH NOZZLE FOR HELIUM TEST).

* FLANGES ARE SYMMETRICAL. CAPTIVE RING AND NUT-HALF RING ARE INTERCHANGEABLE.

** TO AVOID BENDING THE FLANGE, THUS LIMITING SIZE.

FLANGE MATERIAL	BOLT MATERIAL
S.S. ≤ 300°C	316 Cold worked
S.S. > 300°C	660 PH
Inconel > 300°C	Nimonic 80A PH

FIG 2



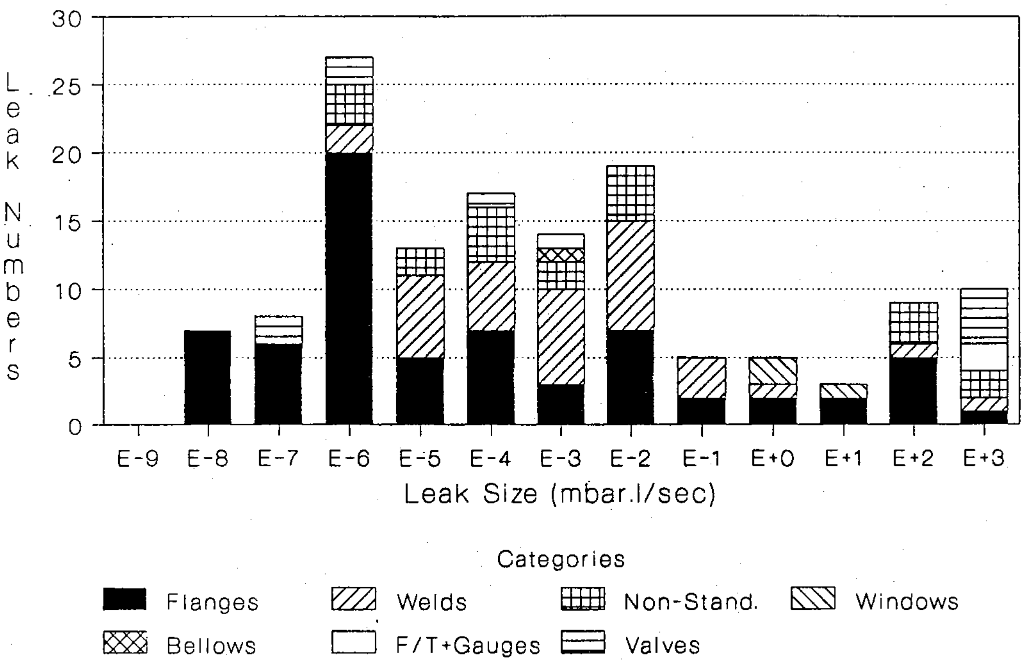


Fig.3 Bar Chart showing the distribution of sizes of leaks encountered during installation on the JET machine

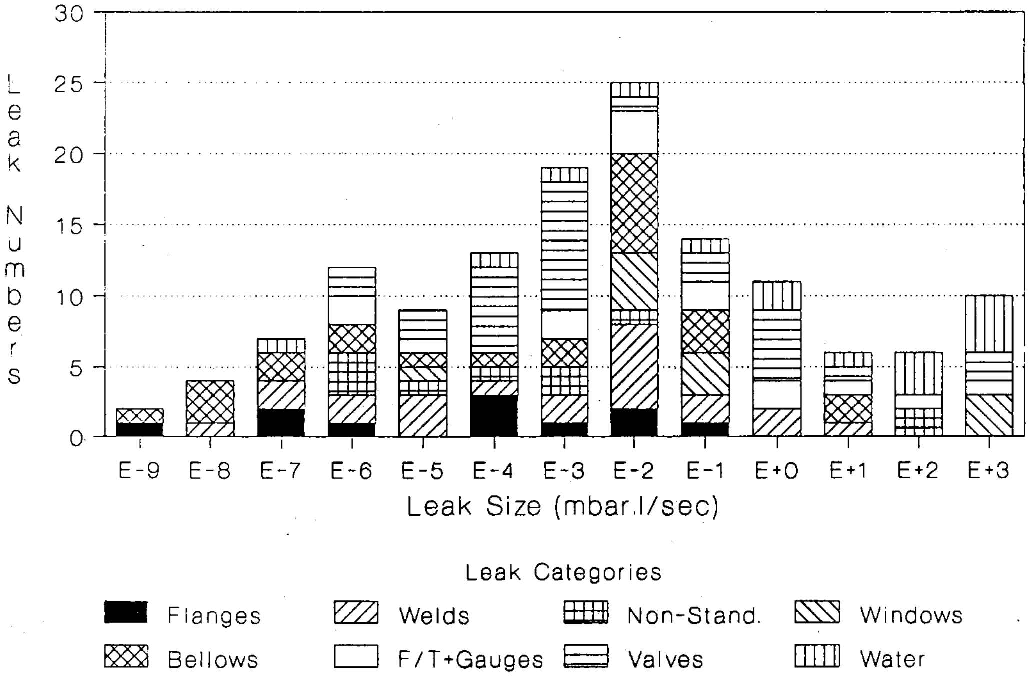


Fig.4 Bar Chart showing the leak size distribution of leaks occuring during the operation of JET.