Modification of the JET Vacuum Vessel Support and Restraint System

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1.0 SUMMARY

Since 1983, after the first plasma vertical instability, the support and restraint system has been continuously modified and upgraded to cope with the new design and operational requirement. Fig. 1 shows how the vessel supports and restraints have changed over the life of JET. With the divertor phase, new loads are applied to the vacuum vessel supports and restraints leading to a revision of the complete system.

The elastic suspensions at the equatorial plane have been modified to cope with the increase in vessel weight. The vessel restraints have been modified and tested to cope with the new electromagnetic load in equilibrium and plasma instability.
This paper briefly describes the overall philosophy of the vessel support system, the modification and the tests that have been done. Some experimental results are also reported on the behaviour of the supports and restraints.

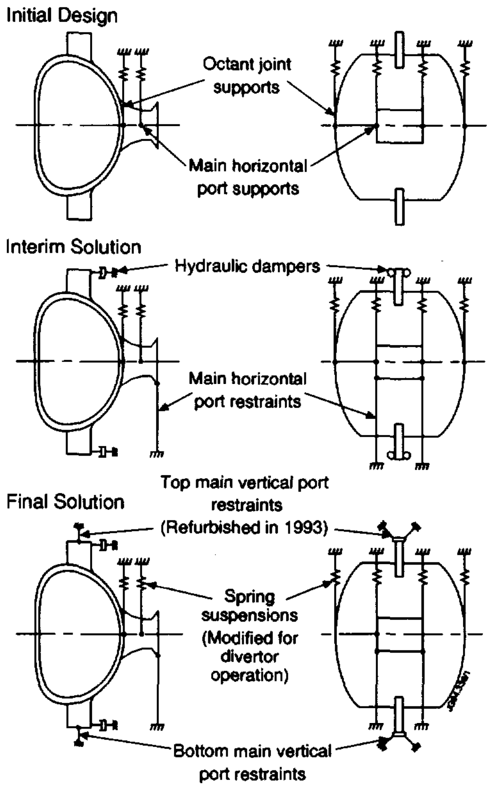


Fig. 1 JET vacuum vessel supports and restraint system from initial design to present day

2.0 THE VERTICAL LOADS ON THE VACUUM VESSEL

With the installation of the divertor coils and components inside the vacuum vessel, the total deadweight of the vessel has increased considerably from 145 tonnes (estimated) to 240 tonnes (measured).

The electromagnetic forces have also changed considerably. Before the installation of the divertor coils, the magnetic loads were mainly dynamic forces applied in a timescale of tenth of milliseconds in a plasma disruption or vertical instability. With the divertor coils inside the vessel, magnetic forces are exerted on the vessel during the whole length of the pulse. The maximum vertical static load on the vessel in a plasma equilibrium configuration is 5.1 MN. The maximum vertical disruption force on the vessel is estimated to be about 8-8.5 MN.

3.0 THE VESSEL SUPPORT AND RESTRAINT SYSTEM

The overall support system of the vacuum vessel is shown in fig. 2. It is composed of the elastic supports at the equatorial plane and the vertical restraints attached to the main vertical and horizontal ports.

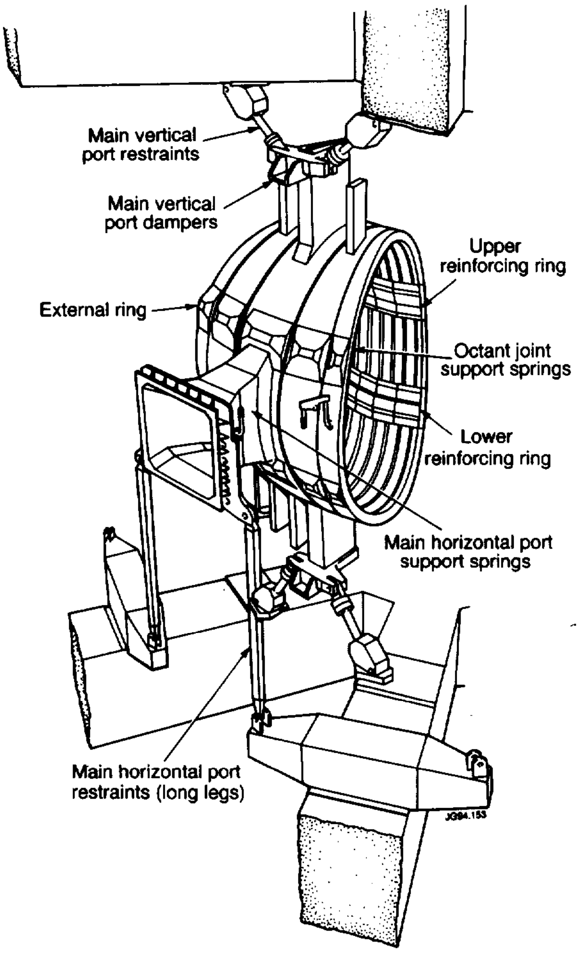


Fig 2 JET vacuum vessel supports and restraints

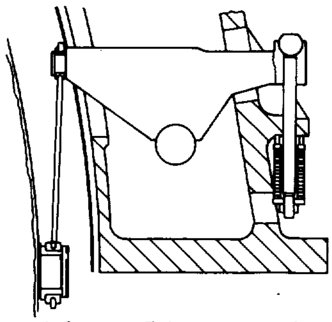
3.1 THE VESSEL ELASTIC SUPPORTS

The vacuum vessel dead weight is supported by 16 elastic suspensions at the octant joints (OJ) and 16 elastic suspensions at the vessel main horizontal ports.

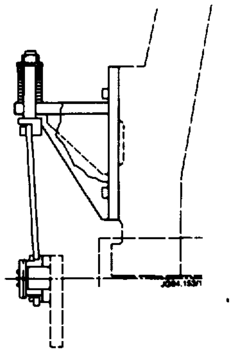
They are connected to the vessel at the equatorial plane in order to allow free and symmetric thermal expansion.

When the vessel is at room temperature, the vessel weight (240 tonnes) is completely taken by the elastic suspensions. (66% by OJ and 34% by MHP).

During the 1992-93 shutdown the elastic suspensions have been modified to cope with the increase in vessel weight. One of the major concern was the strength of the insulation bushes that avoid electrical shortage of the vessel with the mechanical structure. The substitution of them would have required a much longer shutdown. Some spare bushes, identical to those installed on the machines, have been mechanically tested without failure to 192 KN (0J suspensions) and 120 KN (MHP suspensions. These values are much larger than the maximum expected loads.



a) Octant Joint suspension



b) MHP suspension

Fig.3 Vacuum vessel elastic supports

During the vessel warm-up to the final temperature, part of the vessel weight (about 60 KN per octant) is transferred to the restraints at the bottom main vertical ports (MVP). That is obtained locking the bottom MVP brakes before the top ones.

In a plasma instability, the mechanical vertical oscillations of the vessel, generate an increase in the maximum compressive force on each octant joint suspensions up to 50 KN giving a maximum total load of 130 KN per OJ suspension.

3.2 THE VESSEL RESTRAINTS

The vessel restraints have the task of taking the vertical magnetic loads on the divertor coils and vacuum vessel during operation.

The restraints at the main horizontal ports (see fig. 2) hold the port in position in order to prevent any vertical load being transferred from/to all the equipment connected to the port. The proportion of the vertical magnetic force that they take in plasma operation is small (about 9%). Most of the load is taken by the main vertical port (MVP) restraints.

Each upper and lower MVP has two brakes assemblies (total 32) which mechanically connect each MVP to the horizontal transformer limbs as shown in figs. 2 and 4.

Each brake assembly is composed by a drum supported by springs and centered to a housing (1mm clearance on the radius). The support legs that links the drum to the vessel MVP flange is connected to the drum via a spheric bearing with an eccentricity of 20mm respect to the drum centre. During the vessel warm-up, the brake drum are free to rotate on roller bearings as the vessel expands vertically and displaces the leg into the brake housing.

The locking of the brakes is actuated by a device that is basically composed by a finger pressing against the drum with a forces of about 10 KN. The friction between the finger and the drum force the drum to rotate around the contact line and move toward the housing. As the two grit blasted surfaces of drum and housing get in contact, no further internal movement can take place and the subsequent vessel thermal expansion creates a compressive preload on the MVP. The lower MVP restraints are locked before the top ones in order to generate a total preload of about 2 MN and 1.5 MN on the lower and upper MVPs.

This thermal preload guarantees that the locking system is active during operation and reduces the vessel oscillations because all the clearances in the brake assemblies are already recovered when the vertical magnetic forces arise.

The MVP restraints have been designed to work mainly in compression. The thermal preload and the gaps in the brake assemblies guarantee that, even in very severe vertical instabilities, very small tensile forces are applied.

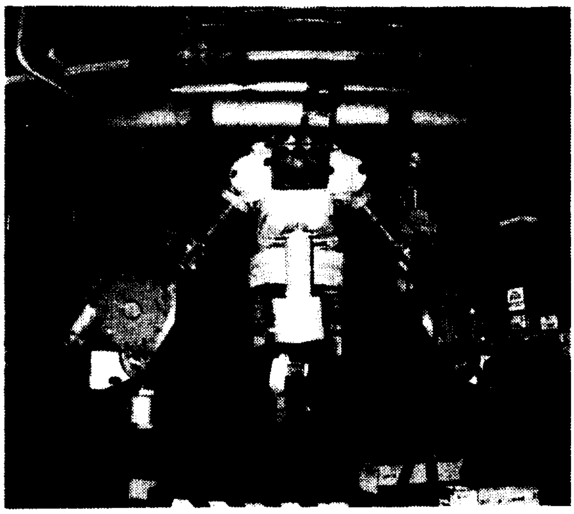


Fig.4 Vacuum vessel MVP restraints

The MVP restraints were installed in 1987 and had been used until 1992. During this operational period they showed a tendency to slip.

In the 1992-93 shutdown the contact surfaces of the drum and the housing have been remachined and grit blasted to increase the frictional force. A new frictional material has been used for the locking device.

The new refurbished brakes with the locking device have been tested statically (slowly increasing load up to 1.2 MN) and dynamically (vibration load at 15 Hz superimposed to different levels of preload).

4.0 OPERATIONAL EXPERIENCES

The MVP restraints are instrumented with strain gauges that are used to compute the applied vertical force. The readings from the strain gauges are monitored during every warm-up and cool-down phase to check the leg preload. Displacement transducers are also installed. They show whether the MVPs are moving freely.

The vessel temperature has been cycled several times from room to operational temperature. The brakes did not show any anomalous behaviour and the measured thermal preload obtained locking them before reaching the final temperature is in very good agreement with that predicted.

At the time of publishing this paper the performed number of JET pulses after the divertor installation is about 2800 (from JET PULSE No. 27968 to 30780). The maximum vertical force F_V on the MVP restraints is 1.8 MN for pulse 29429 (see fig. 5). This force is computed adding all the signals from the strain gauges. The maximum force on a single octant in the same pulse is 360 KN which is more than 1/8 of the vertical force F_V. This indicates that the reaction forces are not uniformly distributed.

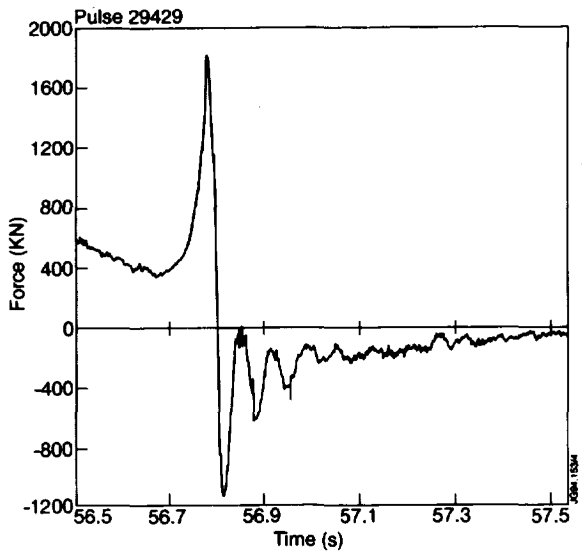


Fig. 5 Vertical force on MVP restraints in JET Pulse No: 29429

5.0 CONCLUSIONS

The MVP restraints and elastic supports have been successfully laboratory tested under static and dynamic conditions.

During operation the control system that locks and unlocks the MVP restraints has been commissioned successfully. The locking operation is done remotely as required for the tritium operation.

The vertical reaction forces due to the magnetic load in a vertical plasma instability are not uniformly distributed on the 8 octants. That could be due to dynamic mechanical effects and/or non symmetric distribution of the applied load.

6.0 REFERENCES

[1] P. Noll et al. - "Electromagnetic forces during JET divertor operation - Proceeding of the 23nd International EMF Workshop UTNL-R-0302 - TOKAI, JAPAN - Sept 1993.