Dynamic Analysis of Wetwell-to-Drywell Vacuum Breakers in BWR Mark I Containments

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Abstract

During steam condensation tests on BWR Mark I Containments, the wetwell-to-drywell vacuum breakers cycled repeatedly during the transient phase of steam blowdown. Since they were not originally designed for the loads resulting from this cycling, further investigation was warranted. A finite element analysis, and tests to confirm the analysis, showed that the valve was overstressed. An acceleration or velocity limiting mechanical snubber in conjunction with a suitable linkage was used to control the operation of the valve and, thus, maintain its functional and structural integrity.

1.0 Introduction

If a Loss-of-Coolant Accident (LOCA) should occur, a key element in the system designed to control the associated high pressures in a General Electric Boiling Water Reactor (BWR) Mark I Containment nuclear reactor is the wetwell-to-drywell vacuum breakers. This paper discusses the engineering effort to ensure the functional integrity of these valves for the new loads developed and defined during GE's Mark I Containment Program. In the first phase of the program, a finite element analysis using the new loads showed that stress levels in the valve exceeded applicable ASME Section II Code allowables. A subsequent test of a prototype valve confirmed the results of the analysis. In the second phase of effort, a linkage joining the moving pallet of the valve and a mechanical snubber fixed to the valve body were designed to control the motion of the pallet and, consequently, the stress levels associated with the impact of the pallet against the valve seat. Analysis showed that this arrangement would control the motion of the pallet yet not interfere with the functional requirements of the vacuum breaker. This novel approach was confirmed by the test of a vacuum breaker with the mechanism installed.

2.0 Statement of the Problem

The Mark I containment concept was the first of GE's BWR Nuclear Plant Designs. This is the familiar wet containment with a torus that contains the water pool for pressure suppression and a light, metal, drywell containment (Fig. 1) enclosing the reactor having the shape of a light bulb. Many of these plants were operating when new hydrodynamic phenomena associated with a LOCA were found, creating new loads and load combinations. Among the new loads were those on the wetwell-to-drywell vacuum breakers.

During the Full-Scale Test Facility (FSTF) steam condensation tests performed as part of GE's Mark I Containment Program, the wetwell-to-drywell vacuum breakers cycled repeatedly during the chugging phase (Fig. 2) of steam blowdown. Chugging is an oscillating differential pressure across the valve's pallet. This load was not included in the original load combinations used in the design of the vacuum breaker. Consequently, the repeated impact of the pallet on the valve seat and body created stresses that would impair its capability to remain functional. The primary purpose of these vacuum breakers is to prevent the formation of a negative pressure on the drywell containment during rapid condensation of steam in the drywell in the final stages of a LOCA. To prevent negative pressures, which the containment has very little chance of surviving, the vacuum breaker opens permitting air to flow into the drywell from the plenum above the suppression pool in the torus. Since the chugging phenomena precedes this depressurization stage of the LOCA, it is imperative that the vacuum breaker sustain the chugging loads without loss of function.

3.0 Analysis

A finite element analysis using the ANSYS computer program was made of the vacuum breaker. The forcing function was a modified time-history of the pressure differential across the pallet measured during the tests carried out at the FSTF. This analysis showed that the controlling factor was the impact velocity and resulting stress in the components of the valve. The linear relation found between impact velocity and stress was confirmed during subsequent tests of a full-size vacuum breaker.

It was clear that, to meet ASME code requirements, the impact velocity had to be controlled. A number of alternatives to mitigating the effects of vacuum breaker cycling were investigated.

4.0 Alternatives to Problem Solution

Since the details of Mark I configurations vary slightly, it was necessary to look at a number of alternate solutions. For some plants, the overstressed components of the vacuum breaker could be replaced with a stronger material to meet ASME Code requirements. For others, it was clear that a mechanical device had to be added to the valve.

Our first alternative was to add a weight to the pallet to reduce its motion. While this added inertial mass reduced the velocity of the pallet, it did not significantly reduce the kinetic energy associated with the motion of the pallet. Stresses in the valve were still too high. Secondly, a friction type damper was attached to the pallet to dissipate energy. However, it was learned that these devices also had a fairly large spring constant; and, under some conditions, it actually intensified the problem.

After investigating these various alternatives, it was found that a mechanical snubber was most attractive. The internal parts of these devices could be machined to produce the required values of limiting acceleration or velocity, and they could be attached to the pallet with a suitable linkage. The design was to be generic with the requirement that it could later be made plant unique.

A mechanical snubber was chosen over a hydraulic one because, if the hydraulic snubber should leak, it would contaminate the water in the suppression system. Both types of snubbers have the same surveillance period (3).

The only drawback to using a mechanical snubber is its mode of failure. Recent failures of mechanical snubbers have shown that they fail by locking. However, it was believed that, with adequate surveillance, this problem could be avoided.

5.0 Generic Modification of the Vacuum Breakers

These investigations concluded that a mechanical snubber with a suitable linkage was the most practical approach. Since a mechanical snubber had not been used in this application before, analytical techniques had to be developed and confirmed by testing.

The snubber was attached to the valve body and a linkage was fitted between the snubber's moving end and the pallet (Fig. 4). This device in no way prevented the vacuum breaker from functioning as originally intended. The time required for the pallet to open fully under a given pressure differential and to close from the open position were still within the design specifications. Furthermore, although the linkage was in the flow area of the valve, the reduction in the flow area was shown by analysis to be insignificant. Consequently, all design criteria were met.

Two mechanical snubbers were tested and analyzed. The first snubber tested was the Pacific Scientific acceleration limiting snubber model PSA-3 in which a constant force produces a constant acceleration. The second snubber was the Anchor-Darling velocity limiting snubber Model AD-1602 in which a constant force produces a constant velocity. This latter snubber was modified by machining the internal parts to obtain a limiting velocity of about 1.75 cm/sec.

Although both snubbers prevented overstress as a result of the impact between pallet and valve seat, the latter snubber was preferred since it controlled the impact velocity directly. Both snubbers performed flawlessly while preventing the overstress and and yet permitting the vacuum breakers to function as intended. The times to open and close were not adversely affected by installation of the linkage and snubber. This was to be expected since the entire system has low friction and inertia. The snubber and linkage was installed on the prototype valve to the left of the air actuator assembly (Fig. 3). Thus, this system which is used to test valve operability was not impaired.

6.0 Conclusion

The significant result of this investigation is the demonstration that mechanical snubbers can be used in applications wherever it is necessary to control unwanted motion. Heretofore, they have been used solely on piping systems and the components usually associated with these systems.

The installation of this device with a suitable linkage permitted ASME Code allowables to be met without a reduction in the operability or functionality of the valve. Flow characteristics through the valve were insignificantly reduced by the installation of the linkage. Furthermore, testing showed that both snubbers possessed the necessary fatigue properties to meet the ASME Section III Code requirements.

7.0 References

/ 1 / "Mark I Containment Program Full-Scale Test Program Final Report," General Electric Co. Report, NEDE-24539, April 1979.

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/ 3 / "Technical Specification Revisions for Snubber Surveillance," U.S. Nuclear Regulatory Commission, November 1980.

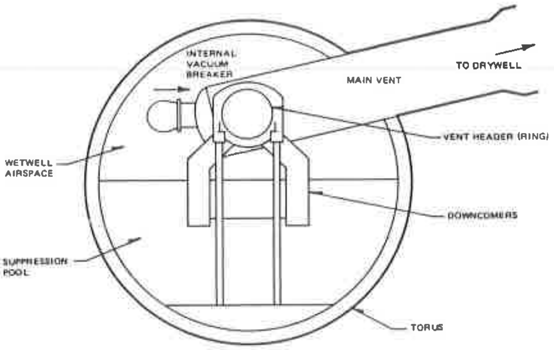

Fig. 1 VACUUM BREAKER INSTALLATION

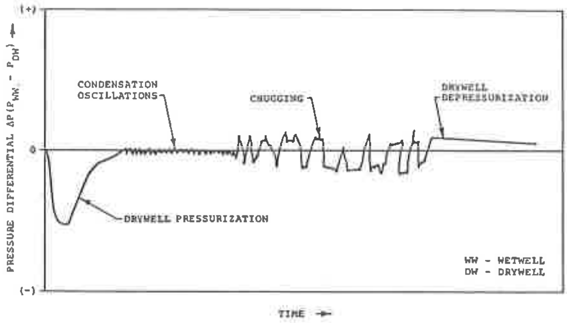

Fig. 2 TYPICAL PRESSURE DIFFERENTIAL ACROSS VACUUM BREAKER DURING LOCA

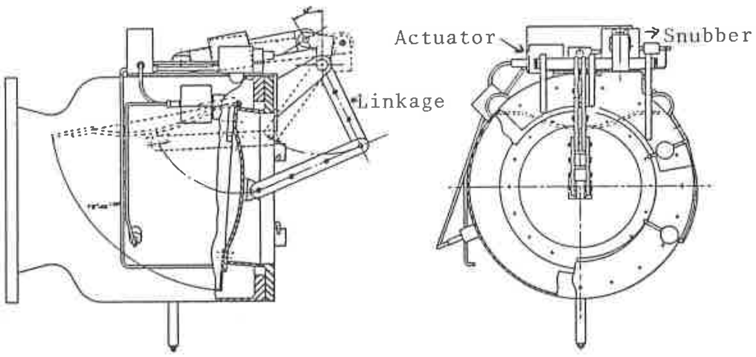

Fig. 3 MODIFIED VERSION OF VACUUM BREAKER