United States Environmental Protection Agency

United States Occupational Safety and Health Administration

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EPA
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SHAFT BLOW-OUT HAZARD OF CHECK AND BUTTERFLY VALVES

The Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) are issuing this *Alert* as part of their ongoing efforts to protect human health and the environment by preventing chemical accidents. Under CERCLA, section 104 (e), the Clean Air Act (CAA), and the Occupational Safety and Health Act (OSH Act), EPA and OSHA have authority to conduct chemical accident investigations. Additionally, in January 1995, the Administration asked EPA and OSHA to jointly undertake investigations to determine the root cause(s) of chemical accidents and to issue public reports containing recommendations to prevent similar accidents. EPA and OSHA have created a chemical accident investigation team to work jointly in these efforts. Prior to the release of a full report, EPA and OSHA intend to publish *Alerts* as promptly as possible to increase awareness of possible hazards. *Alerts* may also be issued when EPA and OSHA become aware of a significant hazard. It is important that facilities, SERCs, LEPCs, emergency responders and others review this information and take appropriate steps to minimize risk.

CHEMICAL SAFETY ALERT

PROBLEM

Certain types of check and butterfly valves can undergo shaft-disk separation, and fail catastrophically or "blow-out", causing toxic and/or flammable gas releases, fires, and vapor cloud explosions. Such valve failures can occur even when the valves are operated within their design limits of pressure and temperature.

ACCIDENT HISTORY

In a 1997 accident, several workers sustained minor injuries and millions of dollars of equipment damage occurred when a pneumatically assisted Clow stub-shaft Model GMZ check (non-return) valve in a 300 psig flammable gas line underwent shaft blow-out. The valve's failure caused the rapid release of large amounts of light hydrocarbon gases which subsequently ignited, resulting in a large vapor cloud explosion and fire.

The check valve was designed with a drive shaft that connects the internal valve disk to an external pneumatic cylinder (see diagram on next page). The valve failed when a dowel pin designed to fasten the drive shaft to the disk sheared and a key designed to transfer torque from the drive shaft to the disk fell out of its keyway, disconnecting the drive shaft from the disk. System pressure was high enough to eject the unrestrained drive shaft from the valve, carrying with it the external counterweight assembly, weighing over 200 lbs., a distance of 43 feet away.

The absence of the drive shaft left a hole in the valve body the diameter of the shaft (3.75 inches) directly to atmosphere, and initiated a high-pressure light hydrocarbon leak. The leak continued for approximately 2 to 3 minutes, forming a large cloud of flammable light hydrocarbon vapor. The vapor cloud ignited, resulting in an explosion felt and heard over 10 miles away. The explosion and ensuing fire caused extensive damage to the facility, completely or partially destroying many major components, piping systems, instruments, and electrical systems, and requiring the complete shut-down of the affected unit for cleanup and repair. Minor damage occurred to nearby residences and automobiles (mostly broken glass and minor structural damage due to the blast wave). Nearby highways were closed for several hours. Damage cost to the facility alone is estimated at approximately 90 million dollars. Fortunately, no fatalities and only minor injuries to workers resulted from the accident.

Previous malfunctions involving check valves of the same or similar design occurred at facilities in 1980, 1991, and 1994. In each case, the affected check valve was located in a large diameter (36-inch or greater) pipe in a hydrocarbon gas compression system. Also in each previous case, a dowel pin fastening the valve's drive shaft to its disk sheared (in the 1980 case the pin was possibly never installed) and a rectangular key fell out of its keyway, disconnecting the drive shaft from the disk. Although shaft-disk separation occurred in each previous case, it did not result in shaft blow-out or catastrophic failure. This may be because the valves in these instances were installed in lower-pressure service, or because the malfunctioning valves were identified before shaft blow-out occurred.

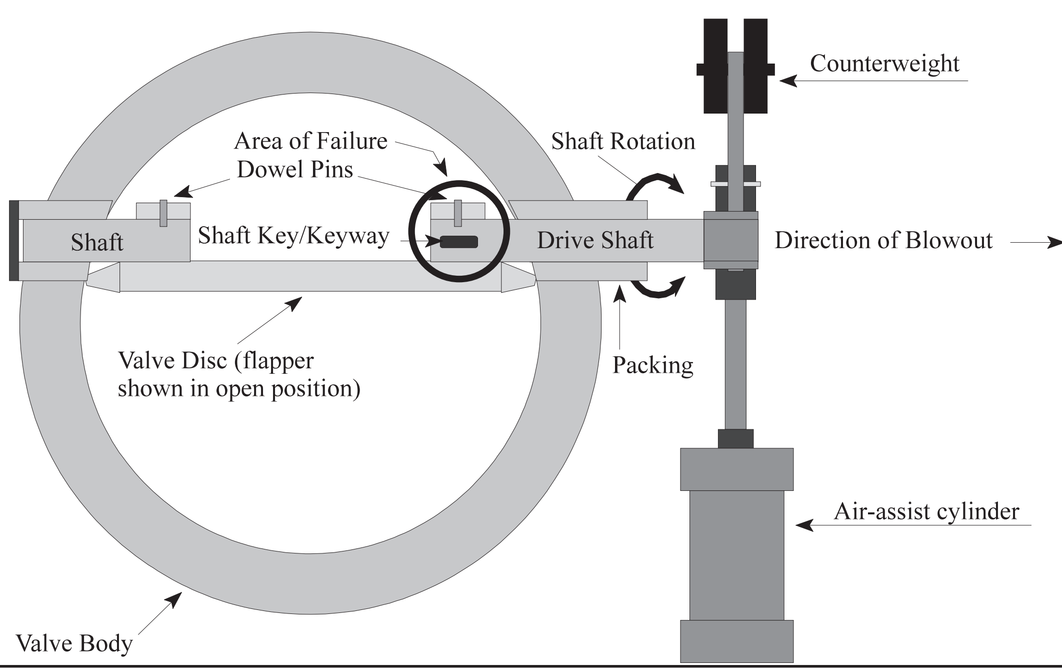
In the 1991 incident, the malfunction was manifested by the erratic operation of the valve, which was observed to operate independently from its external drive mechanism. System pressure was low enough (70 psig) that the failure was detected before the shaft was expelled out of the valve body. (At the time the malfunctioning valve was identified, the valve shaft was protruding about 0.75 inches out of the valve body.) In the 1980 and 1994 cases, the malfunction was identified when workers noted that the external piston rod connecting the air-assist cylinder to the drive shaft had broken due to axial movement of the drive shaft.

Hazard Awareness

Check and butterfly valves are used in many industries, including refineries, petrochemical plants, chemical plants, power generation facilities, and others. Most modern valve designs incorporate features that reduce or eliminate the possibility of shaft blow-out. However, older design check and butterfly valves with external appendages such as pneumatic-cylinders, counterweights, manual operators, or dashpots may be subject to this hazard. Shaft blow-out may be of particular concern wherever these valves are installed in systems containing chemicals leading to hydrogen embrittlement.

Valves subject to this hazard may be designed with a two-piece valve stem (sometimes referred to as a "stub-shaft" design). In each of the cases described above, the malfunctioning component was a Clow stub-shaft Model GMZ pneumatically assisted swing check valve (see diagram below). In these check valves, one stem piece functions as a drive shaft that connects the internal valve disk to an external air-assist cylinder and counterweight assembly. The drive shaft penetrates the pressure boundary through a stuffing box. The exterior portion of the drive

Simplified cross-sectional view of check valve (flow direction is into page)



shaft is connected to a pneumatic piston and counterweight, and the interior portion of the shaft is coupled directly to the valve disk using a cylindrical hardened steel dowel pin and a rectangular bar key. This arrangement provides a power-assist to close the valve during compressor shut down, preventing reverse flow of compressed gases. These particular valves have probably not been produced since 1985, but still exist in some process facilities constructed before that date. Similar valves currently or previously produced and sold by other valve manufacturers may also be subject to this hazard.

Factors in Valve Failure

A number of design and operational factors may contribute to this hazard. These include the following:

Design Factors

- The valve has a shaft or stem piece which penetrates the pressure boundary and ends inside the pressurized portion of the valve. This feature results in an unbalanced axial thrust on the shaft which tends to force it (if unconstrained) out of the valve.

- The valve contains potential internal failure points, such as shaft dowel-pins, keys, or bolts such that shaft-disk separation can occur inside the valve.

- The dimensions and manufacturing tolerances of critical internal parts (e.g., keys, keyways, pins, and pin holes) as designed or as fabricated cause these parts to carry abnormally high loads (e.g., in the 1997 accident, the dowel pin rather than the key transmitted torque from the shaft to the disk).

- The valve stem or shaft is not blow-out resistant. Non blow-out resistant design features may include two-piece valve stems that penetrate the pressure boundary (resulting in a differential pressure and unbalanced axial thrust as described above), single-diameter valve shafts (i.e., a shaft not having an internal diameter larger than the diameter of its packing gland) or shafts without thrust retaining devices, such as split-ring annular thrust retainers.

Operational Factors

- The valve is subject to high cyclic loads. In all of the above incidents, the valve repeatedly slammed shut with great force during compressor trips and shutdowns. Such repeated high stresses may cause propagation of intergranular cracks in critical internal components, such as dowel pins.

- The valve is subject to low or unsteady flow conditions, such that disk flutter or chatter occur, resulting in increased wear of keys, dowel pins, or other critical internal components.

- Valves in high-pressure service lines may be more likely to undergo shaft blow-out (in the 1997 accident, system pressure at the failure point was approximately 300 psig).

- Valves used in hydrogen-rich or hydrogen sulfide-containing environments may be more susceptible to blow-out due to hydrogen embrittlement of critical internal components, particularly if these are made from hardened steel (as was the dowel pin in the 1997 accident).

Hazard Abatement

Facilities should review their process systems to determine if they have valves installed that may be subject to this hazard. If so, facilities should conduct a detailed hazard analysis to determine the risk of valve failure. Check valves or butterfly valves which are subject to several or all of the above design and operational factors are at high risk for shaft blow-out. Detailed internal inspections may be necessary in order to identify high-risk valves. <u>Facilities should consider replacing high-risk valves at the earliest opportunity with a blow-out resistant design.</u> Several blow-out resistant designs of check and butterfly valves are available. If immediate valve replacement is impossible or impractical, facilities should consider immediately modifying the valves to prevent shaft blow-out. Valve manufacturers should be consulted in order to ensure that any modifications made are safe.

Information Resources on Valve Safety

Some sources of information on valve safety are listed below.

General References

Information on cases of valve failure can be found in T. Kletz, *What Went Wrong?*, 3rd Edition, Gulf Publishing Co., Houston (1994). This reference contains general information related to check valve failure (pp 127, 129, and 175) and cites one specific case of check valve failure (page 124) similar to those described in this *Alert*.

Information on hydrogen embrittlement can be found in F.P. Lees, *Loss Prevention in the Process Industries: Hazard Identification, Assessment, and Control*, 2nd edition, Butterworth-Heinemann Publishing, Oxford (1996), pp 12/82-83.

Codes, Standards, and Regulations

The American Society of Mechanical Engineers (ASME) has a standard for valves.

American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017
or
22 Law Drive
Fairfield, NJ 07007-2900
Phone: (800) 843-2763
Web site: http://www.asme.org

Relevant ASME standards include:
ASME B16.34-1996 — Valves - Flanged, Threaded, and Welding End, an American National Standard.

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The American Petroleum Institute (API) has several relevant standards and Recommended Practices.

American Petroleum Institute
1220 L Street NW
Washington, DC 20005
Phone: (202) 682-8000
Web site: http://www.api.org

Relevant API standards include:
API 598-1996 — Valve Inspection and Testing

API 570-1993 — Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-Service Piping Systems

API 941-1991 — Steels for Hydrogen Service at Elevated Temperatures and Pressure in Petroleum Refineries and Petrochemical Plants

Relevant API Recommended Practices include:

RP 574-1992 — Inspection of Piping, Tubing, Valves and Fittings

RP 591-1993 — User Acceptance of Refinery Valves

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Applicable regulations include:

29 CFR 1910.119 Process Safety Management of Highly Hazardous Chemicals; Explosives and Blasting Agents.

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For More Information...

Contact EPA's Emergency Planning and Community Right-to-Know Hotline

(800) 424-9346 or (703) 412-9810
TDD (800) 553-7672

Monday-Friday, 9 AM to 6 PM, eastern time

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Visit OSHA's Home Page on the World Wide Web at:

http://www.osha.gov/