Primatech White Paper - How to Conduct a Damage Mechanism Review (DMR)

DMRs are now considered an essential precursor to PHA studies and they play an important part in MI programs and MOC reviews. A procedure for performing DMRs is described in the white paper, How to Conduct a Damage Mechanism Review .

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PRIMATECH WHITE PAPER

HOW TO CONDUCT A DAMAGE MECHANISM REVIEW (DMR)

Abbreviations

Abbreviation	Meaning
API	American Petroleum Institute
CML	Corrosion monitoring location
DMR	Damage mechanism review
HAZOP	Hazard and operability
MI	Mechanical integrity
MOC	Management of change
OSHA	Occupational Safety and Health Administration
PFD	Process flow diagram
PHA	Process hazard analysis
PSM	Process safety management
P&ID	Piping and instrumentation drawing
RBI	Risk-based inspection

Introduction

A damage mechanism is a mechanical, chemical, physical or other process that results in equipment or material degradation. Damage mechanisms result in flaws and defects that affect the integrity of process piping, vessels, and

other equipment. For example, virtually all crude oil feeds contain sulfur compounds and, as a result, sulfidation corrosion is a damage mechanism present at refineries that process crude oil. Sulfidation corrosion can cause thinning to the point of pipe failure when not properly monitored and controlled. Many different damage mechanisms exist [1]. Table 1 provides examples of different types of damage mechanisms. Table 2 provides examples of process safety incidents that resulted from such causes. The occurrence of such incidents demonstrates the importance of addressing damage mechanisms in process safety.

A damage mechanism review (DMR) identifies potential process damage mechanisms, and the consequences of failures that may result from them, to help ensure that hazards they cause are properly identified and analyzed and effective safeguards are in place to control the hazards and/or new systems are implemented to control or eliminate the hazards.

A knowledge of equipment damage mechanisms is important when developing mechanical integrity (MI) and risk-based inspection (RBI) programs to establish inspection and testing plans, including corrosion monitoring locations (CMLs). It is also necessary when conducting management of change (MOC) reviews and performing process hazard analysis (PHA) studies.

On October 1, 2017 , the Division of Occupational Safety and Health within the California Department of Industrial Relations amended its process safety management (PSM) regulations for petroleum refineries in California to

include requirements for conducting DMRs, preparing DMR reports, and addressing DMR reports during PHA studies [2]. However, no guidance for performing DMRs or addressing DMR reports in PHA was provided or referenced.

Currently, there are no industry standards governing the performance of DMRs. API RP 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry* , contains a compilation of different types of damage mechanisms. The document provides a description of each mechanism, a list of materials susceptible to the mechanism, inspection guidelines for the mechanism, and measures that can be taken to prevent the mechanism. It is a valuable reference for performing DMRs.

The Energy Institute, an industry technical working group organized in the United Kingdom (UK), with contributions from regulators, including the UK's Health and Safety Executive, as well as other entities, developed a document in 2008 that provides guidance on damage mechanism hazard reviews in the UK's offshore petrochemical industry [3]. The guidance notes that damage mechanism hazard reviews should provide a structured framework for identifying risks associated with corrosion and developing suitable risk reduction measures, and that these reviews should cover failure mechanisms including, but not limited to, corrosion, environmental cracking, erosion, and mechanical damage, such as vibration induced fatigue. The guidance states that a formal, documented quantitative and logic-based assessment should be used when

conducting corrosion reviews.

DMRs are new in the context of process safety . This white paper provides guidance on how to conduct DMRs to support process safety management activities, including PHA studies.

Damage Mechanisms

Damage mechanisms may cause the failure of process equipment resulting in loss of containment or impaired operability of equipment. They may cause damage to equipment that contains hazardous materials, such as tanks and reactors, or through which hazardous materials flow, such as piping, valves and pumps. Damage mechanisms also may affect equipment safeguards that protect against process incidents, such as fireproofing, dikes, and deluge systems. Some safeguards may be in contact with process fluids, such as flame arresters, while other are not, such as barriers and fireproofing. Damage mechanisms can exist for either case. Damage mechanisms also may affect equipment in utilities and support systems whose failure may impact on or result in a process safety incident.

Damage mechanisms can arise internally or externally, such as from internal or external corrosion. They can affect not only equipment or materials made from metals, including alloys, but also others, such as polymers, including plastics; ceramics, including refractories; composites, including concrete; and glasses.

Damage mechanisms may apply to a particular part of a process or throughout a process, that is, they may be local or global. For example, one particular vessel may be susceptible to low temperature embrittlement but piping throughout a process may be susceptible to corrosion. Damage mechanisms can be considered to include failures due to causes such as liquid hammer and vibration.

The susceptibility of equipment to damage mechanisms depends on numerous factors such as materials of construction; chemicals present, including contaminants; process operating conditions; operating and maintenance regimes; environmental conditions; and process history.

Performance of DMRs

A DMR may be performed for an entire facility or each process within it may be studied separately depending on the types of damage mechanisms present. Damage mechanisms may affect particular or all parts of a process. Consequently, processes are subdivided into sections for analysis in a similar manner to performing PHA studies where, for example, Hazard and Operability (HAZOP) studies use nodes, defined as pipe sections and vessels. There does not need to be a one-to-one correspondence between the sections used in the DMR and PHA. Certainly, it is possible that damage mechanisms may be possible only for some process sections or that the same mechanism(s) may be present in multiple sections. Of course, the possible presence of damage mechanisms must be considered for all parts of a process.

DMRs must consider all materials of construction that may be subject to damage mechanisms, for example, not just piping but also fittings, connectors, and welds.

DMRs should be performed by a team with expertise in engineering, equipment and pipe inspection, damage and failure mechanisms, and the operation of the process under review. Individuals whose expertise covers possible damage mechanisms for the process are needed. Typical team members may include:

- Materials scientist
- Metallurgical engineer
- Reliability engineer
- Maintenance engineer
- Process engineer
- Process safety engineer
- Facilitator

Information needed to perform a DMR includes:

- Process flow diagrams (PFDs) and piping and instrumentation drawings (P&IDs)

• Equipment specifications

• Equipment fabrication records

• Materials of construction

• Process materials

• Presence of contaminants

• Presence of corrosives

• Safety data sheets (SDSs)

• Heat and energy balances

• Operating and maintenance regimes

• Environmental factors

Information is needed for all process operating modes.

DMRs should be completed for each existing and new process for which damage mechanisms exists. All modes of process operation should be addressed. DMRs should be revalidated on the same schedule as PHAs.

DMRs should be completed for processes before PHAs are performed. DMRs should be reviewed as part of a major change on a process for which damage mechanisms exist. If a major change may introduce a damage

mechanism, a DMR should be conducted. Where a damage mechanism is identified as a contributing factor in an incident investigation for a process and a DMR has not been performed, a DMR should be conducted.

Items to Address in a DMR

Key items to be addressed in a DMR include:

• Identification of potential damage mechanisms. This information must be provided to PHA study teams and MOC reviewers.

• Determination that the materials of construction are appropriate for their application and resistant to potential damage mechanisms. Changing materials may be less expensive than the costs of incurring an incident.

• Methods to prevent the occurrence of damage mechanisms or mitigate damage that may occur considering the design intent and operating envelope for the process. This is particularly important for new processes where an opportunity exists to incorporate safeguards that may not have been considered.

• Identification of operating parameters that affect damage mechanisms. Such information allows PHA teams to recognize circumstances in which process conditions may accelerate or worsen damage. Also, it allows recommendations to be made to modify process conditions to minimize or eliminate damage.

• An assessment of previous experience with damage mechanisms for the

process, including the inspection history. Loss of corporate memory is a real phenomenon. The identification of previous problems can help prevent future ones.

• A review of industry-wide experience with the process. Learning from the experience of others is an inexpensive way of avoiding the same problems.

• Identification of applicable standards, codes and best industry practices. Requirements relating to damage mechanisms are contained in various places and should be identified and addressed. Standards, codes and practices embody lessons learned over the lifetime of an industry and should not be neglected. In some cases they may be required by law.

Procedure for DMRs

Typically, DMRs are recorded in a worksheet (see Figure 1). DMRs can be accomplished by following these steps:

Step 1. Identify process sections for study and their design intentions

Processes are divided into sections for study. Sections can be defined in a similar way to HAZOP nodes, that is as lines and vessels, or What If systems, that is, as combinations of lines and vessels. Alternatively, process sections can be defined as corrosion circuits. Corrosion circuits are process sections that share common damage mechanism susceptibilities. They have similar:

• Process stream compositions

• Operating conditions (pressure, temperature, etc.)

• Materials of construction

• Phases (liquid, vapor, etc.)

• Operating envelopes

• Startup and shutdown considerations

• Equipment characteristics (type of insulation, presence of heat tracing, types of coatings, etc.)

• Environmental conditions

Some damage mechanisms are specific to individual pieces of equipment. Others may apply throughout the process and can be addressed in a global node or system.

Design intention covers all factors that may influence which damage mechanisms are possible for a process section. They must be specified so that damage mechanisms can be identified. In particular, the presence of process materials or contaminants that can accelerate corrosion should be noted. Such chemicals include:

• Acids

• Carbon dioxide

• Chlorides

• Cyanides

• Hydrogen sulfide

• Oxygen

Step 2. Identify equipment items in the process section

All the pieces of equipment within each process section that are susceptible to damage mechanisms must be listed in the DMR worksheet. Both equipment names and tag numbers, or other identifiers, should be recorded. Some practitioners add a Description column to the worksheet to provide more information for each equipment item, e.g. design specifications.

Step 3. Identify materials of construction for equipment items

Pieces of equipment may contain multiple different types of construction materials. For each piece of equipment, all construction materials that are susceptible to damage mechanisms must be listed. Some pieces of equipment may be susceptible to the same damage mechanisms and they can be grouped together in the worksheet.

Step 4. Damage mechanisms

Damage mechanisms that are possible for the materials of construction for each piece of equipment in a section are listed. Reference sources on

possible damage mechanisms, such as API 571, and company data are consulted to identify those possible. The feasibility of particular damage mechanisms depends on the design intent for the section, that is the materials of construction, operating conditions, operating regime, etc.

Some practitioners add worksheet columns to record information on damage mechanisms such as expected damage rates, susceptible locations, etc.

Step 5. Conditions

Those operating parameters that affect the damage mechanisms identified must be listed. They allow the PHA team to recognize circumstances in which process conditions may accelerate or worsen damage. Also, it allows recommendations to be made to modify process conditions to minimize or eliminate damage.

Step 6. Effects

The consequences of equipment failure resulting from each damage mechanism are recorded in the Effects column of the worksheet. The effects may be hazardous material releases, or the impairment of equipment including safeguards, utilities, and support systems.

Step 7. Safeguards

Safeguards that are in place to protect against the occurrence or the

effects of each of the damage mechanisms are listed. Safeguards include items such are corrosion coupons that monitor corrosion rates, use of protective coatings, and alarms on process parameters such as temperature with operator response .

Step 8. Recommendations

Recommendations are made for any additional safeguards and an assignment of responsibility is made for each recommendation. Decisions on the need for recommendations is made based on the existing safeguards present. Some practitioners use criticality or risk rankings to assist in the determination.

DMR Reports

At the conclusion of a DMR, a written report should be prepared, which includes:

• Process description including process drawings

• DMR approach used

• Team members and their qualifications

• Data sources employed

• DMR worksheets

• List of recommendations for temporarily mitigating or preventing damage mechanisms

• List of recommendations for permanently mitigating or preventing damage mechanisms

Recommendations from DMRs should be implemented as soon as possible, preferably before PHAs are conducted. DMR reports should be retained for the life of the process and made available to stakeholders.

Conclusions

The results of DMRs are needed to support process safety activities such as MI programs, MOC reviews, and PHA studies. DMRs are valuable not only for petroleum refineries but also for any facility where equipment failures may result in catastrophic accidents.

References

1. API 571: *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry* , 2nd Edition, April 2011.

2. General Industry Safety Order (GISO) §5189.1 *Process Safety Management for Petroleum Refineries* , State of California, Department of Industrial Relations, Division of Occupational Safety and Health, October 1, 2017 .

3. Energy Institute, *Guidance for Corrosion Management in Oil and Gas Production and Processing* , May 2008.

Table 1. Damage Mechanisms.

Type	Examples
Mechanical loading	Ductile fracture, brittle fracture, mechanical fatigue and

failures	buckling
Erosion	Abrasive wear, adhesive wear and fretting
Corrosion	Uniform corrosion, localized corrosion and pitting, sulfidation corrosion
Thermal-related failures	Creep, metallurgical transformation and thermal fatigue
Cracking	Stress-corrosion cracking
Embrittlement	High-temperature hydrogen attack, low temperature metal embrittlement

Table 2. Examples of Incidents Involving Damage Mechanisms .

Incident	Consequences	Damage Mechanism
Esso Gas Plant, Longford, Australia, 1998	Explosion and fire. 2 fatalities, 8 injuries. Destruction of one plant and shutdown of two others. Loss of gas supplies to businesses.	Low temperature metal embrittlement
Bethune Point Wastewater Treatment Plant, City of Daytona Beach, FL, 2006	Explosion and fire. 2 fatalities, 1 critical injury. The aluminum flame arrester on a methanol tank had corroded to the point that it no longer functioned.	Corrosion of aluminum by methanol
Silver Eagle Refinery, Woods Cross, UT, 2009	Explosion that damaged nearby homes.	Sulfidation corrosion
NDK Crystal, Inc., Belvidere, IL, 2009	High-pressure vessel rupture. One public fatality, one public injury.	Stress corrosion cracking. Temper embrittlement, or some other form of heat treatment embrittlement, may have been a contributing factor .
Tesoro Petroleum Refinery,	Explosion and fire. 7 fatalities.	High temperature hydrogen attack

Anacortes, WA, 2010		
Millard Refrigerated Services, Theodore, AL, 2010.	One employee and 152 offsite workers sustained injuries. 32 workers were admitted to the hospital, and four were placed in intensive care.	Hydraulic shock
Chevron Refinery, Richmond, CA, 2012	15,000 members of the public sought treatment for various ailments including breathing problems. Approximately 20 people were admitted to local hospitals as inpatients for treatment.	Sulfidation corrosion

Figure 1. Example of DMR Worksheet.