GUIDELINES FOR

MECHANICAL INTEGRITY SYSTEMS

An AIChE Technology Alliance
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Center for Chemical Process Safety

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GUIDELINES FOR
MECHANICAL INTEGRITY SYSTEMS

This book is one of a series of publications available from the Center for Chemical Process Safety. A computer list of titles appears at the end of this book.

GUIDELINES FOR
MECHANICAL INTEGRITY SYSTEMS

Center for Chemical Process Safety of the
American Institute of Chemical Engineers

An AIChE Industry
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ITEMS ON THE WEB ACCOMPANYING THIS BOOK

LOCATION

The following files can be found at:

http://www.aiche.org/ccps/resources/publications/books/guidelines-mechanical-integrity-systems

Password: Integrity2008

Chapter 4 Resources

- *Imperfection vs. type of NDE method,* ASME Section V, Article 1, Nonmandatory Appendix A (reproduced with permission)
- Common RAGAGEPs
- Example condition monitoring (CM) techniques:
  - Temperature measurement
  - Dynamic monitoring
  - Oil analysis
  - Corrosion analysis
  - Nondestructive testing (NDT)
  - Electrical testing and monitoring
  - Observation and surveillance
  - Performance monitoring

Chapter 5 Resources

- Sample training guide (repairing a mechanically sealed pump)
- Sample of skills/knowledge list for an electrician
- Sample of skills/knowledge list for a mechanic

Chapter 6 Resources

- Sample procedures:
  - Mass Flowmeter Calibration

  - Level-Indicating Transmitter Function Test and Calibration
  - Heater Inspection
  - Contractor Safety
  - Circuit Breaker Inspection and Maintenance
  - Centrifugal Pump Specification Sheet

- Example procedure formats:
  - Flat procedure format
  - Outline procedure format
  - Playscript or information mapping procedure format
  - T-bar procedure format
  - Checklist procedure format
- Comparison of procedure formats
- Procedure writing checklist

Chapter 9 Resources

- Common RAGAGEPS
- Fixed equipment matrices:
  - Pressure vessel matrix, including columns, filters, and heat exchangers
  - Storage tanks
  - Process piping, and components, including buried piping, flex hoses, and expansion joints
- Relief and vent system matrices:
  - Pressure relief valves (PRVs)
  - Rupture discs
  - Vent headers
  - Flame/detonation arresters
  - Emergency vents
  - Thermal oxidizers
  - Flares
- Instrumentation and controls matrices:
  - Safety instrumented systems (SISs) and emergency shutdown (ESD) systems
  - Process control systems
  - Critical alarms and interlocks
  - Chemical monitors and detection systems
  - Conductivity, pH, and other process analyzers
  - Burner management systems
- Rotating equipment:
  - Pumps
  - Reciprocating compressors
  - Centrifugal compressors, including specific protection systems (e.g., pressure cutouts)
  - Process fans and blowers
  - Agitators and mixers
  - Electric motors

  - Gas turbines
  - Steam turbines
  - Gearboxes
- Fired systems:
  - Heaters/furnaces/boilers
- Electrical systems:
  - Switchgear
  - Transformers
  - Motor controls
  - Uninterruptible power supplies (UPSs)
  - Emergency generators
  - Lightning protection
- Grounding systems

Chapter 10 Resources

- MI program development activity worksheet

Chapter 11 Resources

- Presentation papers related to analysis approaches:
  - *Risk-Based Approach to Mechanical Integrity Success on Implementation*
  - *An Insurer's View of Risk-Based Inspection*
  - *RCM Makes Sense for PSM-Covered Facilities*
  - *Lessons Learned from a Reliability-Centered Maintenance Analysis*

Chapter 12 Resources

- Resources for performing equipment failure analyses:
  - Additional detailed information on the analysis steps
  - An equipment failure analysis checklist
- Resources for performing root cause analyses:
  - SOURCE™ Investigator's Toolkit
  - Root cause map
  - Causal factor chart and fault tree templates
- MI program audit resources
- Presentation paper.—.*Improving Mechanical Integrity in Chemical and Hydrocarbon Processing Facilities.—. A Insurer's Viewpoint*

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ACRONYMS AND ABBREVIATIONS

ACC	American Chemistry Council
ACCP	ASNT Central Certification Program
ACGIH	American Conference of Governmental Industrial Hygienists
AIChE	American Institute of Chemical Engineers
ALARP	as low as reasonably practicable
ANSI	American National Standards Institute
API	American Petroleum Institute
ASM	American Society for Metals (ASM International)
ASME	American Society of Mechanical Engineers
ASNT	American Society of Non-destructive Testing
ASTM	American Society of Testing and Materials (ASTM International)
AWS	American Welding Society
BPVC	Boiler and Pressure Vessel Code
CCPS	Center for Chemical Process Safety
CF	causal factor
CFR	*Code of Federal Regulations*
CI	Chlorine Institute
CM	condition monitoring
CMMS	computerized maintenance management system
CPI	chemical process industries
DOT	Department of Transportation
E&I	electrical and instrumentation
EPA	Environmental Protection Agency
ESD	emergency shutdown

FFS	fitness for service
FM	factory mutual research
FMEA	failure modes and effects analysis
FMECA	failure modes, effects, and criticality analysis
FTA	fault tree analysis
HAZMAT	hazardous material
HAZOP	hazard and operability
HI	Hydraulic Institute
IEC	International Electrotechnical Commission
IIAR	International Institute of Ammonia Refrigeration
IPL	independent protection layer
ISA	Instrumentation, Systems, and Automation Society
ISO	International Organization for Standardization
ITPM	inspection, testing, and preventive maintenance
LOPA	layer of protection analysis
MI	mechanical integrity
MOC	management of change
NB	National Board (of Boiler and Pressure Vessel Inspectors)
NBBPVI	National Board of Boiler and Pressure Vessel Inspectors
NBIC	National Board Inspection Code
NDE	nondestructive examination
NDT	nondestructive testing
NEC	National Electric Code
NFPA	National Fire Protection Association
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
P&ID	piping and instrumentation diagram
PFD	probability of failure on demand
PHA	process hazard analysis
PM	preventive maintenance
PMI	positive material identification
PPE	personal protective equipment

PRV	pressure relief valve
PSM	process safety management
PSSR	prestartup safety review
PSV	pressure safety valve
PWHT	postweld heat treatment
QA	quality assurance
QC	quality control
RAGAGEP	recognized and generally accepted good engineering practice
RBI	risk-based inspection
RCA	root cause analysis
RCM	reliability-centered maintenance
RMP	risk management program
ROI	return on investment
RP	recommended practice
SCBA	self-contained breathing apparatus
SCE	safety-critical equipment
SHE	safety, health, and environmental
SIF	safety instrumented function
SIL	safety integrity level
SIS	safety instrumented system
SME	subject matter expert
TML	thickness measurement location
UL	Underwriters Laboratories Inc.
UPS	uninterruptible power supply
USCG	United States Coast Guard
UT	ultrasonic thickness

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GLOSSARY

Acceptance criteria Technical basis used to determine whether equipment is deficient (e.g., when analyzing inspection, testing, and preventive maintenance [ITPM] results).

Causal factor (CF) Equipment failure or human error that caused an incident or allowed incident consequences to be worse.

Causal factor chart A sequence diagram that graphically depicts an incident from beginning to end; typically used to organize incident data and identify causal factors.

Certification Completion of the formal training and qualification requirements specified by applicable codes and standards.

Computerized maintenance management system (CMMS) Computer software for planning, scheduling, and documenting maintenance activities. A typical CMMS includes work order generation, work instructions, parts and labor expenditure tracking, parts inventories, and equipment histories.

Condition monitoring (CM) Observing, measuring, and/or trending of indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of a structure, system, or component to function within acceptance criteria.

Cost avoidance Return (often expressed in monetary terms) resulting from actions that prevent an incident from occurring.

Critical operating parameter Process condition (e.g., flow rate, temperature) that can lead to an equipment failure if limits are exceeded.

Damage/failure mechanism The mechanical, chemical, physical, or other process that results in equipment degradation. Identifying and inspecting for indications of the damage mechanism can be used to predict future failures.

Decision tree A logic tree used in reliability-centered maintenance (RCM) to help determine the correct type of maintenance (e.g., predictive, preventive) to perform to reduce the likelihood of equipment failures.

Equipment class A grouping of individual equipment items with similar design and operation, such that facilities should perform similar ITPM activities on all of the items.

Equipment deficiency A condition that does not meet the acceptance criteria.

Equipment failure analysis A systematic approach for analyzing equipment failures to determine the failure mechanism(s) and the root cause(s) that resulted in the failure.

Failure mode A symptom, condition, or fashion in which equipment fails. A failure mode might be identified as loss of function, premature function (function without demand), an out-of-tolerance condition, or a simple physical condition such as a leak.

Failure modes and effects analysis (FMEA) A systematic method for evaluating and documenting the causes and impacts of known types of equipment/component failures.

Failure modes, effects, and criticality analysis (FMECA) A variation of FMEA that includes a quantitative estimate of the significance of the consequence of a failure mode.

Fault tree A method for representing the logical combinations of failures that can lead to a specific main event (i.e., failure or accident of interest).

Fitness for service (FFS) A systematic approach for evaluating the current condition of a piece of equipment in order to determine if the equipment item is capable of operating at defined operating conditions (e.g., temperature, pressure).

Gantt chart A manner of depicting multiple, time-based project activities (usually on a bar chart with a horizontal time scale).

Hazard and operability (HAZOP) analysis A systematic method in which process hazards and potential operating problems are identified using a series of guide words to investigate process deviations.

Inspection, testing, and preventive maintenance (ITPM) Scheduled proactive maintenance activities intended to (1) assess the current condition and/or rate of degradation of equipment, (2) test the operation/functionality of equipment, and/or (3) prevent equipment failure by restoring equipment condition.

ITPM program A management system that develops, maintains, monitors, and manages inspection, testing, and preventive maintenance activities.

Layer of protection analysis (LOPA) A process of evaluating the effectiveness of independent protection layer(s) in reducing the likelihood or severity of an undesired event.

Management of change (MOC) A management system for ensuring that changes to processes are properly analyzed (e.g., for potential adverse impacts), documented, and communicated to affected personnel.

Mechanical integrity (MI) A management system for ensuring the ongoing durability and functionality of equipment.

Nondestructive testing/examination (NDT/NDE) Evaluation of an equipment item with the intention of measuring an equipment parameter without damaging or destroying the equipment item.

Operating window The parameters (i.e., safe upper and lower limits, run time) under which equipment can function without failure.

Owner-user Person, plant, or corporation legally responsible for the safe operation of a pressure-retaining item (e.g., a pressure vessel).

Performance measure A metric used to monitor or evaluate the operation of a program activity or management system.

Positive material identification (PMI) The determination of the materials of construction of an equipment item or component (e.g., piping).

Predictive maintenance An equipment maintenance strategy based on measuring the condition of equipment in order to assess whether it will fail during some future period, and then taking appropriate action to avoid the consequences of that failure.

Prestartup safety review (PSSR) A management system for ensuring that new or modified processes are ready for startup by verifying that equipment is installed in a manner consistent with the design intent.

Process hazard analysis (PHA) A systematic evaluation of process hazards with the purpose of ensuring that sufficient safeguards are in place to manage the inherent risks.

Process safety information A compilation of chemical hazard, technology, and equipment documentation needed to manage process safety.

Quality assurance (QA) Activities to ensure that equipment is designed appropriately and to ensure that the design intent is not compromised throughout the equipment's entire life cycle.

Recommended and generally accepted good engineering practice (RAGAGEP) *A* document that provides guidance on engineering, operating, or maintenance activities based on an established code, standard, published technical report, or recommended practice (or a document of a similar name).

Reliability-centered maintenance (RCM) A systematic analysis approach for evaluating equipment failure impacts on system performance and determining specific strategies for managing the identified equipment failures. The failure management strategies may include preventive maintenance, predictive maintenance, inspections, testing, and/or one-time changes (e.g., design improvements, operational changes).

Remaining life An estimate, based on inspection results, of the time it will take for an equipment item to reach a defined retirement criterion (e.g., minimum wall thickness).

Risk A measure of potential loss (e.g., human injury, environmental insult, economic penalty) in terms of the magnitude of the loss and the likelihood that the loss will occur.

Risk analysis The development of a qualitative and/or quantitative estimate of risk based on engineering evaluation and mathematical techniques (quantitative only) for combining estimates of event consequences and frequencies.

Risk-based inspection (RBI) A systematic approach for identifying credible failure mechanisms and using equipment failure consequences and likelihood to determine inspection strategies for equipment.

Root cause analysis (RCA) A method used to (1) describe what happened leading up to and during a particular event, (2) determine how it happened, and (3) identify the underlying reasons the event was allowed to occur so that workable corrective actions can be implemented to help prevent recurrence of the event (or occurrence of similar events).

Safety instrumented functions (SIF) A system composed of servers, logic servers, and final control elements for the purpose of taking the process to a safe state when predetermined conditions are violated.

Safety instrumented system (SIS) One or more SIFs combined to protect a process or a key process component.

Safety integrity level (SIL) Criterion defining the acceptable probability of failure on demand for a safety instrumented system.

Technical assurance The process for communicating that appropriate technology is being applied to process equipment.

Technical evaluation condition An equipment condition requiring further technical evaluation to determine suitability for continued service.

Verification activity A test, field observation, or other activity used to ensure that personnel have acquired necessary skills and/or knowledge following training.