Integrity operating window development and implementation for refinery units

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Abstract
Integrity operating windows (i. e. sets of threshold values on operating conditions or stream composition, solely aimed at preventing static equipment loss of containment) can be developed to account for any changes occurring during plant operation that affect expected damage rate or susceptibility to damage.
API RP 584 provides information and guidance on the work process for development and implementation of such thresholds, but it does not provide a list of specific integrity operating windows for each process unit, nor a detailed method or operating procedure for performing the risk analysis aimed at their definition.
A methodology was therefore developed, based on API RP 584 advice and consisting of the following steps:

- screening of damage mechanisms in plant sub-units and selection of representative equipment;
- selection of parameters to be monitored and definition of related threshold values (i. e. integrity operating windows);
- systematic calculation of probability and consequence of failure and risk analysis of integrity operating windows;
- check of piping coverage and integration;
- definition of corrective measures and related person in charge.

This methodology was later applied to several plant units in different refineries.

Keywords: integrity operating windows; refinery.

Introduction

Asset integrity management is a complex matter, requiring consideration at all times during plant life, starting with design, throughout construction, commissioning and operation, up to decommissioning.
Inspections of static equipment are an essential part of asset integrity management and are nowadays generally scheduled according to the risk level, calculated for each item as a combination of probability of failure and consequence of failure.
Any RBI study, however, is based on a snapshot of average operating conditions and may not retain its validity upon changes e. g. in the type and concentration of contaminants in the process streams or in physical parameters like temperature, pressure or flow velocity.
An efficient system of integrity operating windows prevents the impact of such variations on asset integrity from being overlooked and provides a certain degree of flexibility to the RBI planning, moving from a static picture into a somewhat dynamic perspective.
Using recognized guidelines as a starting point, the methodology for IOW definition presented in this paper was developed and applied to a selection of refinery units.

Methodology

At present, API RP 584:2014 is the main reference document for integrity operating windows. This recommended practice explains the importance of integrity operating windows for process safety management and provides guidance in how to establish and implement an IOW program for refining and petrochemical process facilities, for the express purpose of avoiding unexpected equipment degradation that could lead to loss of containment [1].

Nevertheless, application of these guidelines is less than straightforward, as it requires considerable customization to the specific equipment, process and scenarios under examination.

The methodology presented in this paper was therefore developed, as an attempt of systematization of the possibly intricate process of defining integrity operating windows. It comprises the five steps described in the following subchapters.

Step 1: screening of damage mechanisms in plant sub-units and selection of representative equipment

All relevant information on the plant unit under examination shall be collected and reviewed; it typically includes design and operating parameters, normal and special operating procedures, chemical composition of fluid streams and results of process data monitoring, laboratory routine tests, equipment inspection and failure analysis activities.

The plant unit is then usually divided into functional subsections; for example, within an atmospheric distillation unit, the feedstock preheating train, the desalter, the furnace, the distillation column bottom, middle and overhead sections and the product strippers may be recognized as sub-units. Expected damage mechanisms are defined for each subsection in all usual operating scenarios.

Representative equipment for each sub-unit and for each damage mechanism can subsequently be selected, based on operating condition severity with reference to process variables that affect damage mechanism activation, rate or likelihood, thus reducing the overall number of integrity operating windows required to protect the whole plant unit.

Step 2: selection of parameters to be monitored and definition of related threshold values (i. e. integrity operating windows)

Based on plausible scenarios, the nature and extent of possible changes in the process streams or in physical parameters is assessed.

The most significant variable is then chosen for each integrity operating window, i. e. for each representative item and for each damage mechanism; if necessary, an envelope of validity is defined by setting limits to other, less fluctuating variables: for example, if a damage mechanism depends not only on temperature, but also on feedstock acidity and sulfur content, an integrity operating window established on an upper temperature limit will be valid for all streams up to a defined TAN and sulfur percent weight concentration.

An upper or lower threshold is established for the chosen parameter, beyond which an appreciable worsening of the damage mechanism takes place; this aggravation can take up different forms:

- for thinning-type phenomena, it means an increase of the corrosion rate;
- for cracking-type phenomena, it means an increase of the susceptibility;
- additional customized definitions apply to damage mechanisms of different type, such as creep.

As an example, if a component operates at 65°C and its corrosion rate doubles with each ten-degree temperature increase, the integrity operating window upper limit may be set at 75°C, with a worsening factor equal to 2.

Step 3: systematic calculation of probability and consequence of failure and risk analysis of integrity operating windows

Risk analysis is performed through a risk matrix, which requires the calculation of the probability of component failure in case the IOW threshold is trespassed and of the anticipated consequence of such event.

The latter index is determined through a procedure similar to the calculation of consequence of failure in RBI planning, which generally accounts for safety, environmental and operational issues. On the other hand, probability of failure is related to the concept of worsening: the larger the aggravation, the higher the probability rating.

It may be possible to define several threshold values for a damage mechanism affecting an item; as a result, several integrity operating windows with generally increasing risk level may be defined, as shown in Figure 1.

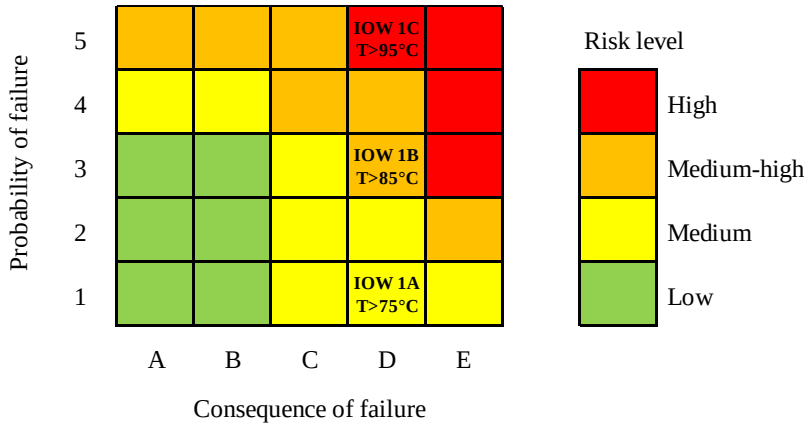

Figure 1: Example of IOWs with increasing risk level

Step 4: check of piping coverage and integration

Since equipment like pressure vessels, heat exchangers, reactors and so on may be made of nobler materials than related inlet and outlet piping, additional IOWs for the latter are established if existing ones for representative equipment do not provide enough protection.

As soon as all required integrity operating windows have been defined, an optimization process takes place, for example by deleting the less conservative IOWs among those depending on the same monitoring point.

Step 5: definition of corrective measures and related person in charge

According to API RP 584, the position of an integrity operating window within the risk matrix identifies the risk level and, as a consequence, the type of IOW (informative, standard or critical) and recommended actions.

Corrective measures are basically aimed at re-establishing operating conditions leading to the damage rate or susceptibility to damage taken as reference for the RBI study, or otherwise regarded as normal.

Appointing a person in charge of corrective measures is fundamental for the proper functioning of the IOW program and, in addition, helps spreading awareness of how the way a plant is operated affects its integrity.

For thinning-type damage mechanisms only, response time may also be provided, as a discretionary fraction of allowable time of worsening. This parameter, as shown in Figure 2, is defined as the time span during which the damage mechanism under consideration, proceeding at the rate associated with the aggravation, causes a thickness loss equal to that

caused by the same damage mechanism, proceeding at the rate taken as reference, up to the end of the RBI study timeframe.

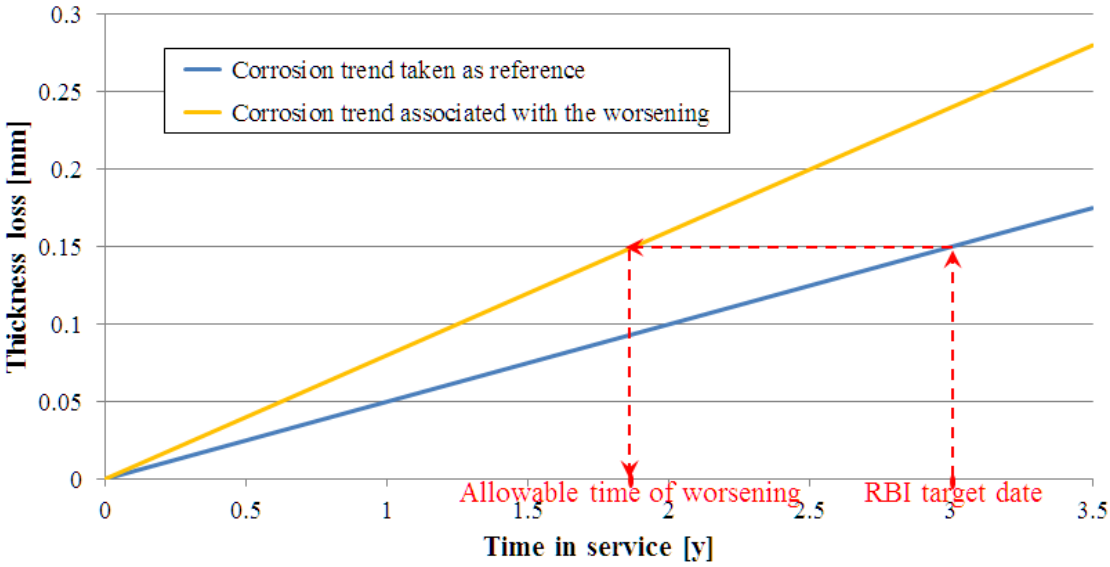

Figure 2: Allowable time of worsening

Examples of application

Within an operating project commissioned to RINA by ENI, the methodology described above was applied to several refinery units, listed hereunder:

- atmospheric distillation (Taranto and Livorno refineries);
- vacuum distillation (Taranto and Livorno refineries);
- hydrocracking (Sannazzaro de' Burgondi refinery);
- isomerization (Sannazzaro de' Burgondi refinery);
- catalytic reforming (Venice refinery);
- hydrodesulfurization (Taranto refinery);
- Ecofining™ (Venice refinery);
- tank farm (Gela refinery);
- hydrogen production (Taranto refinery).

This process led to the development of approximately 10 to 30 integrity operating windows per plant unit, depending on complexity.
The main damage mechanisms were covered, including the following:

- sulfidic and naphthenic acid corrosion;
- hydrogen-induced cracking;
- sulfide stress cracking;
- creep;
- high-temperature H_2/H_2S corrosion;
- hydrochloric acid corrosion;
- high-temperature hydrogen attack;
- oxidation;
- caustic cracking;
- amine cracking;
- amine corrosion.

Through a careful selection of the significant variables and of the monitoring points used for the development of integrity operating windows, the impact of the implementation phase was kept to a minimum.
The majority of the integrity operating windows consisted of an upper temperature limit, which sometimes required nothing more than an adjustment of existing alarm settings to be effectively put into use.

Conclusion

The guidelines provided by API RP 584 were developed into a detailed methodology that was later applied to several refinery units.
This work allowed a first step towards systematization of integrity operating window identification, to the advantage of completeness and coherence of IOW programs.
The main features of this methodology can be summarized as follows:

- selection of representative equipment, so as to reduce the overall IOW number;
- choice of significant variable, possibly in conjunction with an envelope of validity;
- reference to damage mechanism aggravation for IOW risk analysis;
- definition of allowable time of worsening for the calculation of response time.

An opportunity for improvement was also identified.
Estimating the damage mechanism worsening requires a quantitative correlation between operating parameters and damage rate or susceptibility to damage, which may not be available in literature. Moreover, some of the operating parameters required as input data for such predictive models may not be easy to obtain in practice. As a consequence, some damage mechanisms may not be controllable through an IOW program.
Therefore, the full application of the methodology presented here relies upon the availability of well-suited predictive models for all relevant damage mechanisms.

References

1. API RP 584:2014.