The Need for Risk-Based Inspection Planning

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Executive Overview

Until recently, the structural integrity of most plant items has been assured by two factors:

- Design in accordance with codes or rules incorporating empirical safety factors.
- In-service inspection to provide assurance that no accidental or unanticipated damage has occurred.

However, it is prudent to accept that operational loads may vary beyond design levels, and that material degradation may be greater than anticipated. The safety factors used at the design stage may not, therefore, guarantee through-life structural integrity. Hence periodic inspection is also carried out to determine the actual levels of damage, and to check the adequacy of the design loads and resistance values.

Both design and inspection strategies must take account of the risk of structural failure: that is, both the probability of failure and its consequences have to be considered. Using traditional approaches to inspection planning, risk tends only to be considered implicitly and is not assessed in an auditable manner. There is thus a real concern that high-risk and low-risk areas may not be clearly identified. This may then mean that low-risk areas are inspected to an excessively high level which leads to needlessly high inspection costs, while high-risk areas may not all be afforded sufficient attention and priority. Without the explicit consideration of risk, it may not therefore be possible to demonstrate that the structural integrity of the plant has been satisfactorily characterized.

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An inspection strategy based on risk avoids the inadequacies of the traditional approach. The concept of risk takes into account, not only the probability of failure, but also the consequences of failure. These may encompass consequences in terms of lost profits, repair and re-justification costs, human casualties and environmental clean up costs. Such a strategy ensures that inspection effort is targeted appropriately to optimize costs and benefits, and provides an auditable demonstration that this has been done with due diligence.

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Risk-Based Inspection Approach

Qualitative versus semi-quantitative

In some cases, initial turnaround inspection planning is based on qualitative risk ranking (QRR). Whereas, quantitative risk assessment attempts to perform a precise numerical evaluation of the risk exposure represented by equipment, qualitative risk-based inspection (RBI) planning provides a means of making a risk categorization. Therefore, qualitative RBI planning provides a useful methodology for correctly targeting inspection expenditure to components of the plant where it will be most effective in maximizing the safety of plant personnel and minimizing the cost exposure to failure.

A qualitative RBI methodology presents, to an expert study team, each of the factors influencing the likelihood of equipment failure and each of the factors influencing the consequences of that failure in the event it were to occur. Based on the study team's combined expertise, judgments are then made as to the magnitude of each factor, for each item, according to a pre-determined scheme. The result of such an assessment is an evaluation of risk category (or ranking) for each item, the severity of which then dictates the appropriate required effectiveness of the inspection response.

In cases where the assessment procedure for determining the magnitude of any of the factors influencing either likelihood or consequences of failure, replace expert judgment by numerical rules, the approach is termed 'semi-quantitative'.

For a typical process unit, the differences in the factors contributing to overall risk represented by any given vessel or exchanger, for example, are usually readily resolved based on expert judgment. However, for a large number of similar items, such as pipeline items, a numerical rule basis and hence a semi-quantitative approach can greatly assist discrimination of the appropriate risk category.

Objectives

The objectives of the RBI methodology described below are:

1. To provide the methodology for risk ranking of equipment encapsulated in a software package.
2. To undertake a risk ranking assessment of equipment items.
3. To define a risk-based inspection and, often, maintenance or other risk mitigation controls plan for the selected items.

Consistency with industry standard RBI procedures

ESR Technology's approach to RBI planning is consistent with API RP580 and API 581. The detailed implementation varies but the fundamental definitions of risk and the use of a semi-quantitative methodology described below aligns this approach closely to the API practice.

Overview of semi-quantitative methodology

The following provides key features of the semi-quantitative approach for RBI/RBM (risk-based maintenance)

- Built upon demonstrable experience in the application of RBI/RBM procedures to a wide range of refinery plant world-wide.

- Proven damage assessment modules developed for use with RBI/RBM software programs. These damage assessment modules are:
  - Where relevant, based on published data.
  - User accessible.
  - Can be tailored to specific plant requirements.

- Designed to involve extensive participation by plant personnel in the RBI/RBM planning process. This participation ensures:
  - User ownership of the RBI/RBM plan through participation in the assessment process.
  - The user can update and modify the plan for future inspections.
  - Incorporation of a rigorous expert review process.

- Designed for resource efficient data collation:
  - The systematic procedures for the expert review process ensure any shortcomings in the equipment inventory or other data are readily identified and overcome.

- The RBI/RBM studies culminate in a detailed inspection and maintenance plan. This plan is provided in a form that:
  - Can be implemented at a plant turnaround or, where applicable, during a given operating period.
  - For pressure parts, has been accepted by Regulatory Authorities as being an acceptable 'Written Scheme of Examination' to allow:
    - » Deferment of vessel internal examination.
    - » Substitution of non-invasive inspections.

The methodology

The key components of this methodology are as follows:

1. **Define probability of failure**

   Failure probability rules have been developed such that data requirements are minimized as much as possible. Generally, data required can be obtained from P&ID and PFD drawings, piping and valve specifications, process mass balance data etc., with only minimal requirement to reference design drawings, piping isometrics etc. The principle is that such detailed data should only need to be reviewed for more detailed analysis if deemed appropriate following risk ranking using the standard easily applied rules. Major features include:

   - Two probabilities of failure are derived for pressure vessels and pipework, probabilities of failure due to internal damage and due to external damage.
   - Where appropriate failure probabilities are defined in terms of remaining life where the life is calculated according to an assessed or measured degradation rate, a life in service, and a degradation tolerance.
   - For damage mechanisms for which a remaining life is not appropriate, such as Stress Corrosion Cracking, a failure probability score is derived according to how the actual process conditions compare with permissible process conditions for the materials in question.
   - Failure probability rules address a wide variety of degradation mechanisms grouped under the following:
     - Wall thinning mechanisms e.g. Corrosion
     - Cracking mechanisms e.g. Stress Corrosion Cracking
     - Mechanical damage e.g. Fatigue
     - Metallurgical Damage e.g. Embrittlement

     There could be a number of possible degradation mechanisms acting on an item. Whereas the greatest evaluated failure probability becomes the overall failure probability, lower levels of failure probability are also recorded since inspection techniques chosen for the most probable damage type may be inadequate for detecting the lower probability damage.

2. **Define consequence of failure**

   Three categories of failure consequence are assessed.

   1. Safety: toxic, fire, explosion, pressure and temperature hazards
   2. Environment: pollution hazard to surrounding population or landscape
   3. Business: instant and longer term effects on production

   Failure consequence rules have been developed such that data requirements are minimized as much as possible. Generally data required is overall process conditions together with easily chosen parameters describing plant characteristics such as numbers of staff, population densities nearby to the plant, equipment densities, equipment redundancy etc. Rules allow for possible escalation, for example through fires leading to further fires or explosions in surrounding equipment.

3. **Define maintenance/inspection effectiveness**
   RBI/RBM rules allow for inspection effectiveness in apportioning confidence grades to each equipment item. In the first instance these grades are taken to be the same as the plant's existing inspection grades. In effect the grading represents confidence in the current and future condition of an item, confidence is lowest if there is no inspection evidence and highest if there is lots of appropriate inspection evidence or well behaved degradation. Major features include:
   - For any given risk ranking, items graded high will be allocated longer inspection intervals than items graded low confidence.
   - Probabilities of detection are not used in the standard methodology but can be taken account of in Inspection Value Analyses.

4. **Risk mitigation methodology**
   Inspection alone is not sufficient to mitigate risk, action arising out of inspection is also required.

   Through use of Confidence Grading and remaining wall thickness measurements etc., allows for information on known condition of items and this is then used to influence 'perceived' risk. For example, a wall thickness measurement can be used to refine judgments on historical corrosion, this is refinement of perceived risk.

5. **Fitness for purpose and remaining life evaluation**
   Within ESR Technology's RBI/RBM methodology 'fitness for purpose' is represented by either remaining life or failure susceptibility. Remaining lives in the first instance are calculated according to assessed or measured corrosion rates, design corrosion allowances, time in service, and presence and condition of any protective coatings. In almost all instances such a basic remaining life can be extended through use of improved determination of corrosion allowance e.g. through more detailed application of design codes, finite element analysis etc, or through more in depth corrosion assessment, or through better corrosion rate trending from wall thickness measurements.

   Very high failure susceptibilities e.g. due to cracking, apply to items, which have materials in environments for which they are not suitable. In such instances it is possible that more detailed review will enable refinement of either process conditions or material specifications. It is inevitable that there will be some items with high failure susceptibility even after more detailed review, for these items either further inspection, retirement or more detailed analysis may be appropriate.

6. **Inspection strategy**

Inspection activities are assigned in terms of damage needing to be checked for as follows:

- Wall thinning inspection.
- Cracking inspection.
- Mechanical damage inspection.
- Metallurgical damage inspection.
- Internal visual inspection (an activity intended to check for more than one type of damage category and assigned in instances of either low confidence and/or high risk).

Inspection frequencies are assigned for each of the above activities as the soonest of two calculated dates as follows:

- A frequency obtained from a lookup table according to risk rank and confidence grade (where the risk is defined by the overall failure consequences and the failure likelihood rank for the type of damage).
- A percentage of the remaining life calculated for the type of damage, where the percentage is obtained from a look up table according to the derived overall failure consequence ranking.

Internal visual inspection frequencies are derived in the same way as described above except that the frequencies are looked up according to lowest calculated remaining life and highest calculated failure likelihood.

There are standard default values for the inspection lookup tables referred above. These can be revised if appropriate to suit local regulatory or other considerations. Different look up tables are available for different equipment types or, to allow intrusive inspection requirements to be waived when confidence is high and assessed risk is low.

For any given inspection task the exact choice of technique can be made from standard tables. The choice of technique is provided through the Inspection Value Methods. These methods are applied when the choice of technique is not obvious.

Cost and benefit analysis

Field experience reports that good quality and thorough RBI/RBM will result in more efficient inspection scheduling through which high risk items can be concentrated on using better inspection whilst inspection requirements are relaxed on lower risk items. ESR Technology has experience of calculating the impact of RBI/RBM programmes, the results can be dramatic. In practice the success of any cost benefit analysis depends very much on the data that can be obtained from the plant.

RBI/RBM software

AXSYS®.Integrity is the latest RBI/RBM module as part of the DigitalPlant solution from Bentley Systems and incorporates the RBI/RBM methodology described into an intelligent engineering system, which is used to handle the information and schematic diagrams used in the design and operation of process and power generation plant. AXSYS.Integrity is a multi-user and multi-discipline system, which provides an integrated environment for electrical, instrumentation, process and mechanical engineers to access and manipulate information throughout the life cycle of a plant.

In addition to implementation of the RBI/RBM features, the AXSYS system also offers the following general capabilities:

- Central project database holds a unique representation of the logic of the plant, including connectivity and other relationships. Each object in the plant occurs only once in the central project database, but may occur on any number of drawings. For example the same instrument may appear on a P&ID and on an instrument hookup diagram; the system will treat this as one instrument and it will occur only once in the central project database. A list of all the drawing sheets that a given object appears on is held at the object in the central project database.

- Drawing databases hold the schematics, which are the graphical representation of the plant data. Drawing databases are intimately connected to the central project database by means of a two-way link, so that changes made to a drawing database may cause data in the central project database to be updated, and vice versa. For example text on a drawing is often defined in a “dynamic” format which can include data from the central project database; when that data is changed the text appearing on the drawing also changes.

- Library databases hold libraries of graphical symbols that can be used on the schematics. There is a system library for company wide symbols, and project libraries for project specific symbols. Symbols covering a range of standards can be held in these libraries, and the user can select the symbols for a given standard.

- Catalog databases hold standard data that is available to the user. There is a system catalog for company wide data, and project catalogs for project specific data. Catalog data includes property definitions, unit of measure definitions with corresponding unit conversions so that properties can be displayed in consistent units, data model dynamically defining the properties required for any given object type (pump, vessel, pipe, etc.) and selection tables for determining a certain course of action depending on predefined conditions.

- Administration database holds information controlling access to the system and to particular parts of the data. The rights of individual users are defined here, and these can range from the ability to access certain drawings to the ability to create certain types of object or to change certain attributes. The make up of a project is represented here in terms of the address of its central project database and of its drawings, and access rights to the component parts of the project are defined here.

- Revision and change management mechanisms are provided to control workflow and release of information during the design process. A designer never works directly on the approved data but on a checked-out copy. When a portion of work is complete he can produce a report showing the changes he has made. Controls can be set for review and sign-off of this work, which can then be approved into the system. Procedures are built into the Approval process to ensure that one user does not overwrite the work of another.

- An application programming interface (API) is published and makes the system open for input and output.

- Data output facilities for producing reports and schedules, including through Microsoft Excel.

Management Reporting

Flexible RBI/RBM report formats include the following:

a) Risk definitions
b) Failure probability
c) Failure consequence
d) Authoritative review
e) Inspection scheduling
f) Detailed item analysis
g) Risk statistics
h) Inspection schedule statistics
i) Comparisons of current vs RBI/RBM inspection schedules
j) Implications for future RBI/RBM

Principal benefits of using Bentley DigitalPlant to host the RBI/RBM study include:

- A system for generating intelligent engineering drawings - intelligent data model structure for engineering components and handling connections between components.
- Component level document management - the system automatically maintains a list of applicable documents for each component for fast, consistent and accurate access.
- Central database - for comprehensive, consistent and redundancy-free data management, providing integration of drawings and data.
- The ability to connect AXSYS.Integrity databases directly to other applications, such as Microsoft Excel and Word and other Bentley solutions.
- Flexible data modelling - Users can configure unique components and component properties.
- Legacy data tools - utilities provided for linking legacy drawings.
- Concurrent engineering environment - multi-user and multi-discipline for reduced project-cycle time.
- Fast track change management providing complete control over all changes.
- Comprehensive component catalogs - eliminates data redundancy and provides rapid database population and implementation of standard designs.

Detailed RBI assessment

The AXSYS.Integrity software provides an excellent means of quickly determining equipment criticalities and inspection schedules. For the majority of plant items the AXSYS.Integrity derived inspection plans will be acceptable without more detailed assessment. However for a small number of assets the inspection plans will benefit from more detailed assessment. Possible reasons for this are:

- The impact of taking an asset 'off-line' may be significant owing to non-redundancy and importance for maintaining production or quality levels.
- The cost of inspecting an item may be prohibitive owing to its size, ease of access, or because inspection requires use of sophisticated inspection techniques.
- Under the above circumstances there are benefits if more detailed assessment allows:
- Focussing of inspection on only a part of an asset.
- Replacing intrusive inspection with non-intrusive inspection.
- Extension of inspection intervals
- The techniques for addressing these requirements are varied and include:
- Structured HAZOP analyses
- Quantitative consequence analysis
- Detailed defect analysis

The exact choice of more detailed analysis technique is made according to the inspection constraints that emerge from the AXSYS.Integrity software results.

Finally, although more detailed analysis can occur outside of the AXSYS.Integrity software, it is nonetheless possible to summarize and implement the results of the analysis in the software through use of the authoritative review. This enables the audit trail for any item's inspection planning to be maintained within the AXSYS.Integrity database.

Further information

Bentley Systems, Incorporated, is a global provider of collaborative software solutions that enable our users to create, manage and publish architectural, engineering and construction (AEC) content. As a part of those solutions, Bentley provides professional services including implementation, integration, customization and training.

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