**Synopsis**

In order to promote good practice in the design and operations of offshore installations the HSE has sponsored a suite of Safety Inspection Guidance Notes for machinery and rotating equipment. These “Notes” support non expert inspectors to understand and evaluate of the hidden risks associated with high hazard rotating equipment associated with offshore installations. They are based on a distillation of experience gained within the petrochemical industry, with the corporate knowledge of machine safety developed within ICI and ABB applied to provide this guidance. This work is reported through ABB Ltd following the transfer of the ICI Engineering Group and the associate corporate knowledge to ABB. The Project Officer for the HSE OSD Mr Prem Dua has provided technical guidance for the structure and scope of the “Notes” to suit their intended use by inspectors.

**1. Introduction**

The objective of the Machinery and Rotating Equipment Integrity Safety and Inspection Guidance Notes is to aid understanding of the technology used and consider aspects of the equipment, which might present hidden major risks to operators of the equipment. The health of the equipment needs to be viewed both in terms of the process integration of the equipment, and the operating and maintenance management.

As a consequence of the diversity of equipment employed on offshore installations, any inspection must cover a wide range of technology and operating requirements and provide a basis for assessment of compliance with the legislation and appropriate safety practices.
This is a real challenge. The concerns noted in the enquiry into the Piper Alpha Disaster (Reference 3) concluded the inspections carried out at that time were “superficial to the point of being little use as a test for safety on the platform”, noting the limitations of sampling on the basis of “what catches the eye” within a relatively short visit to an installation, and that the guidance available for such inspections was limited.

2. Background

Safety issues introduced by equipment for chemical and petrochemical processing plant are addressed by ICI and other Plant Operators in the design stage of an installation through the HAZOP process, and supported by a large pool of experienced Engineers. The operational safety assurance of static equipment is then verified by a registration process for pressure systems, and pressure relief devices. Historically, an equivalent process was not used for machinery and rotating equipment.

The development of a structured safety assurance and auditing approach to machinery and rotating equipment was undertaken by ICI following two significant machine failures within a short period of time over 10 years ago.

The failure of a high pressure injection pump (opposite) was one of these. This incident showed that dangers from rotating equipment may not be understood by the operators. Appreciation of the inherent dangers with equipment is necessary to ensure that equipment integration, maintenance and operation addresses such dangers. As a result of these incidents specific learning points were identified for the need for better understanding of the safety assurance required for machinery and rotating equipment, and the opportunity was seized to address machinery safety in a more structured way.

This structured approach has been previous reported to the IMechE (see reference 1 and 2). This process was recognised by the IMechE Reliability Committee (now the Safety and Reliability Group) and through the encouragement of Bill Wong a guidance book was produced “Process Machinery – Safety and Reliability” (reference 3). This has enabled the IMechE to show how industry might respond to the needs of improvement in safety standards particularly when considered against the increasing legislative requirements from the Supply of Machinery Safety Regulations, and the Provision and Use of Work Equipment Regulations.

The work into the understanding and auditing of operating high hazard machinery and rotating equipment safety provided a basis for establishing guidance for both the understanding and evaluation of the hazards associated with such equipment.

This work was extended within the then ICI Companies to review all the high hazard machinery in operation. Benefits resulted from the learning aspects of the retrospective reviews and the reinforcement of many generic issues for machinery and rotating equipment. The rigor imposed by the registration process has introduced an
improved the documentation and effectiveness of the repair techniques practised on high hazard equipment.

The above gives a background to a process already reported through the IMechE with guidance detailed for the study process. The reality is how to take advantage of all the learning established by such a process? Obviously the awareness of such hazards help improve operations and design, but as little is documented in the standards where to turn to for such guidance?

3. Development of Guidance Notes

The guidance for inspectors provides:

- A top level process identifying and ranking the evidence that can be gathered on a general visit to support judgements on the apparent state of the unit.

- A structure for assessment of operating units by observations to allow deeper understanding of the machinery, leading to judgements on the requirements for action, or further investigation.

- Means by which machine related observations and auditable points, supported by additional information, can be used to evaluate the state of machine systems.

- Structured technical data to support the observations and assessments of the inspector.

Visits by safety inspection engineers to offshore installation or other process plants operating major machinery historically have concentrated on dangers due to potential contact of operators or technicians with parts of the machine. These concerns are valid, and in some cases will pose a significant immediate hazard to the operators and technicians. The contact dangers, however, are in general not the worst case event. A range of other dangers will exist from the loss of process fluid containment, loss of restraint of a high energy element within a machine, or introduced from enclosures and service supplies which can result in significant damage to the machine and anything or anybody near it.

To be effective, any inspection or review needs to be aware of the potential hazards, in terms of process and process consequential hazards, as well as mechanical hazards both visible and inherent with the equipment design.

The development of the guidance notes for the HSE OSD was structured to provide a broad appreciation of equipment, their hazards, and provide a framework for assessment.
4. Application of Guidance Notes

- The Inspection Guidance Notes are split into two major parts, the Evaluation Process providing a structure for gathering and evaluating relevant information, and the Technical Guidance Notes on machinery and rotating equipment provided as a series of notes on specific systems.

Evaluation Process

The information gained from a general visit to an installation can provide important clues to the state of the care of the rotating equipment. Inferences can be drawn from this, in some cases the need to follow up concerns is clear and can be well focused. In such cases detailed information evaluation may not be necessary.

The cultural and organisational approach to running equipment does not directly affect machine and rotating equipment safety, but taken as a whole gives the background against which a machine incident may occur. In a good operating regime the potential incident will be recognised and controlled with no significant effect on the safety or operation of the platform. In a poor operating regime an incident may reach a dangerous state before its effect is recognised.

The challenge for any inspection or audit of an installation is to identify the operations that are being well done, those that will need development, and any practices that may lead to serious incidents. The gathering of the right information and the evaluation of it, supported by appropriate guidance needs to be structured.

The map shows the structure for a process which an Inspector goes through during a general visit. The guidance documents have been prepared for both training and reference purposes. These identify topics for review and associated evidence of a satisfactory system. They have been split into 3 streams: Induction / Meetings ; Control Room ; Plant Tour.

The observations made of the general state of the installation and manning is "filtered" through an evaluation matrix, with a
view to identifying those issues / practices which raise sufficient concern to justify deeper investigation. Any particularly serious concerns may require immediate discussion with the OIM.

The "filtered" observations can then be used to aid in the planning of a structured review of those parts of the installation which give rise to concerns. The approach may equally be used to deal with non-machines issues.

The Guide provides two fundamental levels of evaluation for the assessment of information gained during initial or general contact with a facility.

**Use of Word Models**

Firstly at a summary level, where general impressions have been reached from experience or by the limited nature of the information available.

For simplicity, a "3 row" word model is used, based on the activity to be performed providing examples and concerns against key words.

The evaluation guidance is structured allowing a summary level approach, a detailed approach, or a combined approach, with consideration of the detail where required.

The results from the evaluation of elements is then focused on follow up activities by considering the synergies between areas of observation. This allows the observations made during initial contacts to be melded with technical background on the equipment under consideration to aid the development of a strategy for further investigation.

**Evaluation Summary**

The process is summarised by relating the points of concern to the structured review process. In practice the relationships between observations and evaluations are handled on a database, with the chart indicating the underlying structure for the process.
5. Structured Reviews

- **The objectives of the structured review are:**
  - To confirm that engineering equipment and associated systems are designed, installed and maintained in accordance with legislative requirements, good engineering practice and in a manner that ensures that they are fit for purpose for safe operation for a defined period.
  - To ascertain compliance with statutory requirements.
  - To ascertain that engineering teams are working to defined procedures, best practice, or appropriate relevant Site instructions.
  - To raise awareness of the necessary engineering knowledge, standards, best practice and to encourage staff to seek appropriate technical help, advice and training.

The evaluation process described above allows the data gathered during any inspection or audit visit to be considered against the needs for of the different equipment using the information in the Technical Guidance Sections to support judgements made.

The quality of sample auditing was questioned in the report on the Piper Alpha Disaster (Ref 3), to avoid such auditing being superficial it is important to have structured processes to ensure the quality of the review and knowledgeable people available to carry out such audits.

The guidance provides a framework for reviewing the procedures, processes and practices on a facility. The approach gives an overall indication of the context, desired standards, and effectiveness of activities. Evidence gathered during a structured review provides the basis for technical consideration of the facility and support for the conclusions reached by such analysis. It also gives the opportunity to probe sensitive areas to show the adequacy or otherwise of the systems, practices, and equipment.

The judgement on the systems relating to machinery and rotating equipment is supported by the technical reviews (described later) within the Guidance Notes, which can be used both as preparatory support and evaluation of the information found.

During the course of such studies the effectiveness of organisation practice can be reflected back to the Operating Management. Even straight forward observations on the availability of information can be significant. In one case it was found that the quality procedures ensued that the operating team had access to all current procedures, but only in the control room. Maintenance was carried out well away from the control room and consequently suffered from the lack access to the maintenance procedures and information necessary to carry out the repairs.
6. Technical Support Guidance

**Technical Guidance Notes**

The technical guidance is written in a series of sections covering packaged machine systems. There are separate notes giving more detailed information on the specific machine and rotating equipment included in the package and the ancillary equipment installed to support the operation of the packaged equipment.

The technical guidance covers:
- General Description
- Main components
- Main sub systems (seal supply, lubrication)
- Safety systems
- Main services

with identification of:
- Hazards
- Operation
- Maintenance
- Control
- Key technical areas

The technical guidance gives both an outline of how the equipment should work and in contrast how it responds when things go wrong, and how they might fail in ways which would give concern for safety. These comments have been drawn largely from the experience within ICI where a systematic process had been established to identify and share the learning from failures. The series of guidance notes covers common packages of equipment, which are supported by more detailed notes on the major equipment items.

**Treatment of Equipment within Inspection Guidance Notes**

The guidance notes provide information on the machines in terms of background and history, hazards, operational needs, maintenance, and identification of the main components.

In this way the guidance helps the understanding of the task of the machine and provides an overview of the issues that can be experience from operation and maintenance of such equipment.

The technical guidance notes have been produced to cover 15 typical machine package with detail on the machines and rotating equipment within each package as well as the ancillary systems and equipment.

The notes show where learning from failures of similar equipment can be used to anticipate problems with currently operating equipment. These notes prompt questions about the current operating or maintenance practice to establish how these potential pitfalls can be avoided. The guidance has been developed to cover most of
the packaged machinery equipment present on offshore installation and brings
together information on how the equipment should operate as well as what happens
when things go wrong.

For example, in the case of the reciprocating compressor on a flammable gas duty the
range of hazards are considered. The assessment needs to address the issues from the
operational access to shut down the equipment through to the consequences of liquid
ingestion. The latter may lead to the machine being wrecked. The guidance notes
allows users and reviewers to appreciate the effect of machine deterioration.

For a reciprocating compressor this could be from the machine valves passing causing
high temperatures, interstage pressure, loss of forward flow, and allows comparison
with other issues such as liquid ingestion which can cause devastating effects.

Learning points can be drawn from examples such as the consequence of failing to fully secure and
check distance piece bolts to the cylinder head. In this case these have progressively loosened and
lead to the cylinder head displacement, with the consequential miss alignment causing the cross
head to fracture. The machine has then run on with extreme vibration levels until security of all the
bolted connections is compromised. Apart from the immediate root cause to ensure that the maintenance is done correctly, further learning
can be deduced about the value of high vibration trip systems, and even the position of the emergency stop control.

A range of pumps is also covered within the guidance, again the hazards associated
with standard pumps are recognised and then for particular types these are developed.
For multi-stage pumps operational hazards are extended to cover:

**Multi-stage pumps have a low tolerance to a dead head pumping situation
with a consequent rapid rise of internal temperatures and pressures.
Discharge pressures can easily exceed 100 barg, even a pin-hole leak can
give a dangerous fluid jet or atomised spray of considerable length.
Higher head rise increases the sensitivity of the design to changes in fluid
density, the design should accommodate all operating conditions – start up,
normal operations, operating excursions, washing / purging operations, and
shut down.**

These learning points can be presented in such guidance to show the importance of
the attention to detail necessary for all machine maintenance. As failure of machines
can be identified by monitoring, and avoided by use of appropriate protective devices,
the amount and effect of monitoring, and the protection requirements need to be
identified. For example operational monitoring:

<table>
<thead>
<tr>
<th>Operational Monitoring</th>
<th>Gas Turbine</th>
<th>Centrifugal Compressor</th>
<th>Recip Compressor</th>
<th>Pumps</th>
<th>Motors</th>
<th>Diesal Engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet / outlet temps</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Inlet / outlet pressure</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power draw / fuel flow</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow forward / recycle</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum flow</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process density / MW</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Process feed density / Mole Weight / contaminants</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Process feed availability</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The observation that is relevant to inspection visit are described in word models where impact, inference and possible actions are shown an extract of this for a reciprocating compressor:-

The process for evaluation outlined above allows the methodology to be written into an expert system, where the evaluation can be established and supported by a series of structured questions. Currently this has been done for a limited amount of the process and further development will depend on the final requirements to provide an interactive system for the users.

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7. **References**

1. C449/013 IMechE 1993 by Dr Harald Carrick and Mr Keith Rayner
2. Registration and Verification of Critical Machines Mr J J Lewis – IMechE Seminar Maximising Rotating Reliability Dec 94
3. The Public Enquiry into the Piper Alpha Disaster (Cm 1310) – The Hon Lord Cullen
4. “Process Machinery – Safety and Reliability” Editor Bill Wong

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