IMPLEMENTATION OF A PREVENTIVE / PREDICTIVE MAINTENANCE SYSTEM IN STEAM DISTRIBUTION NETWORKS USING ULTRASOUND DIAGNOSTICS

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Abstract. Steam is the most used source of energy in typical chemical, industrial and petrochemical plants all over the world. Although the savings can be enormous, the steam distribution and condensate collection network is an area that in most cases only receives attention, when operating conditions are threatening production commitments. The results of various steam trap performance assessment programs show that approximately 20% of the steam leaving a central boiler plant is lost via leaking traps in typical space heating systems without a proactive maintenance program.

The use of portable ultrasound based diagnostic equipment can have a great impact on cost reduction if implemented as part of a structured preventive/predictive maintenance program. Every monitoring program will result in an increase of labor. Much time will be spend in the activity of walking from one steam trap to another performing inspections and measurements. Documenting and analyzing the results and keeping track of corrections made by the maintenance work force demands also considerable time and effort, this in an environment in which the trend is to downsize on work force.

This paper describes the implementation of a steam trap performance assessment system at the grass roots crude oil refinery of Staatsolie in Suriname, South America.

Keywords. Ultrasound, steam trap, predictive maintenance, heat transfer.

1 INTRODUCTION

The Staatsolie refinery, in Suriname, transforms heavy crude oil in fuel oil, heavy vacuum gasoil (hvgo), asphalt, diesel and naphtha. The refining processes take place at elevated temperatures and heat transfer is the most used transport phenomenon. To maintain the temperature on the products, reactors, vessels and equipment a vast network of steam is used, that contains about 470 steam traps of which approximately 96% are of the thermodynamic disc type. On the other side, although the steam trap is one of the elements most encountered in any refinery, in most cases it is simply neglected by the preventive maintenance system, resulting in a substantial loss of steam produced by the industrial heating system. These losses justify the implementation of a program for periodic maintenance for the steam distribution network in its totality, increasing plant efficiency.
1.1 Function of the steam trap

Steam traps are automatic valves used in steam lines to remove condensate, air and other non-condensable gases, while preventing or minimizing the passage of vapor.

The air that remains in the steam lines after start-up reduces steam pressure and temperature, acts like an insulator, and finally decreases thermal capacity in heat transfer equipment. On the other hand, non-condensable gases like oxygen and carbon dioxide cause corrosion, damaging tubes and traps. The steam leaking through traps executes no heating service. The reduced heating capacity of the steam network demands a higher production of steam in the generators.

2 ULTRA-SOUND TECNOLOGY

Every piece of equipment produces a characteristic sound when functioning. The frequency is the parameter that determines the classification in audible or ultra-sound.

The frequency $f$ is proportional to the inverse of the wavelength $\lambda$, conform stated in Eq.(1):

$$f = \frac{1}{\lambda}$$

The sounds in the 20 Hz to 20 kHz range are perceived by the human ear. Audible sound has a long wavelength and has the capacity to turn around obstacles. The sound waves known as ultra-sound are found in the 20 a 100 kHz frequency range and are not audible for humans. The fact that the ultra-sound wavelength is between 3.175 mm and 15.875 mm, makes the sound radiation almost directional. This makes it easy to distinguish ultra-sound from background noise and determine the exact localization of the source.

Any change in operation of equipment, alters the characteristic sounds and because of the nature of ultra-sound, these warning signs can be detected before a failure occurs in the equipment.

3 MODELING

Any maintenance program will be deficient if there is no system to verify and measure the results and efforts of the parties engaged. Depending of the size of the steam distribution network, availability of qualified craft, accessible technology, various options exist. In some places it is advantageous to source out the service of assessment and/or maintenance, other areas rely on the internal workforce. Staatsolie option has been the acquisition of the necessary equipment and training, while an internal team of mechanics and operators does execution.

At Staatsolie the preventive maintenance is planned and initiated by the Maintenance Control Center, which is responsible for the Computerized Maintenance Management System. Although the existing CMMS has various options, modeling the structure of the steam system would require drastic changes in the internal database, something out of the scope of work. The solution adopted was to construct an independent database system for generating inspections.

3.1 Operational Strategy

Fig.(1) synthesizes the workflow of a survey or steam trap assessment cycle. The Maintenance Control Center releases a steam trap inspection work order, directed to the Refining Operations
Department. The inspection lists for the requested routes are generated, and trained operators execute the service. The results are sent to the Maintenance Department for the necessary corrections and the work order is closed by Maintenance. In traditional systems, technicians execute this labor during the normal working hours in their working routine.

The most favorable period to execute an ultra-sound inspection is during the evening or night when background noise is at a minimum. Another strong point is that in a plant operating 24 hours a day, the operators are the most adequate inspectors because of their working shifts and they have the opportunity to know in dept their equipment mode of operation, since they are the first ones to detect the symptoms of a malfunctioning steam distribution net. Operation people have more ability to relate product quality, increased steam production, electricity demand and fuel consumption to problems somewhere in the process.

Figure 1. Inspection workflow

3.2 Trap Management System Objectives

The objectives of the program are listed below:

- Maintain a list of all steam traps grouped by location, model, type, inspection route, connection to headers or manifolds, and also function of the trap;
- Maintain a list of all manifolds, headers and tubes of steam and condensate;
- Maintain a identification system of all components of the steam and condensate distribution network based on actual P&ID ("Processes & Instrumentation Diagrams") information;
- Generate inspection routes to be used for assessments done with portable ultra-sound equipment;
- Generate lists containing equipment found defect during an inspection or assessment;
- Supply statistical data based historical analysis;
- Supply isolation information necessary for work permits and lock-out, tag-out procedures;
3.3 Physical Model

The basic components encountered in a refinery’s steam distribution net are:

- **Steam Trap**: a tube, branch or recipient that distributes steam to various points. The main headers are also considered manifolds because they have condensate pits in low points to remove the formed condensate;

- **Steam Manifold**, a tube, branch or recipient that distributes steam to various points.

- **Condensate Manifold**, a tube, branch or recipient that collects condensate from various points. The atmosphere is considered a virtual manifold, although the condensate is not returned for recycling in the steam system.

From a functional point of view the steam trap is assigned to execute a certain action in the refining process like: maintain line 3"-HR-710-1A1B-2"ST at the desired temperature. On the other side every trap receives steam from a steam manifold and discharges to a condensate manifold or atmosphere.

3.4 Collected Information

The components described in the physical model must be entered in a database system in a manner that the link between the various components remains intact. Various trap properties has to be recorded in an efficient way for a system with more then 100 traps spread over the plant. The questions one may ask about a certain trap are:

- Model, brand etc.
- Type
- Localization
- Area
- Source
- Destiny

- Function
- Inspection route
- Inspection sequence
- Characteristics
- Reference documents

The same observations are valid for steam and condensate manifolds.

- Model, brand etc.
- Type
- Localization
- Area
- Number of connections
- Spare connections
- Source (steam manifolds)
- Destiny (condensate manifolds)
- Reference documents

Other relevant aspects are:

- Inspection route description
- Results
- Period
- Defects lists
- Reports

After analysis of all these requests a database has been developed which in its basic version is compounded of 8 tables, generated in a SQL Compliant Relational Database Management System or Client – Server Database. The Client-Server option is in nowadays multi user industrial
environment the approach that assures best functionality and data integrity in medium to big size industrial installations.

3.5 Database structure

The eight basic tables mentioned can be classified as:

- **Static and dynamic tables**
- **Dependent and independent tables**

The explanation of above classification is as follows:

- **Static**: these tables will not grow significant over time once the data is entered. In general, they will contain technical information and properties of the steam distribution net.
- **Dynamic**: these tables will grow over time, because they have operating conditions of the system stored.
- **Independent**: contain additional information for other tables, these are the so-called “look-up” tables.
- **Dependent**: are linked to “look-up” tables or are generated by means of internal processes or table combinations.

![Figure 2. Database Structure.](image-url)
The inspections are generated by internal procedures or stored procedures, a feature found in Relational Database Management Systems. An inspection is initiated and the program “TrapMan” creates lists with inspection routes in a way that the inspector has all the information to execute his task. The logic structure of the database is depicted in Fig.(2).

4 CODING AND IDENTIFICATION

In medium to big size systems the importance a good identification system can not be over emphasized, this will assure database integrity especially when multiple users are connected and can modify data the same time.

In some cases it is sufficient to stick with the coding system used on the Process Flow Diagrams (PFD) or Process & Instrument Diagrams (P&ID) existing at the facility. At older plants sometimes a universal coding system does not exist.

4.1 Steam and Condensate Manifolds

Traps have an entrance for steam and an exit for condensate. The entrance is coupled to a steam distribution point, while the exit is linked to a condensate collection point. For data consistency we distinguish 6 combinations:

- Steam Manifold ⇒ Steam trap ⇒ Condensate Manifold
- Steam Manifold ⇒ Steam trap ⇒ Line/Header
- Line/Header ⇒ Steam trap ⇒ Condensate Manifold
- Line/Header ⇒ Steam trap ⇒ Line/Header
- Equipment ⇒ Steam trap ⇒ Condensate Manifold
- Equipment ⇒ Steam trap ⇒ Line/Header

A steam header is also considered a “steam manifold” because in the low points purge traps are installed to prevent the accumulation of condensate formed, that will interfere in a negative way with the heat transfer process.

At Staatsolie the following notation is used: SM-nn (Steam Manifold & number), MS-nnnX (Medium pressure Steam Header & number), LS-nnnX (Low pressure Steam Header & number), CM-nn (Condensate Manifold & number), SC-nnnX (Steam Condensate Header & number). With this system the following coding examples can be encountered: MS-801, SC-801C, LS-811, SM-02 and CM-04

4.2 Table SMAN

A Steam Manifold is basically a collecting tube with isolating valves at the different. The table that contains the data of steam manifolds is called SMAN. The properties (fields) in the table are:

- **SMCODE**: identification of the manifold, also key field
- **LOC**: short description of the localization
- **ZONE**: plant coordinates
- **SOURCE**: steam supply line
- **TYPE**: M, L, O ⇒ Manifold, Line, Other
- **MOD**: module or process unit
- **VALVES**: number of branch connections
- **FREE**: spare connections
- **REMARKS**: additional information

### 4.3 Table CMAN

The same considerations are valid for condensate collection points. A curiosity is when a trap discharges to the atmosphere, the atmosphere is considered a virtual manifold. In some occasions it is more advantageous to waste the condensate then recycle the condensate.

The same fields used in table SMAN appear, except two.

#### Table 1. Steam distribution point.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMCODE</td>
<td>MS-804</td>
</tr>
<tr>
<td>LOC</td>
<td>COOLING TOWER TO LPG BULLET</td>
</tr>
<tr>
<td>ZONE</td>
<td>E1</td>
</tr>
<tr>
<td>SOURCE</td>
<td>MS-801</td>
</tr>
<tr>
<td>TYPE</td>
<td>L</td>
</tr>
<tr>
<td>MOD</td>
<td>800</td>
</tr>
<tr>
<td>VALVES</td>
<td>4</td>
</tr>
<tr>
<td>FREE</td>
<td>0</td>
</tr>
<tr>
<td>REMARKS</td>
<td>3” STEAM HEADER</td>
</tr>
</tbody>
</table>

#### Table 2. Virtual condensate manifold.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMCODE</td>
<td>ATM</td>
</tr>
<tr>
<td>LOC</td>
<td>VIRTUAL</td>
</tr>
<tr>
<td>ZONE</td>
<td>NA</td>
</tr>
<tr>
<td>DESTINY</td>
<td>NA</td>
</tr>
<tr>
<td>TYPE</td>
<td>M</td>
</tr>
<tr>
<td>MOD</td>
<td>800</td>
</tr>
<tr>
<td>VALVES</td>
<td>0</td>
</tr>
<tr>
<td>FREE</td>
<td>0</td>
</tr>
<tr>
<td>REMARKS</td>
<td>VIRTUAL MANIFOLD</td>
</tr>
</tbody>
</table>

### 4.4 Table ROUTES

The table “ROUTES” stores inspection route data. The routes are grouped in logical blocks based on localization and/or functionality, facilitating diagnostics in parts with performance below expected.

### 4.5 Table MODELS

This table stores the trap characteristics or properties based on brand and model. A binary large object field (blob field) can be used to store the typical operating sound of trap for comparison during inspection.

### 4.6 Table TRAPINV

The table TRAPINV (trap inventory) is the most complex table. TRAPINV is related to other tables by means of “look-up” references:

- **TMCODE**: unique identification also key field
- **LINE**: description of the main line served by the trap
  Steam supply section
  - **SMCODE**: source identification
  - **SUPVALVE**: supply valve number
Condensate discharge section

- **CMCODE**: destiny identification
- **RETVALVE**: return valve number
- **ROUTE**: inspection route
- **SEQUENCE**: order of inspection
- **LOC**: description of localization
- **SERVICE**: trap functionality, T = tracer, L = Line purge, E = equipment purge
- **MODEL**: trap model, brand

A screen shot of TRAPINV is depicted in Fig. (3).

![Screen shot of TRAPINV](image)

**Figure 3. TRAPINV**

### 4.7 Dynamic Tables

This category encloses as following tables:

- **SURVEYS**, data relevant to a steam trap assessment or audit;
- **INSPECTION**, data of results of an audit for every trap analyzed.
- **REPAIRS**, list of defect traps found during an audit.

An example of inspection results is showed in Fig.(4). The different conditions can be:

- **OK**
- **PLUGGED**
- **RATTLING**: rapid cycling, a sign of deficient sealing
- **HISSING**: steam pass through caused by internal wear
• OTHER

• LEAKING: external steam leaking

![Figure 4. Audit screen]

5 PROJECT DATA

Table. (3) shows some relevant data about the project like implementation costs, targets, technology, and software, among others.

Table 3. Project information

<table>
<thead>
<tr>
<th>FACILITY</th>
<th>STAATSOJIE REFINERY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCAL</td>
<td>SURINAME, SOUTH AMERICA</td>
</tr>
<tr>
<td>ESTIMATED IMPLEMENTING COST</td>
<td>US$ 15.000</td>
</tr>
<tr>
<td>START</td>
<td>NOVEMBER 2000</td>
</tr>
<tr>
<td>DELIVERY</td>
<td>APRIL 2002</td>
</tr>
<tr>
<td>EQUIPMENT &amp; TRAINING</td>
<td>US$ 8.000</td>
</tr>
<tr>
<td>EQUIPMENT</td>
<td>ULTRA PROBE 2000</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>UE SYSTEMS</td>
</tr>
<tr>
<td>NUMBER OF STEAM TRAPS</td>
<td>470</td>
</tr>
<tr>
<td>GRAPHIC SOFTWARE</td>
<td>AUTOCAD, AUTODESK WHIP</td>
</tr>
<tr>
<td>DATABASE</td>
<td>INTERBASE</td>
</tr>
<tr>
<td>APPLICATION LANGUAGE</td>
<td>DELPHI</td>
</tr>
</tbody>
</table>
6 CONCLUSION

In an undertaking of this nature the part of mapping, verify and documenting the whole steam system is the most time and resource consuming activity. In most cases the available information is not in a format adequate for storing in an electronic system or database.

The simple mapping and categorizing of the entire steam network in a database reduces the time needed for isolating production lines for maintenance, resulting in a powerful tool for both operating and maintenance personnel in a refinery.

REFERENCES


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