Consultancy Services for the Plant Audit in various Pump Stations and Reservoirs (OP18REFCS03)

Technical Report for Noveleta (NVL) Pump Station

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Chapter 1

Introduction

1.1 General introduction

The station is located in Noveleta, Cavite (refer to Figure 1.1 - a) and was built in the year 1996. The station went thru upgrading in 2009 and became operational since 2011. At present, 4 submersible turbine pumps are installed (Figure 1.1 - b) and deliver water from the reservoir to the discharge line serving the area. This station has an average power consumption of 79,075 kW per month based from 2017 data.

a - Location: $[14°25'28.73''N, 120°52'44.99''E]$

b - Pump gallery

Figure 1.1: Noveleta PSR

Recently rehabilitated in 2017, this PS has been included by the Client in the first cluster of pump stations for systems audit, benchmark establishment and asset management.

The Client has therefore awarded GHD and its sub-consultants (RB Sanchez and APSI) to conduct a plant audit project with an expectation to establish rigorous asset management framework based on reliability study and to determine optimal intervention program for the next five (5) years.

1.2 Objectives

The objectives of this work are as follows

- To evaluate the current operating condition of PS as compared to the original design intent and to provide recommendations for improving the operational efficiency and lowering operating cost;
- To be able to determine an optimal intervention program for the PS in the next 5 years with reference to the recommendations from the assessment and audit based on life cycle cost; and equipment efficiency study whether the equipment is subjected to replacement or repair. These equipment are:
  - Pumps;

- Motors;
- Generators;
- Electrical System and Protective Device;
- Substation (Transformer, Switchgears);
- MCC (VFDs, Soft starters, Circuit Breakers, and Protective Devices);
- Motorize Valves.

1.3 Scope of Work

Scope of Work (SOW) has been defined in the Contract Agreement and be in compliance with the GHD technical and financial proposal and the agreements made during a number of project meetings (refer to minutes of meeting of the project).

It is important to note that the electrical audit and analysis is not part of this report but will be included in the next revision.

1.4 Limitations

Results of the study with analysis, conclusion, and recommendations are only within the scope of work and agreements, and particularly under the following major constraints:

- Operational constraint: It was not possible to shutdown the entire PS for visual inspection of assets, particularly mechanical assets;
- Incomplete historical data: It was a matter of fact that Maynilad has not established an asset management system, thus data regarding historical intervention is limited and incomplete, leading to non-optimal reliability analysis;

1.5 Glossaries

Following glossaries are defined and used in the report:

Level of Services (LOS)

A Level of Services (LOS) is any value or expectation of asset managers and beneficiers regarding the functionality and serviability of an asset of a system of assets.

Intervention

Intervention is a generic and global term used to refer to non-physical and physical activities on assets. It encompasses do-nothing, or do somethings like repair, maintenance, rehabilitation, renewal, investment, and inspection and testing.

Corrective Intervention (CI)

A Corrective Intervention (CI) is an intervention executed without proper and systematic plan. An CI is often incurred by failure/breakdown of assets. In most of cases, it incurs significant negative impacts (e.g. cost to repair, disruption of service, loss in revenue).

Preventive Intervention (PI)

A Preventive Intervention (PI) is an intervention executed with proper and systematic plan. Note that an PI is executed on asset that is still working but not provide adequate level of services.

Intervention Type

An Intervention Type (IT) is a specific and well-defined type of work/task that can be executed on/for an asset (e.g. replacement of a bearing for a pump).

Intervention Strategy (IS)

An Intervention Strategy (IS) is a set/collection of intervention types.

Intervention Program (IP)

An Intervention Program (IP) is a set/collection of intervention strategies for one asset or more than one assets of the same system.

Work Program (WP)

A Work Program (WP) is an execution program consisting of Intervention Program and management program (e.g. project management, procurement) that shall be implemented in order to realize/actualize the Intervention Program.

Chapter 2

Preliminary Assessment and Data Gathering

GHD conducted preliminary assessment on a set of data provided by Maynilad. The data set includes a number of records on daily production and power consumption and intervention reports issued after Maynilad experienced failure/breakdown of assets.

The assessment provided a base for GHD to generate the Inspection Testing Plan (ITP) [6] aiming to gather necessary data for conducting reliability study. The ITP has been reviewed by Maynilad, together with the Work Safety Permit (WSP), prior to execution of visual inspections and testings at the site.

2.1 Maynilad's data

Maynilad provided a set of data as shown in Table 2.1

Table 2.1: Data provided by Client.

No.	Data	Remarks
1	As-built drawings	Contains CAD drawings of recent rehabilitation, however small attention given to mechanical as-builting with only top view of pump room included
2	Monitoring dashboard	Year 2015 to 2017
3	CI records	The numbers of records are limited.
4	Asset registry	Asset registry was incompleted as confirmed by the IAM team of Maynilad.

2.1.1 Intervention records

The current format and structure of the monitoring dashboard somehow presents difficulty in useful and consistent use of the dashboard. Entries are varied and input consistency is low. On which monitoring activity, test and on which part is not readily determined. There is a need browse the item individually. These show that the dashboards may not be really performing its function as a monitoring tool but rather simply is a log with varied maintenance with low consistency.

Particularly, the most important historical data concerning specific failure of components of pumps with elapsed time is missing. Thus, the provided information is not useful for detailed reliability study on frequent failure of assets at component level.

The problem with missing specific failure data was due to a matter of fact that Maynilad still has not come up with preventive maintenance program within the overall asset management framework. The IAM team has recently established with expectation to generate short-term, medium-term, and long-term preventive intervention program. In close discussion with Maynilad, GHD learns that Maynilad has a regular/frequent activities for check-up (e.g. monthly and quarterly), however, recorded data has not been digitalized and the data itself has not aligned well with the asset registry.

There is no significant data to be found on the monitoring dashboard relating to the pumps currently installed in the station since all logs date back before rehabilitation and the pumps were replaced during the rehabilitation.

Table 2.2 presents highlights on intervention data on pumps.

Table 2.2: Highlight of intervention data on pumps.

Pumps	Description of PI/CI	Date/Remarks
All Pumps	Inspection of pump drive coupling, mechanical seal, MCC components. Conducted pump and motor vibration test using vibration meter and monitored bearing condition using thermal scanner. Also check gen-set's engine oil, radiator's coolant, battery solutions and filters	Regular monthly maintenance activity, may vary at times depending on availability of test equipment
P4	Install newly rewind motor and alignment of pump and motor	9/14/2016
P4	Replacement of motor inner bearing	1/20/2017
P4	Continue repair, Removal of bolts.	2/10/2017
P4	Pull out of pump	9/6/2017
P3	Pulled-out of motor inner and outer bearing for replacement and cleaned motor winding	12/28/2016
P3	Replaced outer motor bearing	5/5/2017

2.1.2 Interview data

GHD conducted an interview session on 07/12/2018. Results of the interview are summarized in the minutes [4], with the following highlights.

- No further data is available aside from the provided set presented in earlier section;
- There is an existing regular check-up for assets but data is not digitalized and the information is only generic;
- Spare parts are not stocked for most of components, except for bearing. Regarding service delivery, the required discharge pressure remains the top priority in pump operation modulation and sequencing. Critical parts and components for VFD and bearing are usually stacked to have spared in case of emergency repair and replacements. The consumables on the other hand, are not stacked but ordered in advance for use in maintenance activities;
- No visual bank of assets;
- No standard testing regime that follows a regular scheme based on optimality;
- Pumps are operated based on pressure and not manual;
- No existing PI/CI procedure to be followed;
- No expansion plan is forecasted;physically impossible to add another pump in the existing pump room
- There is a problem with the inflow of incoming water, leading to lower level of reservoir chambers that has affected pump operations occasionally;
- no historical data on pump efficiency, which is a simple yet useful value in determining pump performance. The main impediment in the individual pump efficiency is the measurement of flow produced by each pump. The existing configuration of the pump-motor and piping system do not cater to conventional methods of flow determination;
- No intervention records for FDAS. It was revealed that different version on operation and functionality of the FDAS was reported by both guard and site operators.

2.1.3 Asset hierarchy

During the bidding phase, Maynilad did provide the first draft of the Asset Registry (AR) that describes a hierarchy of eight (8) levels. Figure 2.1 visualizes the hierarchy with brief description presented in Table 2.3.

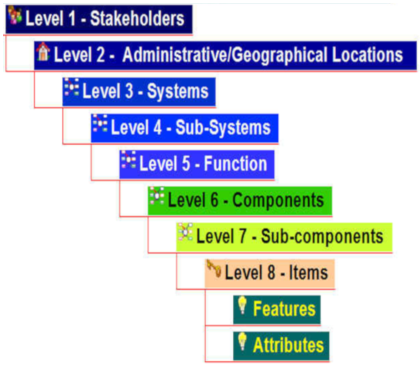


Figure 2.1: Asset Hierarchy

Table 2.3: Condition state definition - Multiple.

Asset hierarchy	Description
Level 1	Stakeholder level. For example, an pump station belongs to MWSI
Level 2	Geographical locations/ or administrative zone (e.g. a pump station belong to Quezon city or Makati)
Level 3	System (e.g. the entire pump stations and reservoir system)
Level 4	Sub-system (e.g. one specific pump station and reservoir such as the Lamesa PSR)
Level 5	Functional system (e.g. booster system or storage system)
Level 6	Component (e.g. Suction line, Reservoir line and Tank)
Level 7	Sub-component (e.g. Suction pipe and fittings, Concrete reservoir, pump)
Level 8	Items (e.g. valve, bearing, motor)

GHD received the latest version of the AR with about 100 assets for this PS. The full list of assets is given in the excel file provided by Maynilad in 2018. GHD has developed a MS Access program to convert the data in the excel file to a relational database structure. Per agreement with Maynilad, GHD will only verify level 7 of the AR with the actual site condition for the study [5].

2.2 Preliminary assessment

Assessment on the lastest provided intervention records reveals that the provided pertinent data is incomplete and cannot be used as representative data for a complete reliability study.

It is also confirmed from the provided data that the Client has done regularly check-up on GENSETs to ensure that it provides adequate level of services in case of emergency. To date, no failure records has been observed for the GENSET.

Further evaluations and tests have to be conducted to identify the areas for improvement of preventive measures in mitigating corrective measures and study the ways to strengthen preventive measures to improve operating conditions and life of pump components.

Improving the reliability of the pump stations for the next coming years require evaluation of the existing pump station conditions and maintenance practices, particularly assessment of the pump and its components. With that, areas for improvement of operation and maintenance be addressed through action items that come from the resulting recommendations.

In order to capture a relatively good picture on the reliability of the pump system and its associated assets, a number of tests shall be conducted.

2.3 Summary of the inspection test plan (ITP)

A complete write-up on testing shall be referred to the ITP [6], which has been submitted, reviewed, and approved by the Client. This section only provides highlights to help readers keeping abread of the flow of the report.

2.3.1 Mechanical Audit

The Mechanical Tests to be conducted are enumerated and discussed hereunder including their background and applications, standards used if applicable, and the equipment to be used. During testing, the following are the assumptions and considerations:

- The operation of the pumps cannot be interrupted (at day time when demand is high).
- The valve settings then cannot be adjusted to produce different flow rates.

2.3.1.1 Structural Inspection for Pump Discharge and Suction Line

This activity measures the current thickness of the existing pipelines at the pump vicinity using ultrasonic thickness gauging. The flow regime especially around the elbow and possibly corrosion and scaling conditions are to be predicted from the measurements of this test.

Following procedures will be executed

Step 1: Locate and mark testing points

At a minimum of two (2) meters away from the pump intake/discharge flange, the test points shall be marked at 3, 6, 9 and 12 o'clock positions and at one (1) meter interval along the pipes, additional test sections with same set points shall be added as long as available beneath the immediate ground level (Figure 2.2). Note that there will be no testing at sections that fall on valves or stc connections. The next 1 meter away from the pump flange will be considered instead.

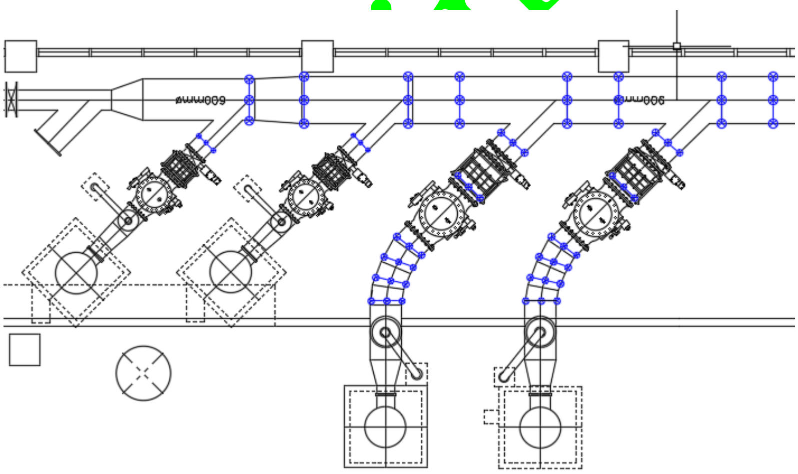


Figure 2.2: UTG test points

Step 2: Prepare test point surfaces

- Wipe the surface free of dirt (no need to remove paint)
- Using a chalkstone (erasable), mark x on the test point

Step 3: Apply sufficient couplant on test point surface

- Use petroleum jelly/Vaseline as couplant

Step 4: Set transducer probe on test point

Step 5: Read and record value as indicated on module display

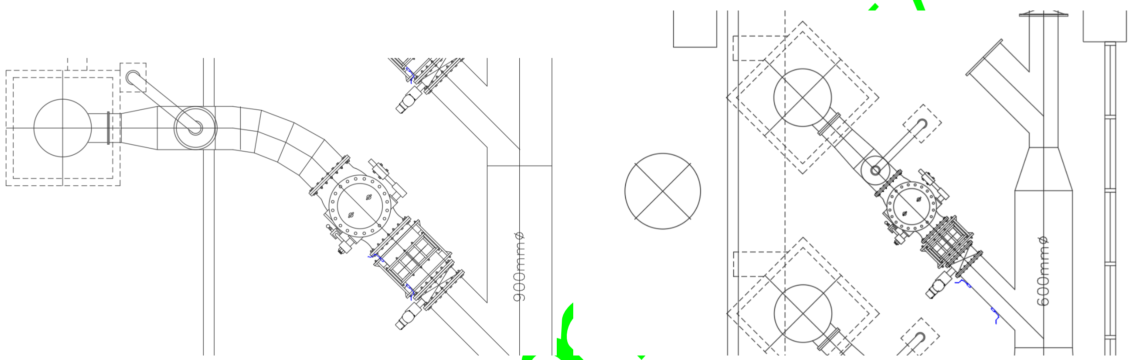
Step 6: Clean test point after reading

2.3.1.2 Unit Flow Measurement

The activity measures pump capacities. Pump efficiency is then calculated using the measured values.

Step 1: Locate Sensor Position Point Area and mark all points to be taken.

- Observe required offset distance from fittings/pump to consider the fully developed flow. At least 10 times the diameter distance away from the suction/discharge of the pump if applicable, otherwise consider at least 2D distance away from the fittings. This is to ensure the flow will be stable and fully developed for flow measurement accuracy
- Otherwise, test at near turbulent zones and consider normalizing the flow. Refer to Figure 2.3.



a -Test points for P1 and P2 b -Test points for P3 and P4

Figure 2.3: UFM test points

Step 2: Pipe Specification Input on the Flow Meter.

- Identify nominal pipe size with equivalent parameters such as schedule designation, equivalent thickness, OD, and etc.
- Input outside diameter.
- Input pipe thickness.
- Input pipe material (carbon steel).
- Input pipe medium (water).

Step 3: Prepare test point surfaces

- Clean the surface of pipe with a sandpaper and steel brush or any suitable abrasive materials, exposing the base metal.

Step 4: Install transducers at set points

- Apply enough couplant that it covers transducers sensors to ensure an acoustically conductive connection to the pipe. Also apply couplant on the test point surface
- Clamp the transducers at the side of pipe using metal chains, straps or mounting rails Observing proper spacing and alignment. Note flow direction and install transducers at either 0 or 45 degrees, whichever would give more stable reading

- Wait for the module to display "System Normal" before reading. Inspect set-up for any fault and properly reinstall if signal is poor/low (no reading)

Step 5: Data gathering

Read and record all necessary data measurement by the equipment, (i.e. flow, fluid velocity, sound velocity, Reynolds number, etc.)

Figure 2.4: UFM Measurement Display

Step 6: Remove transducers and restore paints

Remove the transducers and restore the surface of pipe after measurement.

2.3.1.3 Suction and Discharge Pressure Measurement

The activity measures each pump suction and discharge pressure. The pump efficiency is then calculated using the measured values.

Step 1: Disassembly of existing Pressure Gauge

- Inspect for any leaks or unusual noise before proceeding: If anything is detected, report immediately to the operator;
- Close gate valve located before the pressure gauge and wait for the pressure reading to drop;
- Remove the pressure gauge: (1) Hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another; (2) Loosen the pressure gauge then remove it.

Step 2: Installing the Pressure Gauge

- Prepare the connections: (1) Clean the connections before installing; (2) Put Teflon tape on the pressure connection of the gauge;
- Install the pressure gauge: (1) Mount the pressure gauge on the adapter then hand tighten the arrangement; (2) Further tighten the assembly using a pair of wrenches: hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another; (3) Tighten the assembly;
- Inspect the assembly again.

Step 3: Reading the pressure

- Slowly open the gate valve: Observe any leaks or unusual noise;
- Measurement: (1) Wait until reading is stable; (2) Record the pressure as indicated.

Step 4: Restoring the earlier gauge

- Inspect for any leaks or unusual noise before proceeding: If anything is detected, report immediately to the operator;
- Close gate valve located before the pressure gauge and wait for the pressure reading to drop;
- Remove the pressure gauge: (1) Hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another; (2) Loosen the pressure gauge then remove it;
- Prepare the connections: (1) Clean the connections before installing; (2) Put Teflon tape on the pressure connection of the gauge;
- Install the pressure gauge;
- Mount the pressure gauge on the adapter then hand tighten the arrangement;
- Further tighten the assembly using a pair of wrenches: hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another;
- Tighten the assembly.

2.3.1.4 Parameters

Parameters was recorded using visual inspection form, interview questionnaire, and testing results. Main parameters are listed, but not limited to, in the Table 2.4. Raw data is enclosed in the Appendix.

Table 2.4: Main parameters to be collected.

Parameters	Symbol	Remarks
Pipe thickness Gauge	t	mm
Pump Capacity	Q	Gpm/cmh
Suction Pressure	Ps	mH2O
Discharge Pressure	Pd	mH2O
Vibration Data	-	-
Head	H	mH2O
Efficiency	e	%

2.3.2 Vibration and structural assessment

This activity measures the vibrations of the pump and motor at the drive and non-drive ends. The data will be used to address pump vibration problems such as cavitation, pump flow pulsation, bent pump shaft, pump impeller imbalance, shaft misalignment and bearing problems.

Following procedures will be executed

Step 1: Test location identification

Locate the testing points on drive and non-drive ends of pump and motor

Step 2: Set transducer probe on test point. Observe HIRAC for access to elevated positions

Step 3: Read and record value as indicated on module display

2.3.3 Workplace environment management

GHD/RBSanchez conducted WEM tests at designated locations (Figure 2.5) to record values of parameters presented in Table 2.5.

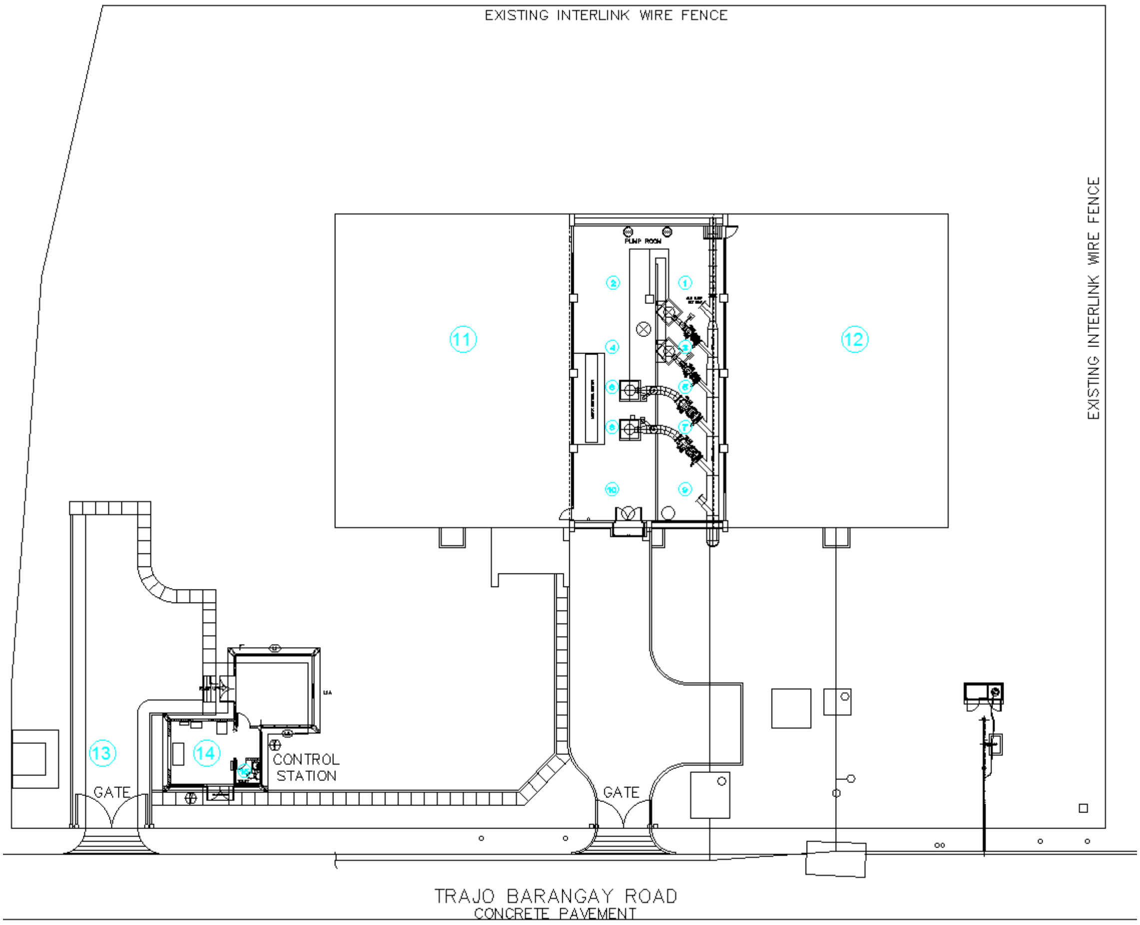


Figure 2.5: Testing locations

Table 2.5: WEM Parameters.

Parameters	Symbol	Units
Dry Bulb Temperature	tdb	oF/oC
Relative Humidity	RH	%
Sound Intensity	-	dB
PM 2.5 Count	PM2.5	ug/m^3
Visible useful light	-	Lux

2.4 Database

GHD developed an MS Access program that functions as a database used to record data collected from visual inspections and testings. The database has been developed using the concept of Relational Database Management System (RDMS), which is a must to record data systematically. The benefits of using the database are

- Eliminate redundancy and repetition of same data
- Eliminate incorrect data entry that is often found when working with excel files
- Provide linkages among asset hierarchy
- Provide ease for programing (e.g. reliability modeling and life cycle cost analysis)
- Support Maynilad AIM team to learn the benefits of using RDMS in developing an integrated Asset Management System for now and future
- Provide compatibility with any CMMS that is often using other RDMS such as Microsoft SQL Server, Oracle SQL server, or MySQL platform

- Provide ease for compilation of desire tables for further analysis using SQL (Structure Query Language)
- Provide ease for importing/exporting to different extension formats (e.g. flat, csv, xlsx)
- Provide a strong background for Maynilad team to migrate recording practices to Web-based that will be part of GHD's recommendation for future usage.

The MySQL database is then migrated into MySQL server, which is powerful database system that is used also to migrate, compile, and store all production and power consumption data into a single table. Main reasons behind the development of the MySQL server are for statistical computing with R and for faster compilation of queries.

GHD will provide these two sets of database as part of our deliverable and will provide training for Maynilad team to learn how to use the database in an efficient approach.

Chapter 3

Methodology

3.1 The Integrated Asset Management Approach (IAM)

We proposes an Integrated Asset Management (IAM) approach with its framework shown in Figure 3.1 for executing this project. The IAM approach will eventually be beneficial to Clients as it will lay a foundation to build up a systematic asset management plan for the future.

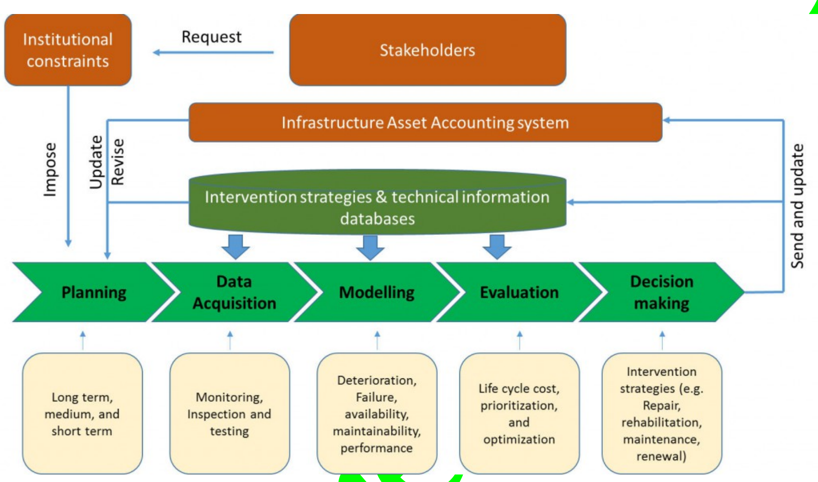


Figure 3.1: Integrated asset management approach (adopted from POM+ http://www.pomplus.vn)

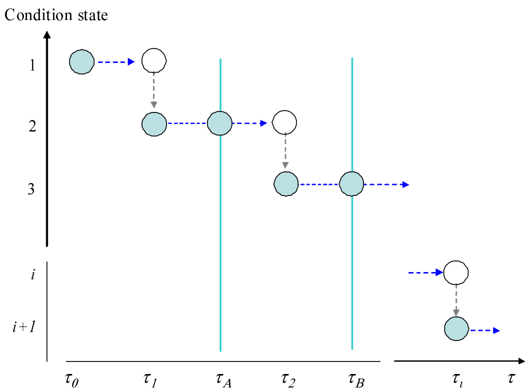
As can be seen in Figure 3.1, we sees the overall picture of works that should be executed in close connection to each other in order to make a full cycle of asset management effectively.

Works associated with auditing equipment and facilities of pump stations and reservoirs, coming up with a preventive maintenance program, tendering, and detailed design can be described explicitly using the framework in Figure 3.1. For example, various type of data concerning physical and operational condition and performance of equipment and facilities will be collected, filtered, and analyzed (Data Acquisition); the data will be further used for modeling purposes (e.g. prediction of failure rate, draw deterioration curve, reliability and efficiency); life cycle cost analysis will be then performed for each equipment and for its system. In this process, either prioritization or optimization technique can be used; finally a set of preventive maintenance intervention strategies will be generated for decision making purposes.

3.2 Deterioration process and rating index

In order to analyze and forecast the deterioration of assets, it is necessary to accumulate time series data on the CS of the assets. The historical deterioration process of an asset is described in Figure 3.2. This figure shows the deterioration progress of a component that has not been repaired. In reality, there exists uncertainty in the deterioration progress of the asset, and moreover, the CS at each point in the time axis is restricted by the time, at which, visual inspection is carried out.

In this figure, τ represents real calendar time (the expression “time” will be used instead throughout this paper). The deterioration of the asset starts immediately after it begins to operate at time τ_0. The CS of an asset is expressed by a rank J representing a state variable i $(i = 1, \cdots, J)$. For a component in the good or new situation, its condition state is given as $i = 1$, and increasing of CS i describes progressing deterioration. A value of $i = J$ indicates that an asset has reached its service limit. In Figure 3.2, for each discrete time τ_i $(i = 1, \cdots, J-1)$ on the time-axis, the corresponding CS has increased from i to $i+1$. Hereinafter τ_i is referred to the time a transition from a CS i to $i+1$ occurs.



Note) In this example, the deterioration process of a infrastructure component if expressed in terms of calendar time $\tau_1, \tau_2, ..., \tau_i$, and condition state of the section is increased in unitary units.

Figure 3.2: Transition Time of Condition State (adopted from [13]).

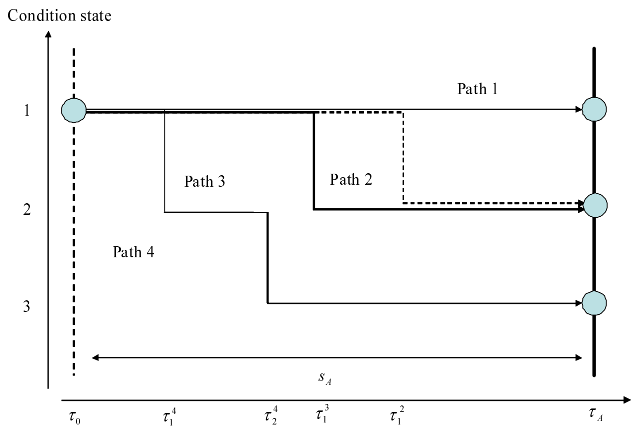
Information regarding the deterioration process of an asset can be acquired through periodical visual inspections. However, information on the CS based on continuous visual inspection is difficult to obtain. In this case, the initial inspections is carried out at times τ_A on the time-axis. It is supposed that at time τ_A the CS observed by inspection is i $(i = 1, \cdots, J-1)$. The deterioration progress in future times is uncertain. Among the infinite set of possible scenarios describing the deterioration process only one path is finally realized.

Figure 3.3 shows four possible sample paths. Path 1 shows no transition in the CS 1 from initial time τ_0 to first inspection time τ_A. In paths 2 and 3, CS has advanced to one upper CS at the calendar times τ_1^2 and τ_1^3 respectively. The CS of these two paths observed at time τ_A become 2. In a periodical inspection scheme, the point times τ_1^2 and τ_1^3 in which the CS has changed from 1 to 2 are not determined. In addition, path 4 shows transitions in the CS at times τ_i^4 and τ_{i+1}^4 during the inspection interval. The CS observed at time τ_A becomes 3. That is, in spite of the transitions in the CS are observable at the time of periodical inspection, it is not possible to obtain information about the times in which those transitions occur.

Figure 3.4 further describes the deterioration process inferring the inspection approach and how the CS is assumed. In this figure, it is assumed that the CS at the calendar time τ_{i-1} has changed from $i-1$ to i. The calendar time τ_{i-1} is assumed to be equivalent to $y_i = 0$. The time represented by the sample time-axis is referred from now on as a “time point”, and differs from “time” on the calendar time axis. The times τ_A and τ_B correspond to the time points y_A and y_B on the sample axis. It can be seen that $y_A = \tau_A - \tau_{i-1}$, $y_B = \tau_B - \tau_{i-1}$.

Information on the CS i at the beginning of the calendar time τ_{i-1} cannot be obtained in a periodical inspection scheme. Therefore, time points y_A and y_B on the sample time-axis cannot be correctly obtained either. For convenience of description, it is assumed that the information at the time a point is known in order to develop the model, despite this assumption is not necessarily essential. The following paragraph discusses that even without information at time points y_A and y_B an exponential hazard model can be estimated.

In the case the CS of an asset at time τ_i (time point y_C) is assumed to change from i to $i+1$, the period length in which the CS has remained at i (referred as the life expectancy of a CS i) is represented by $\zeta_i = \tau_i - \tau_{i-1} = y_C$. The life expectancy of a CS i is assumed to be a stochastic

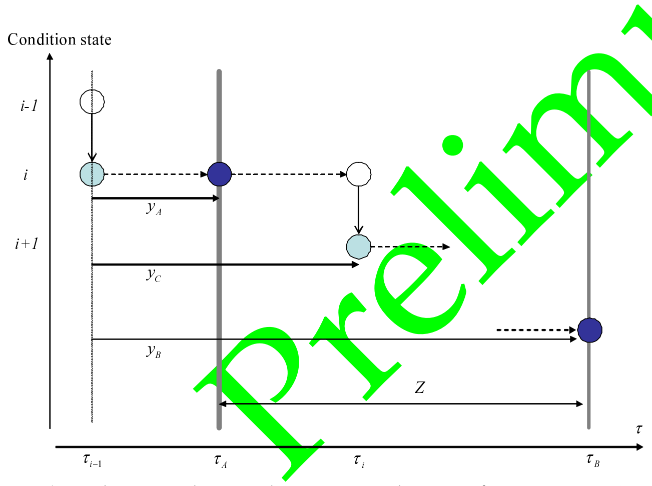


Note) In this example, the deterioration process of an asset is expressed in terms of four different sample paths. In paths 2 and 3 the CS has advanced to one upper CS at the calendar times τ_1^2 and τ_1^3 respectively. In path 4, the CS has increased one state at each time τ_1^4 and τ_2^4. However, in the case of a periodical inspection carried out at times τ_A the CS at any point in time between inspections cannot be observed.

Figure 3.3: Transition Pattern of Condition State.

variable ζ_i with probability density function $f_i(\zeta_i)$ and distribution function $F_i(\zeta_i)$. Random variable ζ_i is defined in the domain $[0, \infty]$. The distribution function is defined as

$$F_i(y_i) = \int_0^{y_i} f_i(\zeta_i) d\zeta_i. \tag{3.1}$$



Note) In the case the condition state changes from $i-1$ to i at the calendar time τ_{i-1} the inspections carried out at times τ_A and τ_B will also correspond to the points in time y_A and y_B when using τ_{i-1} as the time origin. The figure shows a sample deterioration path in which the condition state has advanced in one unit to y_c in the interval time $\tau_{i-1} - y_C$. However, observations at time τ_{i-1} are not possible in a periodical inspection scheme, so there is no way to obtain observation at y_A, y_B and y_C. Nevertheless, it is possible to use the information contained in $z = y_C - y_A \in [0, Z]$.

Figure 3.4: Model of Deterioration Process.

The distribution function $F_i(y_i)$ represents the cumulative probability of the transition in the CS from i to $i+1$. CS i is assumed to be observed at initial time $y_i = 0$(time τ_A). The time interval measured along the sample time-axis until the time point y_i is $\tau_{i-1} + y_i$. Therefore, using the cumulative probability $F_i(y_i)$, the probability $\tilde{F}_i(y_i)$ of a transition in the CS i during the time points interval $y_i = 0$ to $y_i \in [0, \infty]$ is defined by $\tilde{F}_i(y_i)$:

$$\text{Prob}\{\zeta_i \geq y_i\} = \tilde{F}_i(y_i) = 1 - F_i(y_i). \tag{3.2}$$

The conditional probability that the CS of an asset at time y_i advances from i to $i+1$ during the time interval $[y_i, y_i + \Delta y_i]$ is defined as

$$\lambda_i(y_i)\Delta y_i = \frac{f_i(y_i)\Delta y_i}{\tilde{F}_i(y_i)}, \tag{3.3}$$

where the probability density $\lambda_i(y_i)$ is referred as the hazard function.

3.3 Condition State (CS) definition

Condition of an asset can be described either by a range of discrete condition state (CS) or by continuous values of one or more than one parameters such as cracking, thickness, and corrosion. In asset management practice, discrete range of CS is often for the following reasons:

- It can be converted/mapped from continuous value of monitoring data;
- It is convenient for non-technical persons and managers;
- It is suitable for determination of intervention strategy and thus for life cycle cost modeling.

Assets in pump stations are different in category and functionality, thus it is not easy to define a universal range of CSs. However, it is possible that a generic range of CSs can be used to map appropriately different type of assets. In this project, following definitions are used for multiple CSs (Table 3.1) and binary state (Table 3.2) systems.

Table 3.1: Condition state definition - Multiple.

CS i	Definition	Require Intervention	Remarks
1	New/likely new and provide adequate LOS	No	Good (None/Insignificant)
2	Install <=5 years, provide adequate LOS	No	Acceptable (Minor)
3	Moderate aging, not provide adequate LOS, observed moderate breakdown	Yes	Damaged (Significant)
4	Moderate aging, not provide adequate LOS, require frequent CI and PI	Yes	Poor (Extensive)
5	Aging and not provide adequate LOS	Yes	Safety is endangered

Table 3.2: Condition state definition - Binary.

CS i	Definition	Require Intervention	Remarks
0	Not provide adequate LOS	No	
1	Provide adequate LOS	Yes	

3.4 Technical efficiency

Technical efficiency is a coefficient measured as the ratio of actual parameter value and expected/design parameter value. In case of PSs, TE is often discussed around the value of pump efficiency (η), which is a factor that accounts for the kinetic energy lost during the operation [7]. The PE is a product of the followings:

- Hydraulic efficiency (primarily, disk friction against the liquid with impeller shrouds). This efficiency is contributed by the speed and impeller geometry. Shock losses during rapid changes in direction along the impeller and volute can also resulted in additional shock losses;
- Volumetric efficiency (recirculation losses at wear rings, interstage bushes and other);
- Mechanical efficiency (friction at seals or gland packing and bearings)

Hydraulic efficiency and volumetric efficiency are used at the design stage of PS when there is a need to determine suitable pump or group of pumps that satisfies the designed LOS. Whilst, mechanical efficiency is used to determine operational efficiency once pumps are in used.

The mechanical efficiency (η_m) is estimated based on the equation 3.4

$$\eta_p = \frac{P_W}{P_B} \tag{3.4}$$

Where P_W and P_B are water power and brake power, respectively.

Following equations are used to calculated the P_W and P_B:

$$P_{W(kW)} = \gamma \times H \times Q \tag{3.5}$$

$$P_{B(kW)} = P_E \times e_m \tag{3.6}$$

where

P_W	*Water power (kW);*
P_B	*Brake power (kW);*
P_E	*Electric power (kW);*
Q	*Water flow rate (m^3/s);*
H	*Head produced by pump (m_{H_2O});*
η_e	*Motor efficiency (%);*
γ	*specific weight of fluid (water) (kN/m^3).*

3.5 Reliability

3.5.1 Qualitative and Operational Analysis

3.5.1.1 Failure Mode and Effects Analysis (FMEA)

An FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering.

A successful FMEA activity helps identify potential failure modes based on experience with similar products and processes—or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle.

Functional analyses are needed as an input to determine correct failure modes, at all system levels. The FMEA is in principle a full inductive (forward logic) analysis, however the failure probability can only be estimated or reduced by understanding the failure mechanism. Hence, FMEA may include information on causes of failure (deductive analysis) to reduce the possibility of occurrence by eliminating identified (root) causes.

3.5.1.2 Reliability Centered Maintenance (RCM)

Reliability-centered maintenance (RCM) is a process to ensure that systems continue to do what their user require in their present operating context. It is generally used to achieve improvements in fields such as the establishment of safe minimum levels of maintenance. Successful implementation of RCM will lead to increase in cost effectiveness, reliability, machine uptime, and a greater understanding of the level of risk that the organization is managing. It is defined by the technical standard SAE JA1011, Evaluation Criteria for RCM Processes.

Reliability centered maintenance is an engineering framework that enables the definition of a complete maintenance regimen. It regards maintenance as the means to maintain the functions a user may require of machinery in a defined operating context. As a discipline it enables machinery stakeholders to monitor, assess, predict and generally understand the working of their physical assets. This is embodied in the initial part of the RCM process which is to identify the operating context of the machinery, and write a Failure Mode Effects Analysis (FMEA). The second part of the analysis is to apply the "RCM logic", which helps determine the appropriate maintenance tasks for the identified failure modes in the FMEA. Once the logic is complete for all elements in the FMEA, the resulting list of maintenance is "packaged", so that the periodicities of the tasks are rationalised to be called up in work packages; it is important not to destroy the applicability of maintenance in this phase. Lastly, RCM is kept live throughout the "in-service" life of machinery, where the effectiveness of the maintenance is kept under constant review and adjusted in light of the experience gained.

RCM can be used to create a cost-effective maintenance strategy to address dominant causes of equipment failure. It is a systematic approach to defining a routine maintenance program composed of cost-effective tasks that preserve important functions.

3.5.2 Weibull model

In hazard analysis, the deterioration of element is subjected to follow a stochastic process [12]. For binary state system, two condition level $0, 1$ are often used. When receiving a PI or CI, the CS from 1 must be changed into 0. In reliability study, this process is often regarded as renewal process. The renewal is carried out at alternative time t_k $(k = 0, 1, 2, ...)$. In this way, the next renewal time is denoted as $t = t_0 + \tau$, where τ indicating the elapsed time. The life span of an asset is expressed by a random variable ζ. The probability distribution and probability density function of the failure occurrence are $F(\zeta)$ and $f(\zeta)$ respectively. The domain of the random variable ζ is $[0, \infty]$. The living probability (hereafter named as survival probability) expressed by survival function $\tilde{F}(\tau)$ can be defined according to the value of failure probability $F(\tau)$ in the following equation:

$$\tilde{F}(\tau) = 1 - F(\tau). \tag{3.7}$$

The probability, at which the asset performs in good shape until time τ and break down for the first time during an interval of $\tau + \Delta\tau$ can be regarded as hazard rate and expressed in the following equation:

$$\lambda_i(\tau)\Delta\tau = \frac{f(\tau)\Delta\tau}{\tilde{F}(\tau)}, \tag{3.8}$$

where $\lambda(\tau)$ is the hazard function of the asset. In reality, the breakdown probability depends largely on the elapsed time of the asset since its beginning of operation. Thus, the hazard function should take into account the working duration of the asset (time-dependent). In another word, the memory of the system should be inherited. Weibull hazard function is satisfied in addressing the deterioration process [2, 11]:

$$\lambda(\tau) = \frac{1}{\eta}\beta\tau^{\beta-1}, \tag{3.9}$$

where η is the scale parameter expressing the arrival density of the asset, and β is the acceleration or shape parameter. The probability density function $f(\tau)$ and survival function $\tilde{F}(\tau)$ in the form of Weibull hazard function can be further expressed in equation (3.10) and (3.11):

$$f(\tau) = \frac{1}{\eta}\beta\tau^{\beta-1}\exp(-\alpha\tau)^{\beta}, \tag{3.10}$$

$$\tilde{F}(\tau) = \exp(-\frac{1}{\eta}\tau)^{\beta}. \tag{3.11}$$

Estimation for Weibull's parameter is often with Maximum Likelihood Estimation (MLE) approach on historical data. Thus, the model's parameter is sensitive to how data behaves. We recommend to use this model only when there is sufficient data to be used.

An example of source code for education purpose is given in Github site of Nam Le [1]. The complete program is a copyright of Nam Le.

3.5.3 Markov model

The transition process among the condition states of an infrastructure component is uncertain. Therefore, future condition states cannot be forecasted deterministically. In this situation, Markov transition probability is employed to represent the uncertain transition pattern of the condition states during two time points. Markov transition probabilities can be defined for arbitrary time intervals.

For simplification, Markov transition probabilities can be defined and used to forecast the deterioration of a infrastructure component based on the information from periodical inspection scheme shown in Figure 3.4. The observed condition state of the component at time τ_A is expressed by using the state variable $h(\tau_A)$. If the condition state observed at time τ_A is i, then the state variable $h(\tau_A) = i$. A Markov transition probability, given a condition state $h(\tau_A) = i$ observed at time τ_A, defines the probability that the condition state at a future time (τ_B for example) will change to $h(\tau_B) = j$:

$$\text{Prob}[h(\tau_B) = j | h(\tau_A) = i] = \pi_{ij}. \tag{3.12}$$

The Markov transition probability matrix can be defined and rearranged by using the transition probabilities between each pair of condition states (i, j) as

$$\mathbf{\Pi} = \begin{pmatrix} \pi_{11} & \cdots & \pi_{1J} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \pi_{JJ} \end{pmatrix}. \tag{3.13}$$

The Markov transition probability (3.12) shows the transition probability between the condition states at two given times τ_A and τ_B, therefore, it is straightforward that the values of a transition probability will differ for different time intervals. Since deterioration continues as long as no repair is carried out $\pi_{ij} = 0$ $(i > j)$. From the definition of transition probability $\sum_{j=1}^{J} \pi_{ij} = 1$. Following conditions must be satisfied:

$$\left.\begin{array}{l} \pi_{ij} \geq 0 \\ \pi_{ij} = 0 \ \ (\text{when } \ i > j) \\ \sum_{j=1}^{J} \pi_{ij} = 1 \end{array}\right\}. \tag{3.14}$$

The worse level of deterioration is expressed by the condition state J, which remains as an absorbing state in the Markov chain as long as no repair is carried out. In this case $\pi_{JJ} = 1$.

Markov transition probabilities are defined independently from the deterioration history. As shown in Figure 3.4, the condition state at the inspection time τ_A is i, however, the time, at which, condition state changed from $i - 1$ to i is unobservable. In a Markov chain model, it is assumed that the transition probability between the inspection times τ_A and τ_B is only dependent on the condition state at time τ_A.

The Markov chain model is operative and widely applied in management of infrastructure system. Particularly, at management of network level, Markov chain model is used to define the average transition probability of the entire system, or a group of infrastructure components given two periodical inspection data.

Estimation for the Markov transition probability can be done by the MLE approach [12, 13] or Bayesian Estimation approach [8, 10] based on historical data. One advance of using the Markov model is that one time monitoring data can be used. A generic formula to estimate the transition probability is given in following Equations:

[1] https://github.com/namkyodai/Models

$$\pi_{ii} = \exp(-\theta_i Z), \tag{3.15-a}$$

$$\pi_{ii+1} = \frac{\theta_i}{\theta_i - \theta_{i+1}}\{-\exp(-\theta_i Z) + \exp(-\theta_{i+1} Z)\}, \tag{3.15-b}$$

$$\pi_{ij} = \sum_{k=i}^{j}\prod_{m=i}^{k-1}\frac{\theta_m}{\theta_m - \theta_k}\prod_{m=k}^{j-1}\frac{\theta_m}{\theta_{m+1} - \theta_k}\exp(-\theta_k Z), \tag{3.15-c}$$

$$\pi_{iJ} = 1 - \sum_{j=i}^{J-1}\pi_{ij}, \tag{3.15-d}$$

$$(i = 1, \cdots, J-1) \quad (j = i, \cdots, J).$$

An example of source code for education purpose is given in Github site of Nam Le [2]. The complete program is a copyright of Nam Le.

3.6 Intervention Strategy (IS)

Intervention Strategy (IS) is at asset level (level 7). It is a collection of intervention type for component level (level 8). A collection of ISs will form an Intervention Program for (IP) the station. A collection of IPs will form a Work Program (WP) for network level intervention (e.g. a bid awarded for a designer/contractor can be a WP that consists of intervention program for one or more than one pump stations). Following generic IS is defined to guide the selection of IPs that will be details in the later part of the report.

Table 3.3: Generic intervention strategy (IS).

IS	Definition	Remarks
1	Do Nothing	
2	Minor repair	Require minimal effort and can be done only for certain asset type
3	Major repair	Require extensive efforts to return the asset to likely new condition
4	Replacement/Renewal	Replacing assets or components of asset with identical one or with new model

For each type of asset, IS will be selected based on reliability study and consideration of cost. Further more, Employers inputs and requirements are also taken into account.

3.7 Determination of optimal intervention strategy

Following subsections briefly describe the model that can be used to determine optimal intervention strategy.

3.7.1 Block Replacement Model

It is assumed that a PI is executed after a pre-defined time $n \cdot T$ $(n = 0, 1, 2, \cdots, N)$. Once the PI is executed, the functionality and serviceability of the asset could be the same or different from that of the asset before the intervention. In between the time Δt ($[0 \leq \Delta t \leq T]$), hazards could occur and cause the asset in worse CSs (hereafter denoted as i $(i = 1, \cdots, I)$), in which the asset is no longer providing an adequate level of services (LOS). In both cases, when the PI or CI is executed, there are impacts incurred by stakeholders s (e.g. the owner, the users, the public).

Following notations are used to describe the formulation of the model.

[2]https://github.com/namkyodai/Models

$\theta(\Delta t\|t)$	Conditional failure rate i $(i = 1, \cdots, I)$ when the asset has been in service in an interval t after the PI
$\Psi(\cdot\|t)$	Any conditional function Ψ given that a PI is executed by a unit of age t, where t is a random variable
$F(t)$	Cumulative distribution function (cdf) of age t of a unit for a PI at execution time
$w_p^s(t)$	Impacts incurred by stakeholder s due to the execution of PI
$w_c^s(t)$	Impacts incurred by stakeholder s due to the execution of CI
$w_o^s(\Delta t\|t)$	Conditional impacts incurred by stakeholder s when the structure is remains in normal operation (*i.e.* providing an adequate LOS) during time interval Δt after a PI has been carried out and the asset has not entered failure state
ρ	discount factor
$p_l^k(t)$	probability of failure at time t of the affecting other assets k
$C_c^{s,k}$	Impacts incurred by stakeholder s due to the execution of an CI on other assets k
T	interval between the PIs
$T^\star$	Optimal interval time between PIs, which is the variable of the model
$\Omega_p(T,t)$	minimum expected total discounted impact for an infinite time span when the asset has been in service during an interval t after the execution of the PI and the asset has not entered failure state
$\Omega_c(T,t)$	minimum expected total discounted impact for an infinite time span when a CI has been executed, of the asset that has been in service during a time interval t after the execution of the PI and the asset has entered failure state

In the model, it is assumed that at each damage level i, there exists a corresponding well defined CI. Within an increment of time Δt, after the asset has been under the PI after time t, the total expected impacts due to the execution of CIs are:

$$v_c(\Delta t|t) = \sum_{s=1}^{S}\left[w_c^s(\Delta t) + \sum_{k=1}^{K} p_l^k \cdot C_c^{s,k}\right] \cdot \theta(\Delta t|t). \tag{3.16}$$

The total impacts due to the execution of PIs and the total impacts incurred by stakeholders during the service time of the asset are defined in Eq. (3.17) and Eq. (3.18), respectively.

$$v_p(t) = \sum_{s=1}^{S} w_p^s(t). \tag{3.17}$$

$$v_o(t) = \sum_{s=1}^{S} w_o^s(t). \tag{3.18}$$

According to the principle of optimality, which is described in [1, p. 15], the minimum expected total discounted impact $\Omega_c(T,t)$ for infinite time is formulated in following equation.

$$\Omega_c(T,t) = \int_0^\infty \left[v_c(\Delta t|t) + \Omega_p(T,\Delta t|t)\right] dF(t). \tag{3.19}$$

The minimum expected total discounted impact $\Omega_p(T,\Delta t|t)$, which appears inside Eq. (3.16), is obtained as follows

$$\Omega_p(T,\Delta t) = min\Gamma(\Delta t). \tag{3.20}$$

where $\Gamma(\Delta t)$ is defined as

$$\begin{aligned}\Gamma(\Delta t) = \int_0^\infty \Bigg[v_o \int_0^{dt} exp(-\rho\tau)d\tau + \{1 - \theta(\Delta t|t)dt\} \cdot \Omega_p(T, \Delta t + dt|t)exp(-\rho dt) \\ +\theta(\Delta t|t)dt \cdot \Omega_c(T, \Delta t + dt|t)exp(-\rho dt)\Bigg] dF(t).\end{aligned} \tag{3.21}$$

According to [9], Eq. (3.21) is rewritten in following form

$$\begin{aligned}\Gamma(\Delta t) = \Omega_p(T,\Delta t) + \left[-\rho\Omega_p(T,\Delta t) + d\Omega_p(T,\Delta t)/dt\right] dt \\ + \int_0^\infty \left[v_o + v_c(\Delta t|t)\right] dF(t)dt.\end{aligned} \tag{3.22}$$

Thus, from $\Omega_p(T, \Delta t) = \Gamma(\Delta t)$ (Eq. (3.20)), the following equation can be derived:

$$\Omega_p(T, \Delta t) = exp(\rho \Delta t) \left[\Omega_p(T, 0) - \int_0^\infty \int_0^t exp(-\rho \tau) \left\{ v_o + v_c(\tau | t) \right\} \right] d\tau dF(t). \quad (3.23)$$

where,

$$\Omega_p(T, 0) = \left\{ 1 - exp(-\rho T) \right\}^{-1} \int_0^\infty \left[exp(-\rho T) \left\{ v_p(T, t) \right\} \right. \\ \left. + \int_0^T exp(-\rho \Delta t) \left\{ v_o(\Delta t | t) + v_c(\Delta t | t) \right\} dt \right] dF(t). \quad (3.24)$$

when T tends to infinity $T \to \infty$, Eq. (3.24) becomes

$$\Omega_p(\infty, 0) = \int_0^\infty \int_0^\infty exp(-\rho t) \left[v_o + v_c(\Delta t | t) \right] dt dF(t). \quad (3.25)$$

Eqs. (3.24) and (3.25) are the explicit forms of the expected total discounted impact in infinite time horizon. This is the classical optimization problem. By differentiating the expected total discounted impact $\Omega_p(T, 0)$ and $\Omega_p(\infty, 0)$ and setting it equal to zero, the optimal time $T^\star$ can be obtained. The optimal time $T^\star$ for PI is the solution of the following system of equations:

$$\begin{cases} T^\star = \arg \min\limits_{T^\star \in [0,T]} \Theta_p(T, 0) \\ T^\star = \arg \min\limits_{T^\star \in [0,\infty]} \Theta_p(\infty, 0) \end{cases} \quad (3.26)$$

in which the differentiates of $\Theta_p(T, 0)$ and $\Theta_p(\infty, 0)$ are respectively:

$$\begin{aligned} \Theta_p(T, 0) &= \frac{\delta(\Omega_p(T, 0))}{\delta T} \\ &= \left[1 - exp(-\rho T) \right] \int_0^\infty \left[-\rho v_p(T, t) \right. \\ &\quad \left. + d(v_p(T, t))/dT + v_o(T, t) + v_p(T, t) \right] dF(t) \\ &\quad - \rho \int_0^\infty \left[exp(-\rho T) \left\{ v_p(T, t) \right\} \right. \\ &\quad \left. + \int_0^T exp(-\rho \Delta t) \left\{ v_o(\Delta t | t) + v_c(\Delta t | t) \right\} dt \right] dF(t). \end{aligned} \quad (3.27)$$

and

$$\begin{aligned} \Theta_p(\infty, 0) &= \frac{\delta(\Omega_p(\infty, 0))}{\delta T} \\ &= \int_0^\infty \left[-\rho \left\{ v_p(\infty | t) + \int_0^\infty exp(-\rho t) \left\{ v_o(\Delta t | t) + v_p(\Delta t | t) \right\} \right\} \right. \\ &\quad \left. + \lim_{T \to \infty} d(v_p(T, t))/dT + v_o(\infty | t) + v_p(\infty | t) \right] dF(t) \end{aligned} \quad (3.28)$$

3.7.2 Time-dependent replacement model

Time-dependent replacement model (or Age replacement model) are the ones where the following conditions apply:

- the asset starts operating at $t = 0$, i.e. it is newly built or newly restored to a like new condition following an intervention;
- the probability of failure is described with $f(t)$ and $F(t)$, i.e. the lifetime density and the lifetime;
- if the asset fails on the interval $(0, T]$ a CI is executed;

- if the object does not fail on the interval $(0,T]$ the object is replaced at T, i.e. the PI replacement is executed, regardless if the object has failed and been restored in the time interval $(0,T]$;
- the execution of a PI restores the object to a like new condition;
- the execution of a CI restores the object to a like new condition.

3.7.2.1 Minimize impact

If an age replacement IS is followed the time to the first intervention, Z, is the minimum amount of the time to failure of the length of the renewal period:

$$Z = min(\tau, T) \tag{3.29}$$

The expected, or mean, time to the first intervention is then determined by

$$E[Z = \int_0^T (1 - F(x))dx] \tag{3.30}$$

The mean impact in one renewal period then equals the probability of failure on T multiplied by the impacts associated with the CI plus the probability that no failure occurs on T multiplied by the impacts associated with the PI:

$$F(T) \times I^{CI} + (1 - F(T)) \times I^{PI} \tag{3.31}$$

The mean impacts per unit time, therefore, equal the mean cost in one renewal period divided by the length of the renewal period, i.e. the time to the first intervention.

$$\eta_{AC} = \frac{F(T) \times I^{CI} + (1 - F(T)) \times I^{PI}}{\int_0^T (1 - F(x))dx]} \tag{3.32}$$

3.7.2.2 Maximize availability

If it is desired to determine the age replacement IS that maximizes availability the following is often assumed, additionally that:

- the PI replacement takes t^{PI};
- the PI takes t^{CI};

If the asset fails before T then the length of the renewal period will, therefore, be $X = t + t^{CI}$, which has the probability $f(t)dt$ of occurring, and if the object does not fail before T then the length of the renewal period will be $X = t + t^{PI}$, which has the probability $1 - F(T)$ of occurring.

In this case, the expected, or mean, renewal period length is:

$$E[X] = \int_0^T (1 - F(x))dx + t^{CI}F(T) + t^{PI}(1 - F(T)) \tag{3.33}$$

As the asset is operational on average $\int_0^T (1 - F(x))dx$ then the availability is given by:

$$\eta_{AA} = \frac{\int_0^T (1 - F(x))dx}{\int_0^T (1 - F(x))dx + t^{CI}F(T) + t^{PI}(1 - F(T))} \tag{3.34}$$

Chapter 4

Data and Analysis

4.1 Qualitative and Operational Analysis

4.1.1 Facts and Data

Summary of facts and data concerning operational and overall plan reliability is presented in this subsection.

4.1.1.1 Operation Scenario

- Operational since 2011.
- 3 pumps in operation at 125HP each; Pump 2 is soft start (base load) and 1/3 is with VFD.
- 4AM – 10PM 2 pumps are operational maintaining 19psi discharge pressure.
- 10PM – 4AM 1 pump is operational maintaining 12psi discharge pressure.
- Refilling is done from Pagcor line.

4.1.1.2 Spares Policy

- During time of inspection, Pump 4 was under repair/overhaul.
- Switching sequence:
  - 10PM - P2 down; P1 operational
  - 12AM - P1 down; P3 operational
  - 4AM - P3/P2 operational
  - 10PM - P2 down; P3 operational
  - 12AM - P3 down; P1 operational

4.1.1.3 Emergency Situation (loss of electrical power from Meralco)

- Genset on auto-start;
- P1/P3 continue operations; P2 on manual start

4.1.1.4 Maintenance

- For operational problems, operator will call Control Center to report problem.
- Control Center to send contractor within 1-2 hours.
- Maintenance contractors conduct a weekly visit to do some maintenance activities.

4.1.1.5 Current Problems

- P3 VFD fault. It has been down for the last 4 days and no indication when it will be fixed. This problem occurred previously and rework has to be scheduled for more repairs of the VFD.

4.1.2 Recommendations

In order to ensure the PS to provide adequate level of services around the clock, it is important to establish a good operational scheme that allows optimization of use of pumps to reduce breakdown and to conserve energy. A summary of major recommendations to be considered are:

- Monitor installation of P4. With P4 in service, there will be enough capacity to cater for high demand and unplanned equipment failures and/or extended pump maintenance scenarios.
- Consider a dedicated duty and a dedicated spare set-up for the pumps. If this is not acceptable, then consider doing a much longer switch of the storage pumps. Currently, it is being switched daily to supply 700mm distribution system. This allows for almost an equal rate of deterioration between the two pumps and if one pump fails due to age-related component failure, the other one is close to a similar failure which may occur before the first pump is fully repaired. It is suggested that the switch happen once a month or even every 3 months.
- In place of the longer switching cycle (e.g. every 3 months), there should be a corresponding maintenance program for the standby pump for both booster and storage.
- Need to know what maintenance activities are done weekly and how the contractors/Maynilad use the information gathered to predict equipment failures.
- Develop a more structured discipline in applying routine maintenance work process to ensure that maintenance tasks are given the proper priority in terms of mitigation measures and avoid unplanned shutdown of critical pumps in operation.

Aside from the above recommendations, we also generate a list of recommendations based on the RCM methodology. This is presented at at the end of the document on Appendix A. The list shall be considered as a living program, which requires continuously improvement as part of the total quality management system (refer to Deming cycle presented in GHD's technical proposal).

4.2 Pump discharge pipe - thickness

4.2.1 Data and measurement

Thickness data on discharge pipes of pumps is presented in Table 4.1 and refer to Figure 4.1 for the positions and the distances for the Ultrasonic Thickness Gauging (UTG).

4.2.2 Analysis

This section provides analysis/discussion on estimation of minimum allowable thickness of pipes and statistics around the measured data collected during inspection and testings.

<u>BP1</u>

- Discharge Piping System- The component to be monitored is the 45-degree mitered bend, with the thickness ranging from 4.64mm - 5.16mm, the thinnest in the entire discharge piping system.

Table 4.1: Thickness data - Booster Pumps (mm).

Asset	Position	Distance (m)							
		Elbow			Straight				
		2.0m	2.3m	2.7m	3.1m	4.5m	5.8m	7.3m	8.3m
BP1	12	4.90	5.16	5.14	4.89	6.82	6.82	8.44	8.69
	3	4.81	5.07	4.82	4.99	6.93	6.93	8.47	8.34
	6	4.69	4.81	4.92	4.94	6.67	6.67	8.39	8.54
	9	4.72	4.88	4.91	4.64	6.69	6.69	8.39	8.49
BP2	12	4.90	5.00	5.08	4.80	5.17	6.71	8.15	8.20
	3	4.92	5.03	5.07	5.07	5.16	6.69	8.55	8.18
	6	4.80	4.98	5.00	4.71	4.77	6.87	8.28	-
	9	4.81	4.76	4.78	4.56	4.56	6.87	8.25	8.45
		-	-	-	3.0m	4.5m	5.5m	-	-
BP3	12	-	-	-	6.7	8.28	8.39	-	-
	3	-	-	-	6.72	8.06	8.39	-	-
	6	-	-	-	6.8	8.31	8.25	-	-
	9	-	-	-	6.91	8.26	8.33	-	-
BP4	12	-	-	-	6.39	6.35	8.07	-	-
	3	-	-	-	6.37	6.42	8.11	-	-
	6	-	-	-	6.18	6.88	8.47	-	-
	9	-	-	-	6.41	6.89	8.24	-	-

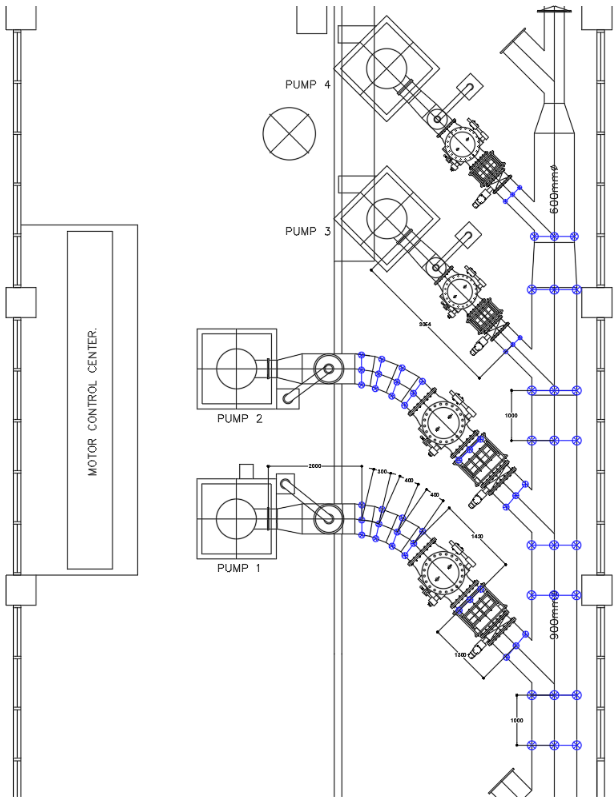


Figure 4.1: Test points and distances of UTG – Booster Pumps Discharge Side

<u>BP2</u>

- Discharge Piping System-The component to be monitored is the 45-degree mitered bend, with the thickness ranging from 4.56 - 5.08. Moreover, it is observed that relative to BP1, the 4.5m distance is thinner. One aspect to investigate that might be resulting to such condition is the unhealthy condition of pump in terms of vibration but still needs further investigation.

BP3

- Discharge Piping System- The measured thickness values are relatively on the upper range of the values from BP1 and BP2 (reference to 5.8m section) which might be attributed to its pump having a healthy condition in terms of its vibration spectrum.

BP4

- Discharge Piping System-The thickness measured at the 3.0 m section of BP4 is the thinnest when compared among other pumps relative to the 5.8 m section. Moreover, comparing its 4.5m thickness to BP3 (similar configuration), the values are relative lower with 1.59mm difference on average. This might be due to the reason that this pump is a high-speed pump, thus generates high flow rate given the fact that in terms of the vibration, the pump is within acceptable levels.

4.2.2.1 Assumptions

Following assumptions are used in calculating the required thickness of pipe

- Maximum Working Head – based on the design drawings and pump nameplate;
- Pipe Material – assume pipe material is ASTM A570 Grade 33 (market available material for spiral welded pipe);
- Design Guide – basis used for the simulated calculation is AWWA Manual M11 – Steel Pipe, A Guide for Design and Installation, 4th Edition. Statement for corrosion allowance is located at Chapter 4, which states *"At one time, it was a general practice to add a fixed, rule-of-thumb thickness to the pipe wall as a corrosion allowance. This was not an applicable solution in the water work field, where standard for coating and lining materials and procedures exists. The design shall be made for the required wall-thickness pipe as determined by the loads imposed, then linings, coatings, and cathodic protection selected to provide the necessary corrosion protection"*;
- Thickness calculation will be based on the internal pressure. External pressure will not be considered because much of the discharge line is not buried.
- Surge Pressure was not considered since there are surge protection along the line.
- This document will only consider the calculation of the minimum thickness along the discharge line since this is the part of the system where maximum pressure is experience.

4.2.2.2 Limitations

As confirmed by Maynilad, there is no available data regarding the design report. Design assumptions herein may be different from what was used by the designer/contractor of this station.

This document will not be able to provide the corrosion/degradation factor of the pipe since there is no available historical data on the thickness of the pipe.

4.2.2.3 Parameter values for thickness estimation

In order to estimate the minimum allowance thickness for pipes in straight line considering material handling (t_{mh}) and maximum internal pressure based on AWWA M11 (t_{sph}), following equations are used, respectively:

$$t_{mh} = \frac{\Phi}{\delta} \tag{4.1}$$

$$t_{sp} = \frac{\epsilon \times P_{max} \times \Phi}{2 \times S_e} \tag{4.2}$$

where P_{max} is maximum internal pressure

$$P_{max} = \frac{\rho_{H_2O} \times g \times H_{max}}{1000} \tag{4.3}$$

In order to estimate the minimum allowance thickness for pipes at elbows (Miter Bend), only maximum internal pressure is considered:

$$t_{mb} = \frac{P_{max} \times \Phi}{2 \times S_e} \times \left[1 + \frac{\Phi}{(3 \times R) - (1.5 \times \Phi_d)}\right] \times \epsilon \tag{4.4}$$

Table 4.2: Parameter values for thickness estimation.

Parameters	Symbol	Unit	Pumps	Remarks
			Booster	
Discharge diameter	Φ_d	mm	600	
Max flow rate	Q_max	m^3/s	0.144	assumed data (no available nameplate data)
Max pump head	H_max	m	10	assumed data (no available nameplate data)
Yield strength of material	S_y	MPa	227.5	ASTM A570 Grade 33, spiral welded pipe based on AWWA C200
Allowable stress	S_e	MPa	113.75	
Density of water	ρ_{H_2O}	kg/m^3	1000	
Gravity constant	g	m/s^2	9.81	
Safety factor	ϵ		1.5	
Bulk modulus of compressibility of liquid	k	Pa	2.1E+09	
Young's modulus of elasticity of pipe wall	E	Pa	2.1E+11	
Radius of Elbow	R	mm	900	
Emprical constant	δ		288	

4.2.2.4 Required thickness

Results of computation for minimum allowable thickness for booster pumps and storage pumps are given in Table 4.3.

Table 4.3: Minimum thickness allowance.

Pumps	Internal pressure (Mpa)	Minimum allowable thickness (mm)		
	P_{max}	t_{mh}	t_{sp}	t_{mb}
Booster	0.098	2.080	0.520	0.689

4.2.2.5 Recommendations

Given the current thickness of pipe the lack of design information, it is advisable to

- Not perform any major intervention on the pipes;
- Keep regular testing on exact locations using the same type of UTG device. It is important for Maynilad to establish a testing regime for obtaining thickness at exact same location over time (e.g. every year). Information obtained from testing will be then used to compute deterioration rate based on thickness value;
- Establish an approach to inspect/test the thickness of underground pipe, which is considered to be more vulnerable to leakage and corrosion on external wall;

- The elbows in the suction and the discharge piping systems must be monitored regularly;
- It is recommended to have a profiling of the piping systems above and below the ground in order to have a baseline in the analysis of the Maynilad Piping System. In order to have a profiling of pipe thickness at differential time T, additional measurement at similar locations shall be conducted periodically, behavior can then be monitored;
- Perform coating regularly of the pipe to prevent possible corrosion/errosion and damage that cause by external factors and surrounding condition;

4.3 Visual Inspection on Pipe, valves, fittings, supports, expansions, and appurtenances

4.3.1 Highlights

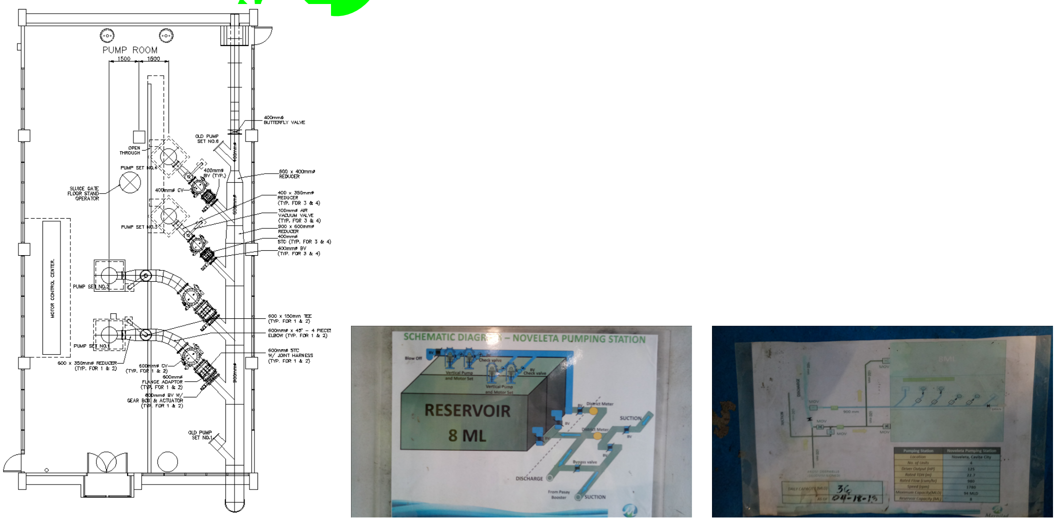
Visual inspection data on pipes, valves, fittings, supports, expansions, and appurtenances is highlighted in Table 4.4.

Table 4.4: Highlights of visual inspection

No.	Items	Remarks
1	Existing piping system	The open space of the above reservoir not well utilized, piping and fittings are compact and barely accomodates conventional measuring devices
2	Instrumentation and monitoring	PLC not fully working. Instrumentation/control diagram as proposed from as-built not completely adhered to. Also, MCC is exposed to the ambient conditions rather than in an air-conditioned room
3	Plant Layout	The layout of the pump station has many setbacks such as: Wide buffer spaces resulting to poor utilization of plant area, Need for remote monitoring devices Access and transport difficulties
4	Pipe support	Some unsupported pipe runs at pump discharge found in need to be supported to avoid strain on pump casing
5	Corrosion	Local corrosions on piping observed

Visual inspections are supported with the photos taken at particular locations or positions in question.

The station houses the pump system on top of the reservoir and is remotely controlled via the control center on an nearby building. See various plant schematic (Figures 4.2 - a, b and c)



a - Cad current schematic b - Plant Schematic (01) c - Plant Schematic (02)

Figure 4.2: Plant Schematics

The pump station has undergone upgrading last 2009. The pump system is designed for 6 avaialble slots for vertical turbine pumps where 4 are currently installed (Figure 1.1-b). The reservoir has an internal partition where 2 pumps draw water from the right side of the reservoir and 2 on the other. Water levels inside the reservoir are balanced thru a pipe that connects to either side.

The top of the reservoir contain the pump room where the vertical turbine pumps are located positioning it on top as part of flood proofing. A fraction of the reservoir top is allotted for the pump room where currently 4 pumps of 22.7m head and 23.52 Mld capacity each are fitted. However better utilization of space could have been made by using a wider portion of the reservoir top. This could have given sufficient allowance for future developments.

The pipes join the main discharge header on Y-type connection (Figure 4.3 - a). This helps to avoid higher head loss and strong water thrust that could develop if T junctions were used. However, the area allotted for the placement of the MCC, pumps, pipes and fittings was rather small. Necessary fittings such as the valves and STC's were installed and thereby only a small portion of straight pipe is left.

The discharge header then elbows down (Figure 4.3 - b) leading the pipe underground to join the supply line. This turn however may result to strong hydraulic thrust as water passes thru and the abrupt change in direction of a considerable volume of water will lead to losses and turbulence. The surface erosion on the elbow may need to check in the future.

a - Discharge header and joining lines

b - Discharge header continued

Figure 4.3: Discharge header

The surrounding areas around the vicinity currently functions as buffer zones between the residential areas and the station itself. However, this area still makes up considerably wide space and can be utilized if the reservoir had been better positioned. (Figure 4.4 - a and Figure 4.4 - b)

Similarly, the space on top of the reservoir not covered by the pump room does not show much opportunity for utilization (Figure 4.4 - c and Figure 4.4 - d). If spaces such as these want to be used however, quite enormous changes and construction might be needed such as installing additional columns on the reservoir to help support the load of the pump room as well as repositioning the entire plant reservoir.

a - buffer space (01)

b - buffer space (02)

c - unused space on reservoir top (01)

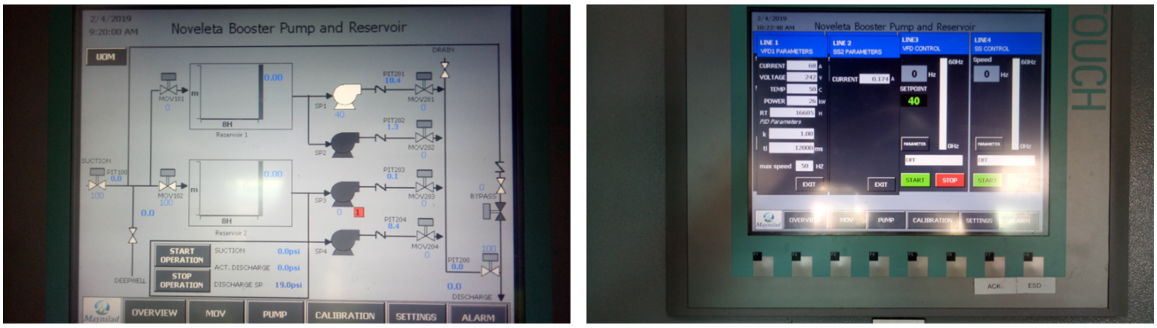
d - unused space on reservoir top (02)

Figure 4.4: Discharge side piping

In contrast to the more prevalent HSC type pumps observed in other stations, the pump station has vertical turbines as its pumps. Relative to the reservoir design, this had the consequence of requiring the pumps be located on top of the reservoir and with it the MCCs. The operator's office is located on a small building nearby and thus does not directly or immediately access the pump room.

The PLC needs to checks and fixed to give complete and accurate readings which as important for consistent plant monitoring. Many values found in the display are either zero (Figure

4.5 - a and Figure 4.5 - b) and do not help the operator at all.



a - PLC overview

b - PLC parameters

Figure 4.5: Discharge side piping

The water level inside the reservoir partitions are displayed in two separate meters. The inflow and outflow are also likewise displayed by two other meters. (Figures 4.8 - a, b and c)

a - water level meters

b - inflow meter

c - outflow meter

Figure 4.6: Indicating devices

There is a lack of monitoring devices necessary for remote monitoring such as vibration, temperature, etc. These are important to keep the operating parts health in check. In case of situational bad operating conditions, these may continue for some time before the operator can recognize it.

This may prove significance in improving CI effectiveness. Consider the following possible root cause as presented in a CI report (Figure 4.7).

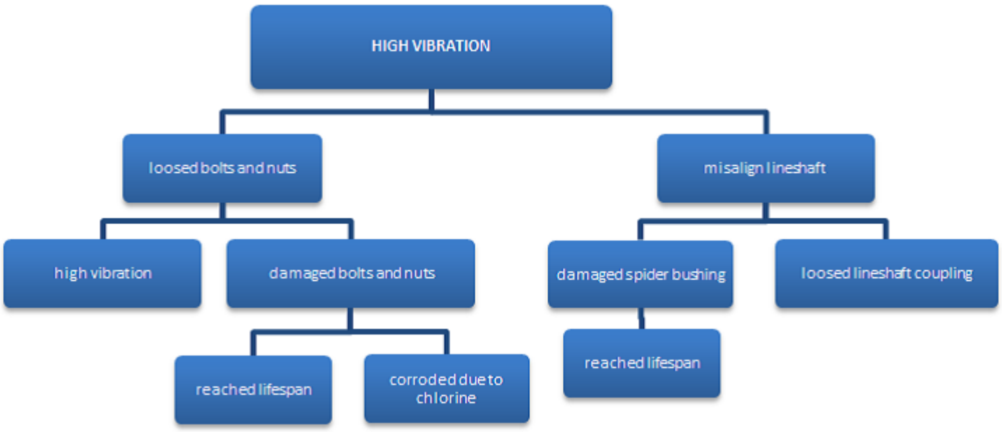


Figure 4.7: CI - Root Cause Analysis

It can be seen that monitoring devices such as those for vibration are important to easily detect disturbances and immediately call for diagnosis of looseness or mis-alignments to avoid such to escalate to major problems requiring major overhaul and/or replacement.

Local corrosion of pipes and fittings are observed along discharge header (Figure 4.8 - a) return lines (Figure 4.8 - b) and on the pump headers (Figure 4.8 - c).

a - discharge header b - return line c - pump header d - piping

Figure 4.8: Corrosion on parts

Also, the column for suction pressure on the recording sheet should be renamed as supply mainline pressure to avoid ambiguity.

All motors lack frame grounding. Assuming the motor power supplies were grounded at the motor control center (MCC), an assumption that still needs to be verified, current may pass through the bearings should the motor shaft be energized while the motor frame is ungrounded, which may lead to bearing damage, especially among variable speed drive (VFD) units. Bonding of non-current carrying metal components (e.g., motor frames) to the ground system is necessary to create an equipotential plane between the concrete floor and plant personnel who may risk electrocution should the frames parts be energized

4.3.2 Visual inspection data

Visual inspection data on assets are summarized in tables of this section.

Table 4.5: Visual inspection data - Drawing from Right Section of Reservoir: P1 and P2

No.	Items	CS	Remarks
1	Elbow after pump discharge	2	Need to be supported
2	CV	1	No leakage found
3	STC with harness	1	Reduces hydraulic thrust on header by allowing minute axial displacement along pipe
4	Header and joining line	1	Joining section via Y connection and long radius miter bend used at later section of discharge header help reduce hydraulic thrust and resistance
5	Bypass line	2	Not fully bolted at base for bypass line of Pump 2; corrosion of flange and bolts observed

Table 4.6: Visual inspection data - Drawing from Left Section of Reservoir: P3 and P4

No.	Items	CS	Remarks
1	Elbow after pump discharge	2	Need to be supported
2	CV	1	No leakage found
3	STC with harness	1	Reduces hydraulic thrust on header by allowing minute axial displacement along pipe
4	Header and joining line	1	Joining section via Y connection help reduce hydraulic thrust and resistance
5	Bypass line	1	no leakage observed

4.3.3 Recommendations

<u>Recommendations</u>

✓ Clear away oxide scales in affected areas until clean base metal is exposed. Repair or reinforce damaged pipe wall and recoat with a suitable protective coating.

✓ Bond motor frames to the station ground bus; review present grounding design or policy for Noveleta PSR.

4.4 Vibration and structural assessment

4.4.1 Measurement and spectrum reading

Rotating equipment generate vibration waveforms that are mathematical functions of machine dynamics, such as speed, alignment, and rotor balance, among others. Vibration analysis entails measurement and analysis of the amplitude of vibration at certain frequencies to gather useful information relating to the accuracy of shaft alignment and balance, the physical condition of bearings, and the possible effects of structural issues; in the case of Maynilad, the problem of impeller possible cavitation is an added and serious concern.

Three main parameters are measured to determine the severity or amplitude of vibration; namely: displacement, velocity and acceleration. Along with temperature, the vibration level is a primary indicator of the physical condition of a machine. As a generally rule, higher vibration levels indicate greater defects.

Rotating speeds below 600 rpm (10 Hz) generate minimal acceleration, moderate velocity, but relatively high displacement. Hence, shaft displacement is a critical parameter for slow speed rotors, such as steam turbines. Between 600 – 60000 rpm (10 - 1000 Hz) velocity and acceleration levels provide useful indications of the severity of defects. While velocity as a parameter may indicate the presence or relative magnitude of a problem, it makes no distinction as to the source or cause. This is where an FFT vibration analyzer comes in. A fast Fourier transform algorithm converts acceleration waveforms into functions of frequency in a way suitable-trained humans can distinguish the component sources or causes of the vibration.

By means of a OneProd Falcon high-resolution FFT analyzer equipped with tri-axial accelerometer with a linear frequency range of 2Hz-30kHz, vibration spectral readings were taken from four bearing locations in each motor-pump unit. Analysis and results are summarized as follows:

4.4.2 Data and analysis

Raw data of vibration measurement is provided in separately digital format. The raw data of each pump is used to generate a set of graphs provided in Appendix B.

Analytical results on vibration are with the Appendix B. A summary of grading for each pump is given in Table 4.7.

Table 4.7: Pump vibration condition state.

Assets	Operational issues detected	Condition	
		Motor	Pump
Pump 1	Vibrations are within acceptable levels Health is good for a long time service without restriction.	1	
Pump 2	Slight Unbalance Motor Fan	2	
Pump 3	Pump under repair during time of testing	-	
Pump 4	Vibrations are within acceptable levels Health is good for a long time service without restriction.	1	

It is noted that the CS 2, and 3 shown in Table 4.7 infers good and fair, respectively [1].

4.4.3 Recommendations

Recommendations are shown in Table 4.8

- The pump head should be relatively free from loads other than the weight of the overhead motor. However, for pumps 1 and 2 (Figure 4.9 - a and Figure 4.9 - b) the immediate discharge has unsupported pipe run of considerable length which will impose undue load of the pump head. Ad-hoc solution of placing a small concrete cylinder on the floor and catching the weight of the pipe and water passing is shown in Figure 4.9 - c.

[1] The CS is slightly different from that defines in Table 3.1

Table 4.8: Recommendation to reduce vibration.

Assets	Condition		Recommendations	IT
	Motor	Pump		
Pump 1	1		Continue monitor vibrations periodically	1
Pump 2	2		Monitor Slight Unbalance Motor Fan.	2
			Clean up on next PM or remove builtup dirt on blades	
Pump 3	-		Pump under repair during time of testing	
Pump 4	1		Continue monitor vibrations periodically	1

a - P1 discharge pipe   b - P2 discharge pipe   c - concrete cylinder as support

Figure 4.9: Discharge side piping

Recommendation

- ✓ Install proper supports along the discharge pipe segments. Additional support preferably under increaser be installed to carry weight of pipe.

- The pump discharge heads lack proper isolation devices, such as flexible joints or couplings.

Recommendations

- ✓ Install flexible joints or couplings at the discharge heads.

4.5 Workplace environment management

4.5.1 Temperature and relative humidity

4.5.1.1 Data

Data concerning the temperature and relative humidity is presented in Table 4.10. Data was measured at targeted points shown in Figure 2.5. Raw data is with the site inspection reports, which will be provided to the Client separately. Persuant to ASHRAE standard, the recommended ranges for temperature and humidity are [72 - 80 $^{\circ}F$] and [45 - 60 %], respectively.

4.5.1.2 Data and Analysis

The temperature inside the office registered values outside of the recommended range since the AC is not operated. Back door and windows are opened for natural ventilation inside the office and so readings are similar with that of the out side.

Readings inside the pump room register similar values as the room is equipped with louver panels and is also naturally ventilated. This could still be acceptable since the operators go on hourly rounds to the pump room to record operating parameters and do not stay there for long. They also hydrate regularly to combat the heat and body perspiration.

The temperature and humidity are correlated and as per ASHRAE standard 55 under summer comfort zone, the recommended combination of temperature and humidity shall be within the comfortable zone as shown in Figure 4.10.

Table 4.9: Temperature and Relative Humidity

Description of Location	Temperature		RH	
	Actual	Range	Actual	Range
A				
Beside P4	84.2	72-80	66.3	45-60
At staging area opposite 1	84.0	72-80	66.6	45-60
Between P3 and P4	83.8	72-80	67.2	45-60
Near MCC opposite 3	83.8	72-80	67.9	45-60
Between P2 and P3	83.8	72-80	68	45-60
Near MCC opposite5	83.5	72-80	66.3	45-60
Between P1 and P2	84.4	72-80	65.4	45-60
Near MCC opposite 7	84.0	72-80	65.4	45-60
Beside P1	84.6	72-80	65.5	45-60
Near door 3 opposite 9	84.6	72-80	64.4	45-60
Average	84.1	72-80	66.3	45-60
B				
Open area beside pump room	33.2	72-80	56.1	45-60
Open area beside pump room	32.1	72-80	59.3	45-60
Average	32.7	72-80	57.7	45-60
C				
Comfort room	30.1	72-80	62.7	45-60
Office	30.5		64.2	
Average	30.3	72-80	63.5	45-60
D				
Near Guard house	30.8	72-80	61.3	45-60

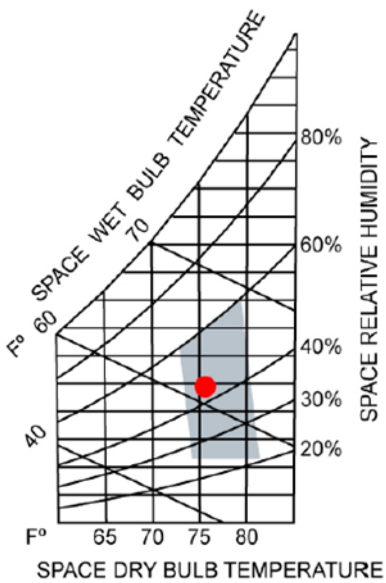


Figure 4.10: ASHRAE standard 55 : Summer Comfort Zone

4.5.1.3 Recommendation

In order to reduce the negative impacts from high temperature, particularly inside the pump house, the Client shall consider

- Establishing a good daily monitoring, exercise, and management considering ergonomic and health and occupational activities (e.g. appropriate time window for break in designated resting area);

Table 4.10: Air Quality - PM2.5

Point	Description of Location	PM2.5
A		
1	Beside P4	10
2	At staging area opposite 1	10
3	Between P3 and P4	10
4	Near MCC opposite 3	10
5	Between P2 and P3	9
6	Near MCC opposite5	10
7	Between P1 and P2	9
8	Near MCC opposite 7	10
9	Beside P1	9
10	Near door 3 opposite 9	9
	Average	9.6
B		
11	Open area beside pump room	10
12	Open area beside pump room	10
	Average	10.0
C		
13	Comfort room	8
14	Office	8
	Average	8.0
D		
15	Near Guard house	10

4.5.2 Air quality

4.5.2.1 Data and analysis

Data concerning the air quality is presented in Table 4.10 with value of PM2.5 measured in ppm. Data was measured at targeted points shown in Figure 2.5. Raw data is with the site inspection reports, which will be provided to the Client separately. Pursuant to currently applied standard, the recommended safe range for PM2.5 is in [0-35].

The average reading inside and outside the vicinity of the Pump Room are well below danger limits and do not pose any significant risk.

4.5.2.2 Recommendation

Though there is no issue with the air quality, it is anticipated that future problem can incur with a certain low probability, a better management approach is to ensure that all activities/tasks to be executed within the premise of the PS to follow strictly safety and environmental regulation. For example, all employees and staff to wear appropriate dust-proofed masks when working with activities that potentially incurs dusts or other harmful particles.

4.5.3 Illumination

4.5.3.1 Data and analysis

Data concerning the illumination is presented in Table 4.11 with the LUX value. Data was measured at targeted points shown in Figure 2.5. Raw data is with the site inspection reports, which will be provided to the Client separately. Persuant to RULE 1075.4 of DOLE-OSH standard [3], the recommended minimum for LUX is in 100.

The illuminations recorded are well above the standard's minimum values. These mean the illumination inside and outside the pump room is suitable for inpsections, and repairs. Considerable natural lighting come from the room windows (Figure 4.11 - a and Figure 4.11 - b) during the day.During evenings artificial lighting provides illumination inside the pump room and is also sufficient for inspections and repairs.

The operators office and vicinity are also well lit and above the standard minimum.

Table 4.11: Illumination

Point	Description of Location	Illumination
A		
1	Beside P4	2660
2	At staging area opposite 1	1647
3	Between P3 and P4	643
4	Near MCC opposite 3	385
5	Between P2 and P3	751
6	Near MCC opposite5	556
7	Between P1 and P2	1073
8	Near MCC opposite 7	676
9	Beside P1	586
10	Near door 3 opposite 9	586
	Average	956
B		
11	Open area beside pump room	15470
12	Open area beside pump room	149000
	Average	82235
C		
13	Comfort room	126
14	Office	183
	Average	155
D		
15	Open area Near Guard house	118600

a - pump room windows (01)

b - pump room windows (02)

Figure 4.11: Pump room illumination

a - pump room louvers (01)

b - pump room louvers (02)

c - louver panels with screen

d - louver panels behind MCC

Figure 4.12: Pump room ventilation

4.5.3.2 Recommendations

- Use artificial lighting equipment when accessing and conducting activities requiring detailed output at darker specific areas especially the route of operator going to the pump room (stairs and open area outside the pump room)

4.5.4 Industrial ventilation

4.5.4.1 Data and analysis

The room is installed with louver panels that provide natural ventilation (Figure 4.12 - a and Figure 4.12 - b) and is further increased by the open access and back doors. The louver panels have an added screen for better weather proofing (Figure 4.12 - c)The room is situated at higher elevations and thus wind flows into the room more freely.

4.5.4.2 Recommendation

- The louver panels facing the MCC panel boards (Figure 4.12 - d) need to be repositioned to avoid corrosion of the back boards due to water infiltrating thru the louvers especially during rains with strong winds.

4.5.5 Housekeeping

4.5.5.1 Documentation

Following problems are the facts:

- Current documentation practice is heavily dominated with paper based system, which follows the current practice in Maynilad. There is a large amount/collection of papers that recorded past activities but is of no use and beneficial if data cannot be transformed into digital format for time series analysis, which is an essential part of asset management practice;
- No proper filing/library system with standardized coding rule that will provide convenience for operators/users to timely find appropriate documents;
- Daily operation data is crucial information for future analysis but it is recorded in excel based file without relational tables, which makes it from hard to impossible for data compilation, filtering, and mining. Many past data has been recorded with outliers and incorrect data types.

4.5.5.2 Waste management and environmental control

There is no significant issue with management and environmental control as confirmed by the checklist shown in Table 4.12

A minor observation that still needs to addressed are lack of appropriate storage. Racks or cabinets could be placed to store miscellaneous items such as cleaning materials, repair tools, assembly parts and/or spares such as those observed during inspection as shown in Figure 4.13.

a - maintenance clutter (01)

b - maintenance clutter (02)

c - maintenance clutter (03)

d - maintenance clutter (04)

e - maintenance clutter (05)

f - maintenance clutter (06)

Figure 4.13: Pump room illumination

Table 4.12: Housekeeping.

Description	Status	CS	IT	Remarks
Pump room cleanliness	yes	1	1	After maintenance or intervention, area should be thoroughly cleaned. Water sumps be dried and grease be wiped
Sufficient waste segregation assets	yes	1	1	
Waste segregation policy	yes	1	1	
Proper/ appropriate signage	yes	1	1	
Genset emission control	yes		1	

4.5.5.3 Office arrangement and ergonomic

Table 4.13 shows the data concerning parameters associated with office arrangement and ergonomic considerations.

4.5.5.4 Recommendations

Followings are recommendations

- Development of a web-based database management system, with appropriate set of relational data tables to record operational data, power consumption data, and intervention data;
- Development of documentation code and naming for appropriate filing and library/referencing;
- Applying best practices with regard to ergonomic in combination with interior design and arrangement of office space.

4.5.6 Noise

4.5.6.1 Data and analysis

Data concerning the noise is presented in 4.14.Data was measured at targeted points shown in Figure 2.18. Raw data is with the site inspection reports, which will be provided to the Client separately.

Regular operation at 2 pumps running was considered during the sound level measurement and so the reading closely represents the normal daily noise level inside the plant. The average sound level inside the Pump room is at 82.7 dBa which means the operator, maintenance team can inspect or repair inside the room for considerably long without hearing impairment.

Sound levels are recorded around the vicinity of the pump room, office and nearby area of the guard house are below 70 dBa. Sound levels within these areas are considered safe even for prolonged stay.

4.5.6.2 Recommendations

- Continue to use protective hearing equipment when working inside the Pump House to further bring down sound level during repair or maintenance.

Table 4.13: Ergonomics.

Parameters	Sub-parameters	Status	Remarks
Posture	Head	1	Ceiling height is high enough to cause head injury while sitting or when standing.
	Neck	1	Neck posture is in good ergonomic condition. Consider having an interval for fit-break to avoid neck muscles stiffening.
	Back	1	Back posture while sitting is in good posture. Consider standing and doing fit-break exercises to relax spine.
	Hands/Wrist	0	Proper hand positioning in the keyboard is not observed. Wrist bending is seldom.
	Feet	1	Feet position is in good posture. Good clearance below worktables.
	Eyes	0	The computer monitor is on eyelevel in a certain operator only. Consider adjusting the monitor level comfortable to every operator. Look away into distance in order to rest the eyes for every 10 minutes or so.
Equipment / Tool			
	Computer display	0	Not adjusted and the operator get used to its current setting. Display brightness must be adjustable in the comfortability of the operator-in-charge. Consider the use of anti-glare and blue light to reduce the possibility of eyestrain.
	Keyboard	1	Keyboard position causes poor hand posture that can lead to injury at long exposure.
	Mouse	1	Mouse usage is average due to monitoring. Prolong usage may cause reduced blood flow leading to muscular injury.
	Chair	0	Consider using ergonomic chair that is capable of back support, height, armrest adjustments.
	Table	0	Consider use of ergonomic tables to adjust the height of the table in desired position easily without exerting much effort to adjust manually.
	Files	1	Hard copy file system and location is well observed. Too high or too low file location may require a person to bend his body or force his hand to grip a file in an awkward posture. Frequent situation may lead to MSD.
Operations / Maintenance	Illumination	0	According to the maintenance team, the motion-activated light is not bright enough to complete their task efficiently at night. Moreover, the light has short on-off delay operation that means that the team must move more often to avoid the light to dim. Consider having a manual switch option to by-pass the motion sensors and le the light on while doing maintenance.
	Noise Exposure	1	Noise emitted by the machines in the pump station is high. Consider the use of proper ear protections to reduce the sound intensity. In offices, the sound intensity is acceptable.
	Temperature	1	Temperature in the pump station is not acceptable at long exposure. Consider cooling down the body temperature at the designated area (i.e. outside, office).
Facility / General Workplace	Layout	1	Layout of the pump station is well observed. Distance between pumps is acceptable for well maintenance movement.
	Height clearances	1	Height clearances from ceiling to head is very high. Chance of getting head injury is very low.

Table 4.14: Sound Levels.

Point	Description of Location	Sound
A		
1	Beside P4	79.6
2	At staging area opposite 1	88.1
3	Between P3 and P4	81.2
4	Near MCC opposite 3	78.4
5	Between P2 and P3	81.1
6	Near MCC opposite5	83.1
7	Between P1 and P2	85.8
8	Near MCC opposite 7	86
9	Beside P1	81.5
10	Near door 3 opposite 9	81.8
	Average	82.7
B		
11	Open area beside pump room	65.6
12	Open area beside pump room	67.9
	Average	66.8
C		
13	Comfort room	66.4
14	Office	65.1
	Average	65.8
D		
15	Near Guard house	58.1

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Appendix A

Recommended Maintenance Program

Maintenance Program

Code	Name	Station ID	Asset Description	Component	Failure Mode	Criticality	Failure Pattern	Task	Frequency	Done by	Comments
For dedicated spare pumps & motors only	**Pump**	**NVL**	**Horizontal pump between bearings**	**Bearings**	**bearing failure caused by false brinelling**	**High**	**Age-related**	**Rotate pump shaft 2-1/4 times**	**Every shift**	**Operator**	**Ensure that pump is isolated from power source**
For dedicated spare pumps & motors only	**Pump**	**NVL**	**Horizontal pump between bearings**	**Bearings**	**Bearing failure caused by contaminated oil**	**High**	**Random**	**Inspect oil for water contamination Regrease as necessary**	**Weekly**	**Maintenance contractor**	
For dedicated spare pumps & motors only	**Motor**	**NVL**	**Horizontal pump between bearings**	**Starter; Auto start system**	**Fail to start**	**High**	**Random**	**Start pump and run for at least 2 hours. Check all functionalities.**	**Monthly**	**Operator**	**Do this during visit by maintenance contractor.**
WSO-NVEPR-0002	R1 Inlet Motorized Actuator	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0003	R1 Inlet Butterfly Valve 1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0004	R1 Inlet Butterfly Valve 2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0005	R2 Inlet Motorized Actuator 1	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0006	R2 Inlet Butterfly Valve 1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0007	R2 Inlet Butterfly Valve 2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0008	R1 Outlet Butterfly Valve 1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0009	R1 Outlet Butterfly Valve 2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0010	R1 Outlet Butterfly Valve 3	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0011	R1 Outlet Butterfly Valve 4	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0012	R2 Outlet Butterfly Valve 1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0013	R2 Outlet Butterfly Valve 2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0014	R2 Outlet Butterfly Valve 3	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.

WSO-NVEPR-0015	R2 Outlet Butterfly Valve 4	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0016	Main Suction Pipe	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0017	Suction Pipe and Fittings North A	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0018	Air valve North A	NVL	Air valve	Actuator	Fail Open/Fail Close	Medium	Random	Overhaul pneumatic actuaor & clean internals	Annually	Maintenance contractor	Assign task to OEM contractor.
WSO-NVEPR-0019	Suction Pipe and Fittings North B	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0020	Air valve North B	NVL	Air valve	Actuator	Fail Open/Fail Close	Medium	Random	Overhaul pneumatic actuaor & clean internals	Annually	Maintenance contractor	Assign task to OEM contractor.
WSO-NVEPR-0021	Suction Pipe and Fittings North C	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0022	Air valve North C	NVL	Air valve	Actuator	Fail Open/Fail Close	Medium	Random	Overhaul pneumatic actuaor & clean internals	Annually	Maintenance contractor	Assign task to OEM contractor.
WSO-NVEPR-0023	Pipes and Fittings NA1	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0024	Suction Butterfly Valve NA1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.

WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0025	Storage Pump NA1	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0026	Check Valve NA1	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0027	Discharge Motorized Actuator NA1	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0028	Discharge Motorized Butterfly Valve NA1	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0029	Discharge Butterfly Valve NA1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0030	Storage Pump Motor NA1	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0030	Storage Pump Motor NA1	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0031	Pipes and Fittings NA2	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0032	Suction Butterfly Valve NA2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0033	Storage Pump NA2	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0033	Storage Pump NA2	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0034	Storage Pump NA3	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0035	Storage Pump NA4	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0036	Storage Pump NA5	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0037	Storage Pump NA6	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.

WSO-NVEPR-0038	Storage Pump NA7	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0039	Storage Pump NA8	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0040	Storage Pump NA9	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0034	Check Valve NA2	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0035	Discharge Motorized Actuator NA2	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0036	Discharge Motorized Butterfly Valve NA2	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0037	Discharge Butterfly Valve NA2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0038	Storage Pump Motor NA2	NVL	Motor	Motor winding	Motor trip due to overloading	[illegible]	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0038	Storage Pump Motor NA2	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0039	Pipes and Fittings NA3	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0040	Suction Butterfly Valve NA3	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.

WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0041	Storage Pump NA3	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0042	Check Valve NA3	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0043	Discharge Motorized Actuator NA3	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0044	Discharge Motorized Butterfly Valve NA3	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0045	Discharge Butterfly Valve NA3	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0046	Storage Pump Motor NA3	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
		NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0047	Pipes and Fittings NA4	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0048	Suction Butterfly Valve NA4	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.

WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0049	Storage Pump NA4	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0050	Check Valve NA4	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0051	Discharge Motorized Actuator NA4	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0052	Discharge Motorized Butterfly Valve NA4	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0053	Discharge Butterfly Valve NA4	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0054	Storage Pump Motor NA4	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0054	Storage Pump Motor NA4	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0055	Pipes and Fittings NA5	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0056	Suction Butterfly Valve NA5	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.

WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0057	Storage Pump NA5	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0058	Check Valve NA5	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0059	Discharge Motorized Actuator NA5	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0060	Discharge Motorized Butterfly Valve NA5	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0061	Discharge Butterfly Valve NA5	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0062	Storage Pump Motor NA5	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
		NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor windings insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0063	Pipes and Fittings NA6	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0064	Suction Butterfly Valve NA6	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0065	Storage Pump NA6	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0066	Storage Pump NA7	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)

WSO-NVEPR-0067	Storage Pump NA8	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0068	Storage Pump NA9	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0069	Storage Pump NA10	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0070	Storage Pump NA11	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0071	Storage Pump NA12	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0072	Storage Pump NA13	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0073	Storage Pump NA14	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0066	Check Valve NA6	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0067	Discharge Motorized Actuator NA6	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0068	Discharge Motorized Butterfly Valve NA6	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0069	Discharge Butterfly Valve NA6	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0070	Storage Pump Motor NA6	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
		NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0071	Pipes and Fittings NB1	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0072	Suction Butterfly Valve NB1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.

WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **<u>xx</u>** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0073	Storage Pump NB1	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0074	Check Valve NB1	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0075	Discharge Motorized Actuator NB1	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0076	Discharge Motorized Butterfly Valve NB1	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0077	Discharge Butterfly Valve NB1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0078	Storage Pump Motor NB1	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0078	Storage Pump Motor NB1	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0079	Pipes and Fittings NB2	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0080	Suction Butterfly Valve NB2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.

WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Packing	Excessive leak	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0081	Storage Pump NB2	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0082	Check Valve NB2	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0083	Discharge Motorized Actuator NB2	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0084	Discharge Motorized Butterfly Valve NB2	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0085	Discharge Butterfly Valve NB2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0086	Storage Pump Motor NB2	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0086	Storage Pump Motor NB2	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0087	Pipes and Fittings NB3	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.

WSO-NVEPR-0088	Suction Butterfly Valve NB3	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0089	Storage Pump NB3	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0090	Check Valve NB3	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0091	Discharge Motorized Actuator NB3	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0092	Discharge Motorized Butterfly Valve NB3	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0093	Discharge Butterfly Valve NB3	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0094	Storage Pump Motor NB3	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0094	Storage Pump Motor NB3	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.

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WSO-NVEPR-0095	Pipes and Fittings NB4	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0096	Suction Butterfly Valve NB4	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0097	Storage Pump NB4	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0098	Check Valve NB4	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0099	Discharge Motorized Actuator NB4	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0100	Discharge Motorized Butterfly Valve NB4	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0101	Discharge Butterfly Valve NB4	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0102	Storage Pump Motor NB4	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.

WSO-NVEPR-0102	Storage Pump Motor NB4	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0103	Pipes and Fittings NB5	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0104	Suction Butterfly Valve NB5	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0105	Storage Pump NB5	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0106	Check Valve NB5	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0107	Discharge Motorized Actuator NB5	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0108	Discharge Motorized Butterfly Valve NB5	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0109	Discharge Butterfly Valve NB5	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.

WSO-NVEPR-0110	Storage Pump Motor NB5	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0110	Storage Pump Motor NB5	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0111	Pipes and Fittings NC1	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0112	Suction Butterfly Valve NC1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0113	Storage Pump NC1	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0114	Check Valve NC1	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0115	Discharge Motorized Actuator NC1	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0116	Discharge Motorized Butterfly Valve NC1	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.

WSO-NVEPR-0117	Discharge Butterfly Valve NC1	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0118	Storage Pump Motor NC1	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0118	Storage Pump Motor NC1	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0119	Pipes and Fittings NC2	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0120	Suction Butterfly Valve NC2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0121	Storage Pump NC2	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0122	Check Valve NC2	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0123	Discharge Motorized Actuator NC2	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.

WSO-NVEPR-0124	Discharge Motorized Butterfly Valve NC2	NVL	Motorized valve	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0125	Discharge Butterfly Valve NC2	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0126	Storage Pump Motor NC2	NVL	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-NVEPR-0126	Storage Pump Motor NC2	NVL	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-NVEPR-0127	Pipes and Fittings NC3	NVL	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0128	Suction Butterfly Valve NC3	NVL	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-[illegible] years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-NVEPR-0129	Storage Pump NC3	NVL	Pump	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-NVEPR-0130	Check Valve NC3	NVL	Check valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.

Appendix B

Vibration Data

DOCUMENT TITLE

NOVELETA PUMPING STATION MOTOR & PUMP UNITS VA STATUS REPORT AS OF FEB 2019

COMMENT

NOVELETA PUMPING STATION

VISA

Written by	Approved by	State	Date
ENGR. JAY DIMALIBOT	ENGR. PETER VASQUEZ	PHI	25/03/2019 09:14:03

Table of contents

Synthesis Report

Filter: Equipment name (+) \ Tree order (+)

Location	Equipment	Diagnosis: Previous Date		Diagnosis: Current Date		Recommendations
NOVELETA\	BOOSTER PUMP UNIT 1			GOOD		No action required
				15/02/2019 09:08:30		
		Oper.		Oper.	DfCnd	
		Vibrations are within acceptable levels				
NOVELETA\	BOOSTER PUMP UNIT 2			FAIR		Monitor Slight Unbalance Motor Fan
				15/02/2019 09:15:13		
		Oper.		Oper.	DfCnd	
		Slight Unbalance Motor Fan				
NOVELETA\	BOOSTER PUMP UNIT 3					
		Oper.		Oper.		
NOVELETA\	BOOSTER PUMP UNIT 4			GOOD		Continue monitor vibrations periodically
				15/02/2019 09:19:08		
		Oper.		Oper.	DfCnd	
		Vibrations are within acceptable levels				

Expertise Report

Filter: Equipment name (+) \ Tree order (+)

Location	NOVELETA\	Fixed speed
Designation	NOVELETA PUMP STATION	
Equipment	BOOSTER PUMP UNIT 1	
Designation		
Abbreviation	BP#1	
Serial No		
Model		
Periodicity (d)	*Normal* 60 *Alarm* 15	

Previous Advice	*Condition*	*Rotation Speed*

Date 15/02/2019 09:08:30	GOOD *Health is good for a long time service without restriction*	*Speed*	19.8 Hz / 1185 rpm
		Author	u1
		System - Serial	FALCON - 11407
Condition DfCnd		*Sensor*	
		Connector	

Diagnosis & Recommendation

Parameters sheet

Diagnosis

Vibrations are within acceptable levels

Good overall state for component 'Electric motor'.

Recommendations

No action required

No action required

IP1.jpg

dirty

Location	NOVELETA\	Fixed speed
Designation	NOVELETA PUMP STATION	
Equipment	BOOSTER PUMP UNIT 2	
Designation		
Abbreviation	BP#2	
Serial No		
Model		
Periodicity (d)	*Normal* 60 *Alarm* 15	

Previous Advice	*Condition*	*Rotation Speed*

Date 15/02/2019 09:15:13	**FAIR** *Health is not acceptable for a long time service.*	*Speed*	29.9 Hz / 1795 rpm
		Author	u1
		System - Serial	FALCON - 11407
Condition DfCnd		*Sensor*	
		Connector	

Diagnosis & Recommendation

Parameters sheet

Diagnosis

Slight Unbalance Motor Fan

Overall state still acceptable for the component 'Electric motor'.
Slight Unbalance Motor Fan

Recommendations

Monitor Slight Unbalance Motor Fan

Monitor Slight Unbalance Motor Fan. Clean up on next PM or remove built-up dirt on blades

IP2.jpg

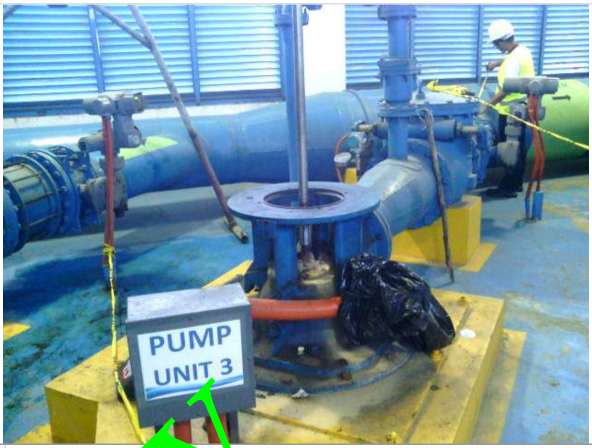
dirty
IP3.jpg


CATALOG#
MODEL#
FR
TYPE
ENCL
PH
DUTY
CONT
1200
LB
BAL
HP
RPM
1780
SF
HZ
VOLTS
AMPS
SF AMPS
CODE
PF
OIL CAPACITY
GREASE
U.S. ELECTRICAL MOTORS
EMERSON

1409d2.jpg


C1 (30 Hz, [0.1031 g, 5.36 mm/s, 28.46 um])
g
[RMS] : BOOSTER PUMP UNIT 2 1-MT-Ax Spectrum LF 15/02/2019 09:15:13
f0
C1
B1
0.1
0.01
0.001
0.0001
0
50
100
150
200
Hz
Asset hierarchy\NOVELETA\BOOSTER PUMP UNIT 2
BOOSTER PUMP UNIT 2 1-MT-Ax Spectrum LF 15/02/2019
C1 30Hz
0.1031g, 5.36mm/s, 28.46um
f0:Rot Speed 29.92Hz
7222BEP [SKF] I1:273.16Hz E1:205.55Hz
B1:158.87Hz C1:12.56Hz
p0:IND-0007 29.92Hz [+/- 0.5Hz]
p1:IND-0008 59.84Hz [+/- 0.25Hz]
p2:IND-0009 89.76Hz [+/- 0.5Hz]
p3:IND-0010 29.92Hz [+/- 0.5Hz]
p4:IND-0011 59.84Hz [+/- 0.25Hz]
p5:IND-0012 89.76Hz [+/- 0.5Hz]
p6:IND-0013 0Hz [+/- 0.5Hz]
p7:IND-0014 0Hz [+/- 0.5Hz]
p8:IND-0015 0Hz [+/- 0.5Hz]
p9:1x 29.92Hz [+/- 0.5Hz]
p10:2x 59.84Hz [+/- 0.5Hz]
p11:3x 89.76Hz [+/- 0.5Hz]

Location	NOVELETA\	
Designation	NOVELETA PUMP STATION	
Equipment	BOOSTER PUMP UNIT 3	Fixed speed
Designation		
Abbreviation	BP#3	
Serial No		
Model		
Periodicity (d)	*Normal* 60 *Alarm* 15	



Previous Advice	*Condition*	*Rotation Speed*

Date		Speed [illegible] Hz / 1750 rpm
		Author
		System - Serial
		Sensor
Condition		Connector

Diagnosis & Recommendation — Parameters sheet

Diagnosis

Recommendations

Location	***NOVELETA***	
Designation	***NOVELETA PUMP STATION***	
Equipment	***BOOSTER PUMP UNIT 4***	***Fixed speed***
Designation		
Abbreviation	***BP#4***	
Serial No		
Model		
Periodicity (d)	*Normal* ***60*** *Alarm* ***15***	

Previous Advice	*Condition*	*Rotation Speed*

Date ***15/02/2019 09:19:08***	***GOOD*** ***Health is good for a long time service without restriction.***	Speed ***29.9 Hz / 1791 rpm***
		Author ***u1***
		System - Serial ***FALCON - 11407***
		Sensor
Condition ***DfCnd***		Connector

Diagnosis & Recommendation — Parameters sheet

Diagnosis

Vibrations are within acceptable levels
Overall state still acceptable for the component 'Electric motor'.

Recommendations

Continue monitor vibrations periodically
Continue monitor vibrations periodically

IP4.jpg

CATALOG#
MODEL#
LOWER END BRG 6212-J
UPPER END BRG 7222-BEM
FR 405TP
TYPE RU
ENCL WP-1
PH 3
MAX AMB 40 °C
ID# M 12 7334875-0015 M-0001
INSUL CLASS F
DUTY CONT
WT 1200 LB
BAL
HP 125.00
RPM 1780
SF 1.15
HZ 60
VOLTS 460
MAX KVAR
AMPS 147.00
CODE G
DES B
SF AMPS
PF
GUARANTEED EFFICIENCY
OIL CAPACITY LOWER END BRG GREASE
QTS UPPER END BRG 5
QTS
NRR
MADE IN MEXICO
U.S. ELECTRICAL MOTORS
DIVISION OF EMERSON ELECTRIC CO
ST. LOUIS, MO.
422703-004
EMERSON.

IP5.jpg

Analysis Report

Filter: Equipment name (+) \ Tree order (+) Alarm type: Danger \ Alarm \ Pre-Alarm \ Error \ Ok \ Undefined \ Inhibited

NOVELETA\

BOOSTER PUMP UNIT 1

Selected Date	15/02/2019 09:08:30	Speed	19.8 Hz / 1185 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Operating param.	1	H/S	Last Date	Value	Unit	T-1	Ref.	Avg									
Ovrl:Rotation speed	Rot Spd	Hard	15/02/2019 09:08:30	1185	rpm		1185										
1-MT-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30	2.15	mm/s		2.15		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30	0.205	g		0.205		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30	2.57	DEF		2.57		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30	0.883	mm/s		0.883		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30	0.0845	mm/s		0.0845		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30	0.199	mm/s		0.199		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30	0.0763	g		0.0763		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30	0.149	g		0.149		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30	0.118	g		0.118		DfCnd	High	0	0	0	0	2	4	0
1-MT-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30	0.844	mm/s		0.844		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30	0.320	g		0.320		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30	2.45	DEF		2.45		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30	0.590	mm/s		0.590		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30	0.0353	mm/s		0.0353		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30	0.0881	mm/s		0.0881		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30	0.0336	g		0.0336		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30	0.239	g		0.239		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30	0.206	g		0.206		DfCnd	High	0	0	0	0	2	4	0
1-MT-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30	0.890	mm/s		0.890		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30	0.254	g		0.254		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30	2.13	DEF		2.13		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30	0.315	mm/s		0.315		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30	0.0441	mm/s		0.0441		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30	0.0676	mm/s		0.0676		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30	0.0420	g		0.0420		DfCnd	High	0	0	0	0	.15	.3	0

NOVELETA\

BOOSTER PUMP UNIT 1

Selected Date	15/02/2019 09:08:30	Speed	19.8 Hz / 1185 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

En-MF	En-MF	Soft	15/02/2019 09:08:30	0.140	g		0.140		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30	0.207	g		0.207		DfCnd	High	0	0	0	0	2	4	0
2-MT-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30	1.08	mm/s		1.08		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30	0.210	g		0.210		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30	2.42	DEF		2.42		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30	0.366	mm/s		0.366		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30	0.0263	mm/s		0.0263		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30	0.0926	mm/s		0.0926		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30	0.0622	g		0.0622		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30	0.0939	g		0.0939		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30	0.169	g		0.169		DfCnd	High	0	0	0	0	2	4	0
2-MT-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30	0.431	mm/s		0.431		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30	0.434	g		0.434		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30	2.41	DEF		2.41		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30	0.239	mm/s		0.239		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30	0.0213	mm/s		0.0213		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30	0.0268	mm/s		0.0268		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30	0.0239	g		0.0239		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30	0.216	g		0.216		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30	0.371	g		0.371		DfCnd	High	0	0	0	0	2	4	0
2-MT-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30	1.08	mm/s		1.08		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30	0.287	g		0.287		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30	2.56	DEF		2.56		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30	0.246	mm/s		0.246		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30	0.0356	mm/s		0.0356		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30	0.0602	mm/s		0.0602		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30	0.0672	g		0.0672		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30	0.159	g		0.159		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30	0.225	g		0.225		DfCnd	High	0	0	0	0	2	4	0

NOVELETA\ BOOSTER PUMP UNIT 1

Selected Date	15/02/2019 09:08:30	Speed	19.8 Hz / 1185 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

3-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	2	4	0

3-PP-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	2	4	0

3-PP-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	2	4	0

4-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30						DfCnd	None							

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BOOSTER PUMP UNIT 1	Selected Date	15/02/2019 09:08:30	Speed	19.8 Hz / 1185 rpm
	Author	u1	Connector	
	System - Serial No	FALCON - 11407	Sensor	

Defect factor	IND-0003	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	2	4	0

4-PP-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	2	4	0

4-PP-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:08:30						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:08:30						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:08:30						DfCnd	High	0	0	0	0	2	4	0

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BOOSTER PUMP UNIT 2	Selected Date	15/02/2019 09:15:13	Speed	29.9 Hz / 1795 rpm
	Author	u1	Connector	
	System - Serial No	FALCON - 11407	Sensor	

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BOOSTER PUMP UNIT 2

Selected Date	15/02/2019 09:15:13	Speed	29.9 Hz / 1795 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Operating param.	1	H/S	Last Date	Value	Unit	T-1	Ref.	Avg									
Ovrl:Rotation speed	Rot Spd	Hard	15/02/2019 09:15:13	1795	rpm		1795										
1-MT-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13	6.53	mm/s		6.53		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13	0.317	g		0.317		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13	2.26	DEF		2.26		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13	5.37	mm/s		5.37		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13	1.19	mm/s		1.19		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13	0.0998	mm/s		0.0998		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13	0.153	g		0.153		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13	0.197	g		0.197		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13	0.189	g		0.189		DfCnd	High	0	0	0	0	2	4	0
1-MT-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13	4.77	mm/s		4.77		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13	0.365	g		0.365		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13	2.42	DEF		2.42		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13	3.95	mm/s		3.95		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13	0.225	mm/s		0.225		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13	0.0340	mm/s		0.0340		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13	0.0956	g		0.0956		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13	0.258	g		0.258		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13	0.231	g		0.231		DfCnd	High	0	0	0	0	2	4	0
1-MT-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13	2.78	mm/s		2.78		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13	0.372	g		0.372		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13	2.35	DEF		2.35		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13	1.36	mm/s		1.36		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13	0.723	mm/s		0.723		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13	0.0347	mm/s		0.0347		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13	0.107	g		0.107		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13	0.304	g		0.304		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13	0.181	g		0.181		DfCnd	High	0	0	0	0	2	4	0
2-MT-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err

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BOOSTER PUMP UNIT 2	Selected Date	15/02/2019 09:15:13	Speed	29.9 Hz / 1795 rpm
	Author	u1	Connector	
	System - Serial No	FALCON - 11407	Sensor	

Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13	3.36	mm/s		3.36		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13	0.437	g		0.437		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13	2.38	DEF		2.38		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13	2.60	mm/s		2.60		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13	0.103	mm/s		0.103		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13	0.0874	mm/s		0.0874		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13	0.145	g		0.145		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13	0.294	g		0.294		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13	0.281	g		0.281		DfCnd	High	0	0	0	0	2	4	0
2-MT-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13	2.31	mm/s		2.31		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13	0.443	g		0.443		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13	2.47	DEF		2.47		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13	1.95	mm/s		1.95		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13	0.0438	mm/s		0.0438		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13	0.0229	mm/s		0.0229		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13	0.0773	g		0.0773		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13	0.359	g		0.359		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13	0.254	g		0.254		DfCnd	High	0	0	0	0	2	4	0
2-MT-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13	1.90	mm/s		1.90		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13	0.489	g		0.489		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13	2.57	DEF		2.57		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13	1.12	mm/s		1.12		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13	0.0532	mm/s		0.0532		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13	0.0371	mm/s		0.0371		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13	0.0869	g		0.0869		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13	0.290	g		0.290		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13	0.384	g		0.384		DfCnd	High	0	0	0	0	2	4	0
3-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13						DfCnd	None							

NOVELETA\

BOOSTER PUMP UNIT 2

Selected Date	15/02/2019 09:15:13	Speed	29.9 Hz / 1795 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Defect factor	IND-0003	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	2	4	0
3-PP-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	2	4	0
3-PP-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	2	4	0
4-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	3	6	0

NOVELETA\ BOOSTER PUMP UNIT 2

Selected Date	15/02/2019 09:15:13	Speed	29.9 Hz / 1795 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

		H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
2x	2x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	2	4	0
4-PP-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	2	4	0
4-PP-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:15:13						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:15:13						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:15:13						DfCnd	High	0	0	0	0	2	4	0

Preliminary

NOVELETA\ BOOSTER PUMP UNIT 3

Selected Date		Speed	29.2 Hz / 1750 rpm
Author		Connector	
System - Serial No		Sensor	

	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Operating param.	H/S	Last Date	Value	Unit	T-1	Ref.	Avg									
1-MT-Ax	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
1-MT-R=	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
1-MT-RT	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
2-MT-Ax	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err

NOVELETA

BOOSTER PUMP UNIT 3

Selected Date		*Speed*	*29.2 Hz / 1750 rpm*
Author		*Connector*	
System - Serial No		*Sensor*	

2-MT-R=	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
2-MT-RT	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
3-PP-Ax	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
3-PP-R=	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
3-PP-RT	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
4-PP-Ax	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
4-PP-R=	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
4-PP-RT	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*

NOVELETA

BOOSTER PUMP UNIT 4

Selected Date	*15/02/2019 09:19:08*	*Speed*	*29.9 Hz / 1791 rpm*
Author	*u1*	*Connector*	
System - Serial No	*FALCON - 11407*	*Sensor*	

Operating param.	*1*	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*									
Ovrl:Rotation speed	*Rot Spd*	*Hard*	*15/02/2019 09:19:08*	*1791*	*rpm*		*1791*										
1-MT-Ax	*9*	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	*IND-0001*	*Hard*	*15/02/2019 09:19:08*	*2.58*	*mm/s*		*2.58*		*DfCnd*	*High*	*0*	*0*	*0*	*2*	*3.5*	*6*	*0*
Overall Acc	*IND-0002*	*Hard*	*15/02/2019 09:19:08*	*0.249*	*g*		*0.249*		*DfCnd*	*None*							
Defect factor	*IND-0003*	*Hard*	*15/02/2019 09:19:08*	*2.29*	*DEF*		*2.29*		*DfCnd*	*High*	*0*	*0*	*0*	*4*	*6*	*9*	*0*
1x	*1x*	*Soft*	*15/02/2019 09:19:08*	*1.62*	*mm/s*		*1.62*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*3*	*6*	*0*
2x	*2x*	*Soft*	*15/02/2019 09:19:08*	*0.134*	*mm/s*		*0.134*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*1.5*	*3*	*0*
3x	*3x*	*Soft*	*15/02/2019 09:19:08*	*0.149*	*mm/s*		*0.149*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*1*	*2*	*0*
En-LF	*En-LF*	*Soft*	*15/02/2019 09:19:08*	*0.103*	*g*		*0.103*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*.15*	*.3*	*0*
En-MF	*En-MF*	*Soft*	*15/02/2019 09:19:08*	*0.180*	*g*		*0.180*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*.5*	*1*	*0*
En-HF	*En-HF*	*Soft*	*15/02/2019 09:19:08*	*0.139*	*g*		*0.139*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*2*	*4*	*0*
1-MT-R=	*9*	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	*IND-0001*	*Hard*	*15/02/2019 09:19:08*	*4.38*	*mm/s*		*4.38*		*DfCnd*	*High*	*0*	*0*	*0*	*2*	*3.5*	*6*	*0*
Overall Acc	*IND-0002*	*Hard*	*15/02/2019 09:19:08*	*0.398*	*g*		*0.398*		*DfCnd*	*None*							
Defect factor	*IND-0003*	*Hard*	*15/02/2019 09:19:08*	*2.43*	*DEF*		*2.43*		*DfCnd*	*High*	*0*	*0*	*0*	*4*	*6*	*9*	*0*
1x	*1x*	*Soft*	*15/02/2019 09:19:08*	*3.74*	*mm/s*		*3.74*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*3*	*6*	*0*
2x	*2x*	*Soft*	*15/02/2019 09:19:08*	*0.165*	*mm/s*		*0.165*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*1.5*	*3*	*0*
3x	*3x*	*Soft*	*15/02/2019 09:19:08*	*0.223*	*mm/s*		*0.223*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*1*	*2*	*0*
En-LF	*En-LF*	*Soft*	*15/02/2019 09:19:08*	*0.0857*	*g*		*0.0857*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*.15*	*.3*	*0*
En-MF	*En-MF*	*Soft*	*15/02/2019 09:19:08*	*0.287*	*g*		*0.287*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*.5*	*1*	*0*
En-HF	*En-HF*	*Soft*	*15/02/2019 09:19:08*	*0.265*	*g*		*0.265*		*DfCnd*	*High*	*0*	*0*	*0*	*0*	*2*	*4*	*0*
1-MT-RT	*9*	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	*IND-0001*	*Hard*	*15/02/2019 09:19:08*	*1.59*	*mm/s*		*1.59*		*DfCnd*	*High*	*0*	*0*	*0*	*2*	*3.5*	*6*	*0*
Overall Acc	*IND-0002*	*Hard*	*15/02/2019 09:19:08*	*0.350*	*g*		*0.350*		*DfCnd*	*None*							

NOVELETA\
BOOSTER PUMP UNIT 4

Selected Date	15/02/2019 09:19:08	Speed	29.9 Hz / 1791 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Defect factor	IND-0003	Hard	15/02/2019 09:19:08	2.37	DEF		2.37		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08	0.998	mm/s		0.998		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08	0.114	mm/s		0.114		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08	0.0913	mm/s		0.0913		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08	0.104	g		0.104		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08	0.151	g		0.151		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08	0.296	g		0.296		DfCnd	High	0	0	0	0	2	4	0
2-MT-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08	1.70	mm/s		1.70		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08	0.304	g		0.304		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08	2.37	DEF		2.37		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08	0.902	mm/s		0.902		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08	0.0804	mm/s		0.0804		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08	0.0837	mm/s		0.0837		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08	0.0849	g		0.0849		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08	0.201	g		0.201		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08	0.202	g		0.202		DfCnd	High	0	0	0	0	2	4	0
2-MT-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08	1.68	mm/s		1.68		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08	0.472	g		0.472		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08	2.47	DEF		2.47		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08	1.40	mm/s		1.40		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08	0.0486	mm/s		0.0486		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08	0.0881	mm/s		0.0881		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08	0.0436	g		0.0436		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08	0.410	g		0.410		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08	0.238	g		0.238		DfCnd	High	0	0	0	0	2	4	0
2-MT-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08	1.83	mm/s		1.83		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08	0.368	g		0.368		DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08	2.45	DEF		2.45		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08	0.645	mm/s		0.645		DfCnd	High	0	0	0	0	3	6	0

NOVELETA\
BOOSTER PUMP UNIT 4

Selected Date	15/02/2019 09:19:08	Speed	29.9 Hz / 1791 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

2x	2x	Soft	15/02/2019 09:19:08	0.158	mm/s		0.158		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08	0.127	mm/s		0.127		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08	0.119	g		0.119		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08	0.200	g		0.200		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08	0.278	g		0.278		DfCnd	High	0	0	0	0	2	4	0
3-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	2	4	0
3-PP-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	2	4	0
3-PP-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1	2	0

NOVELETA\
BOOSTER PUMP UNIT 4

Selected Date	15/02/2019 09:19:08	Speed	29.9 Hz / 1791 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

En-LF	En-LF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	2	4	0

4-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	2	4	0

4-PP-R=	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	2	4	0

4-PP-RT	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	15/02/2019 09:19:08						DfCnd	None							
Defect factor	IND-0003	Hard	15/02/2019 09:19:08						DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	15/02/2019 09:19:08						DfCnd	High	0	0	0	0	.5	1	0

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BOOSTER PUMP UNIT 4	*Selected Date*	***15/02/2019 09:19:08***	*Speed*	***29.9 Hz / 1791 rpm***
	Author	***u1***	*Connector*	
	System - Serial No	***FALCON - 11407***	*Sensor*	

En-HF	***En-HF***	***Soft***	***15/02/2019 09:19:08***	***DfCnd***	***High***	***0***	***0***	***0***	***0***	***2***	***4***	***0***