EVALUATION OF WATER PUMPING SYSTEMS

Maintenance Manual
First Edition

Water and Sanitation Intiative

Sustainable Energy and Climate Change Initiative

Inter-American Development Bank

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Water and Sanitation Initiative
Sustainable Energy and Climate Change Initiative
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PRESENTATION

As part of its Technical Cooperation "Energy Efficiency for Caribbean Water and Sanitation Companies," the Sustainable Energy and Climate Change Initiative (SECCI) of the Inter-American Development Bank (IDB) financed the development of a regional methodology to improve energy efficiency and maintenance of water companies in Latin American and Caribbean countries. This methodology, developed by the consulting firms Econoler International and Alliance to Save Energy, focuses mainly on electromechanical efficiencies of water pumping systems in the Caribbean. This publication presents the maintenance manual for the evaluation of the systems. The calculation sheet, a guide to the calculation sheet, and an energy efficiency assessment are also available on the IDB Publications Portal: *http://www.iadb.org/publications/* and the Water and Sanitation Initiative Portal: *http://www.iadb.org/en/topics/water-sanitation/energy-efficiency-for-utilities,4492.html*.

The following people from the Sustainable Energy and Climate Change Unit (ECC) and the Water and Sanitation Division (WSA) supervised the preparation of this manual: Christoph Tagwerker (ECC), Marcello Basani (WSA), Rodrigo Riquelme (WSA), and Gerhard Knoll (WSA). Econoler International and Alliance to Save Energy developed the manual – Arturo Pedraza and Ramón Rosas.

Water and Sanitation Initiative
Sustainable Energy and Climate Change Initiative

EXECUTIVE SUMMARY

The Integrated Maintenance Plan (IMP) of a water and sanitation system implies the development of an ordered sequence of actions to help maintain and sustain equipment and installations in efficient operating conditions. In essence, the IMP is made up of the following three elements:

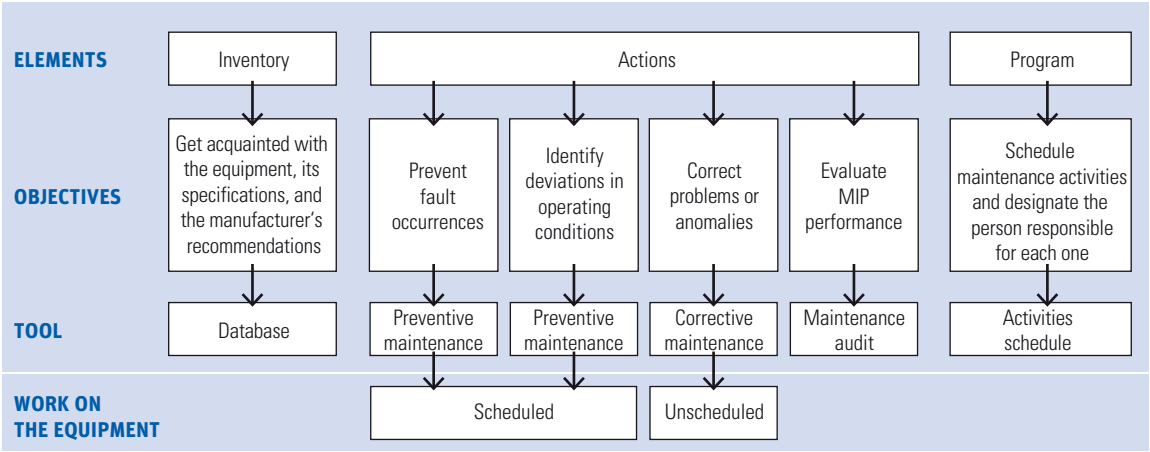
- Equipment inventory, which must include equipment specification and components as well as operation and maintenance recommendations issued by the manufacturer;
- Definition of actions and frequency of action execution, which should be objective-oriented and structured according to the maintenance plan; and
- A working program, which is a matrix with arrows on one axis and activities on the other that designates the person responsible for each activity.

Maintenance actions are divided into four types according to the specific target:

- Activities to prevent problems: the tool that combines and structures these activities is ***preventive maintenance.*** The main activities carried out as part of this type of maintenance are inspection of the equipment, cleaning, lubrication, and replacement of components.
- Activities to identify problems: the tool that combines and structures these activities is ***predictive maintenance.*** This maintenance is based on monitoring, recording, and analyzing the behavior of the main variables of equipment and facilities operation. Predictive maintenance is used to correct equipment operation by observing any deviation from normal operating conditions and then scheduling the corresponding corrective activities.
- Activities to correct problems: the tool that combines and structures these activities is ***corrective maintenance***. This work may be scheduled or unscheduled; scheduled activities are planned as a result of the identification of a potential problem, and the unscheduled activities must be carried out to correct or repair some fault in the equipment.
- Activities to evaluate IMP performance: the tool that combines and structures these types of activities is the ***maintenance audit.*** It includes data collection and operating parameter measurements, as well as the evaluation of the maintenance plan carried out at the facilities. Based on these data, actions for improvement are determined to guarantee continuous service of the equipment and avoid their efficiency reduction.

Figure 1 shows the IMP process and describes the interrelation among several tools to carry out actions on the equipment.

FIGURE 1: Integral Maintenance Plan Process



TERMS

The purpose of the definitions, terms, and symbols is to provide all users of the manual with a common technical language so they can handle the execution of the concepts presented herein.

Capacitive reactance – resistance offered by pure capacitors (condensers) to the passage of alternating current, or currents, with no internal resistance.

Capacitor – device formed by two plates or sheets separated by dielectric material, which acquires a specific electric charge when subjected to electric voltage.

Circuit breaker – device able to disconnect an energized circuit under the condition of an electrical fault.

Compact substation – transformer included in a metallic cabinet that enables operators to touch it externally without risks.

Corrective maintenance – a set of actions executed to fix a malfunction or fault that affects the system operation.

Design temperature – maximum temperature that equipment or components can endure.

Dielectric material – those materials that do not conduct electricity.

Electrical conductor – copper, aluminum, or any other metal wire that serves as a good conductor of electric power.

Electric current – flow of electric charge in ampere (A) that passes through a conductor with resistance ***R*** under voltage **U**.

Electric tension (voltage) – electric potential difference in (V) required between the binding post, or between two active parts of an installation so that electric current flows in it.

Flow – water volume measured by any time unit, typically expressed in liters per second (l/s).

Ground electrode – conductor (typically rods, tubes, or plates) buried in the ground to dissipate electrical faults.

Hot spot – maximum temperature spot on the external surface of an equipment or device.

Inductive reactance – resistance offered by pure inductance (coils) to the flow of alternating current, or currents with no internal resistance.

Insulation aging – observed decrease of the insulation quality and therefore of the service life of a piece of equipment.

Insulation resistance – resistance offered by an insulating material to the flow of electric current produced when applying a continuous voltage.

Knife switch – device to open a deenergized electrical circuit.

Level to manometer centers – vertical distance between the reference level and the position of the manometer used to measure pressure heads at suction and at discharge.

Oil dielectric strength – oil's characteristic resistance to the flow of the electric current.

Power factor – relation between the active power and the apparent power. The power factor describes the relation between the power converted into actual and effective power and the total power consumed.

Predictive maintenance – technique to forecast the potential time of a fault of a component in a machine in such a way that the faulty component may be replaced just before the fault takes place.

Preventive maintenance – set of actions taken to prevent faults that may affect the pumping system operation.

Pump - hydraulic machine that transforms mechanical energy into pressure energy, which is then transferred to water.

Reference level – level chosen as a reference for all the hydraulic measures; it is typically the lower plane of the mounting base plate of the pumping equipment.

Service life – time in which the project work or element is estimated to work adequately.

Suction level – vertical distance from the reference level to the water surface when the pumping equipment is operating.

Supply line – conductors through which electric energy is supplied.

Surge arrester – protective device that sends atmospheric electrical discharges to the ground.

Temperature rise to transformer – plate data that show the difference or maximum increase of the transformer as compared to an average value of room temperature.

Total pumping head – algebraic addition of the pressure head at discharge, the suction level, the level at the manometer center, frictional and singular losses at conduction, and speed head.

Transformer – device to increase or reduce electric tensions.

Valve – mechanical device used to stop or control water flow in pressure pipelines.

SYMBOLS

The following symbols are used in the manual:

IMP = Integrated Maintenance Plan

ELECTRICAL

DBI = Current imbalance (–)
I_A = Phase A current (A)
I_B = Phase B current (A)
I_C = Phase C current (A)
I_{prom} = Three-phase average current (A)
DBP = Power imbalance (–)
P_A = Phase A power (kW)
P_B = Phase B power (kW)
P_C = Phase C power (kW)
P_{prom} = Three-phase average power (kW)
P_e = Electric power required by the motor as obtained in field measurements (kW)
HP_{nom} = Nominal power of the engine (actual power verified on field) in horsepower (HP)
DBV = Voltage imbalance (–)
V_{A-B} = Voltage between phases A and B (V)
V_{B-C} = Voltage between phases B and C (V)
V_{A-C} = Voltage between phases A and C (V)
V_{prom} = Average voltage between phases (V)
V_{placa} = Nominal voltage value shown on the plate (V)
VDN = Percentage difference between the measured voltage value and the plate data of the nominal voltage (–)
X_c = Capacitive reactance (Ω)
η_m = Motor efficiency or good performance of the motor as indicated by the manufacturer (–)

HYDRAULIC

DQ_b = Hydraulic deviation as compared to design deviation (–)
D_{r-m} = Reference level to manometer centers (m)
LF = Load factor of the motor operation as determined by the manufacturer (–)
H_{FS} = Friction losses in suction line (wcm)
H_T = Total pumping head (wcm)
Hv = Velocity head (wcm)
lps = Water flow unit of measure in liters per second (l/s)
wcm = Manometric pressure unit in water column meters (wcm)
Ns = Suction level (m)
P_d = Delivery pressure measured (kg/cm^2)
P_s = Suction pressure measured (kg/cm^2)
Q_b = Pumping design hydraulic flow (l/s)

Chapter 1

INTRODUCTION

An Integrated Maintenance Plan (IMP) for a water and sanitation system attempts to develop an ordered sequence of activities to keep all equipment and installations in ideal conditions at all times. A maintenance audit (MA) in a water and sanitation system involves data collecting and survey, measuring operating parameters, and becoming acquainted with the existing maintenance plan carried out at the facilities. Based on the data collected and observations made in an MA, improvements to be carried out are determined, thus guaranteeing the continuous service of equipment and avoiding unnecessary loss of efficiency. This document has seven chapters and an appendix. Sections 2, 3, and 4 focus on premaintenance safety, as well as predictive and preventive maintenance. Section 5 details the corrective maintenance steps and Section 6 evaluates the company's current maintenance activities. Lastly, the appendix presents the methodology to carry out an audit of the company's water pumping system maintenance.

Chapter 2

PREMAINTENANCE SAFETY REQUIREMENTS[1]

Before any maintenance work is carried out on electrical equipment, safety measure must be taken to ensure personnel are protected against electric shocks. The following simple lockout steps are provided to assist in developing basic safety procedures:

- When the energy isolating devices are not lockable, tagout may be used, provided the water utility complies with the provisions of the standard that require additional training and more rigorous periodic inspections.
- When tagout is used and the energy isolating devices are lockable, the water utility must provide full employee protection, as well as additional training and more rigorous periodic inspections.

TYPICAL MINIMAL LOCKOUT PROCEDURES

These procedures establish the minimum requirements for the lockout of energy isolating devices whenever maintenance or servicing is done on machines or equipment. It shall be used to ensure that the machine or equipment is stopped, isolated from all potentially hazardous energy sources, and locked out before employees perform any servicing or maintenance where the unexpected start-up or release of stored energy could cause injury.

All employees must comply with the stated restrictions and limitations when performing the lockout. Upon observing a machine or piece of equipment that is locked out for service or maintenance, employees shall not attempt to start, energize, or use it. Employees working on maintenance of electrical equipment should carry with them a noncontact voltage detector to verify that the work environment is safe in terms of exposure to live circuits.

SEQUENCE OF LOCKOUT PROCEDURES

1. Notify all affected employees that servicing or maintenance is required on a machine or piece of equipment, and that it must be shut down and locked out to perform the servicing or maintenance. Prepare a list of affected employees (include names and job titles) and method of notification.
2. Authorized employees should refer to the company procedure to identify the type and magnitude of the energy that the machine or equipment utilizes, as well as understand the potential hazards and the methods to control them.
3. If the machine or equipment is operating, shut it down by the normal stopping procedure (depress the stop button, open switch, close valve, etc.).
4. Deactivate the energy isolating device(s) so that the machine or equipment is isolated from the energy source(s).
5. Lock out the energy isolating device(s) with assigned individual lock(s).
6. Dissipate or restrain stored or residual energy (such as that in capacitors, springs, elevated machine members, rotating flywheels, hydraulic systems, and air, gas, steam, or water pressure, etc.) by methods such as grounding, repositioning, blocking, bleeding down, etc.
7. Ensure that the equipment is disconnected from the energy source(s) by checking that no personnel

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[1] http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9805

are exposed. Then, verify the isolation of the equipment by operating the push button or other normal operating control(s) and by testing using a voltage detector or other test tool to ensure the equipment will not operate. **Return operating control(s) to neutral or "off" position after verifying the isolation of the equipment.**

8. The last step is to ground and short-circuit all possible power sources on the deenergized side.

RESTORING EQUIPMENT TO SERVICE

When the maintenance is completed and the machine or equipment is ready to return to normal operating conditions, the following steps should be taken:

1. Check the machine or equipment and the immediate area around the machine to ensure that nonessential items have been removed and that the machine or equipment components are operationally intact.
2. Check the work area to ensure that all employees are at a safe distance or removed from the area.
3. Verify that the controls are in neutral or "off".
4. Remove the grounding and short-circuiting.
5. Remove the lockout devices and reenergize the machine or equipment. Note: After the removal of some forms of blocking, it may be necessary to reenergize the machine before safe removal.
6. Notify affected employees that the servicing or maintenance is complete and the machine or equipment is ready for use.

Chapter 3

PREDICTIVE MAINTENANCE

Predictive maintenance to a water pumping system is based on monitoring, recording, and analyzing the behavior of the main variables of equipment and facilities operation. Predictive maintenance is used to verify efficient operation and observe any deviation from normal operating conditions in order to schedule the corresponding corrective activities.

3.1. PREDICTIVE MAINTENANCE TO TRANSFORMER

3.1.1. *Electrical Parameters Measurement and Analysis*

Electrical parameters measurement and analysis includes frequent electrical measurements to the transformer by means of digital measurement equipment with internal memories to detect faults and apply corrective maintenance. The following measurements are necessary:

- Voltage; use voltmeter (V)
- Current; use ammeter (A)
- Electric power; use wattmeter (kW)
- Power factor; use a power factor or (cos phi) meter (PF)
- Harmonic distortion; use NETWORK analyzer (THD percentage)
- Insulation resistance; use megohmmeter (Ohms)

Take the measurements on a monthly basis and take the following precautions:

- Keep a safe distance from energized or moving parts.
- Use safety clothing and equipment appropriate to tension (voltage) levels.
- Do not carry out any type of repair on live or energized circuits.

Calculate the load factor, and consider the measurements of required electrical power. Transformers operate at their maximum efficiency between 35 and 40 percent load. However, their efficiency is very good between 30 and 90 percent load. It is not recommended to make transformers work with load factors over 90 percent, which can lead to diminished efficiency and a shortened service life.

3.1.2. *Physical and Chemical Analysis to Dielectric Oil of Transformer*

Physical and chemical analysis of oil determines the oil's condition as well as any need to restore its physical and chemical properties. This analysis must be carried out yearly. The level of dielectric oil must be constantly measured. Low or high levels may cause overheating in the transformer.

3.1.3. *Insulation Resistance Measurement*

It is necessary to carry out insulation resistance measurements one or more times per year to take advantage of the transformer down times. Conductors with which transformers are wound must be perfectly insulated to prevent spires, layers, and high and low tension coils from contacting. Conductors must not touch other conductors, coils, or the core.

The quality and condition of insulations are of special interest in the testing of transformers because the service life of the equipment depends on these insulation characteristics. The first test to determine the condition of insulations is the resistance measurement. This value must be around hundreds of megohms (MΩ). A low value would indicate possible moisture at insulations and a zero Ohms reading means that there is considerable wear at some point of the winding, indicating a current leakage to another element.

Insulation must be measured between high and low tension windings, between high tension and ground winding, and between low tension and ground winding. These measurements are taken with a megohmmeter, or meggers. Meggers are devices that generate high tensions (typically 500 or 2,000 volts) and they directly show on the dial the insulation resistance value according to the intensity of leakage currents.

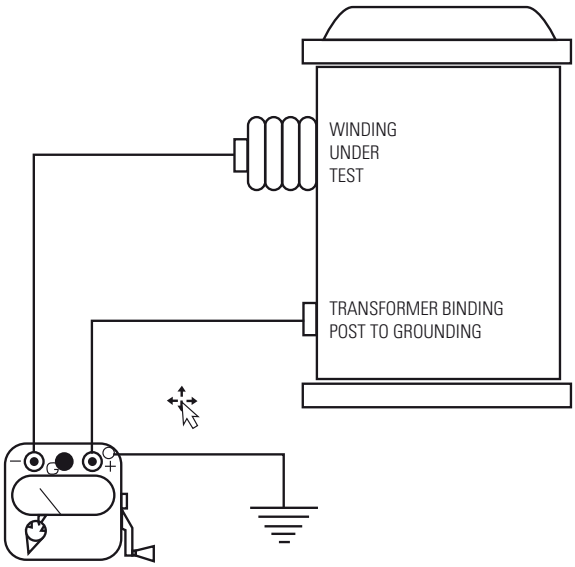
It is recommended to put the high-tension terminals and low-tension terminals into short-circuit, because possible fluctuations in the generated voltage can induce tensions in the transformer windings, which can result in a reading error. Conduct the test as follows:

1. Consult the megger operating instructions.
2. Identify the high-tension terminals of the transformer and put them into short-circuit by means of a jumper. Do the same with the low-tension terminals.
3. Locate a point where it is possible to have a good ground connection. It may be in the transformer core, if it is accessible, or in the tank if the transformer core is not accessible.

Procedures:

1. Connect the megger to the high- and low-tension terminals.
2. Energize the megger, and then write down the reading.

FIGURE 2: Transformer Insulation Resistance Measurement



3. Connect the megger to the high-tension and ground terminals.
4. Energize the megger, and then write down the reading.
5. Connect the megger to the low-tension and ground terminals.
6. Energize the megger, and then write down the reading.

3.1.4. *Test Turn Ratio (TTR)*

The purpose of the test turn ratio is to determine faults to the coil based on the variation of its transformation ratio. The turn ratio must be determined for all tappings, as well as for all possible connections of the transformer windings.

The transformation ratio test must be carried out with nominal voltage or less and at a nominal or higher frequency with no load. To obtain the transformation ratio of transformers, use test equipment called test turn ratio (TTR).

To make a transformation ratio test, ensure that the tested transformer is completely deenergized and disconnected, and verify that the breakers and/or knife switches of each one of the circuits connected to the transformer windings are in the open position. If the transformer is close to the equipment and energized with high voltage, ground a terminal from each winding and the TTR.

TTR equipment uses the following test methods:

- The two-voltmeter method: The device has four terminals, two of which are connected to the input and output of the high-voltage winding and two that are connected to the low-voltage winding. The device internally carries out the voltage measurements between the input and the output, thus requiring two voltmeters. The ratio between voltages is the transformation ratio. This repeats in the three legs of the transformer and the results must coincide.
- Standard transformer methods: The TTR must be tested and certified at the laboratory by using a sample transformer, the transformation ratio of which must be known. The test is carried out to determine the degree of precision of the TTR.
- Method of the ratio bridge: The ratio bridge is the result of the voltage measurement. The measurement of the spire ratio of a three-phase transformer consists of single-phase measurements to determine the ratio between primary spires and secondary spires of each phase.

3.1.5. *Thermographic Analysis*

Infrared thermography is a technique that enables users to precisely see the temperature of a surface without having any physical contact with it. Users can convert the measurements of the infrared radiation into temperature measurements by measuring the emitted radiation in the infrared portion of the electromagnetic spectrum from the object surface and converting the result into electrical signals.

The thermographic analysis consists in taking an x-ray of the infrared spectrum in the transformer. The different temperatures will be seen in different colors, which indicates overheating and damaged components. It is necessary to measure the transformer casing, the radiator, and the mechanical connections and terminals including nozzles. If there is no thermographic camera available, the measurements may be taken with an infrared thermometer.

3.2. PREDICTIVE MAINTENANCE TO MOTOR CONTROL CENTER

3.2.1. *Inspection of the Equipment*

Every month, the motor control cabinet should be inspected to check if it is in good condition regarding painting, finishing, and coupling. The following activities should be included:

1. Check the operation of indicator lamps.
2. Ensure that the measuring equipment provides correct readings.
3. Touch the doors, cabinet sides, and dead front surfaces with your palms, focusing mainly on the breaker and disconnect switches. Any heat detected by the hand may indicate a serious problem.

3.2.2. *Thermographic Analysis*

The thermographic analysis consists in taking an x-ray of the infrared spectrum in the motor control. The different temperatures will be seen in different colors, indicating damaged components or loose or poorly tightened connectors. It must be measured at least in the following points: breaker input, breaker output, starter input, starter output, and contactors and joints; abnormal heating indicates a loose connection.

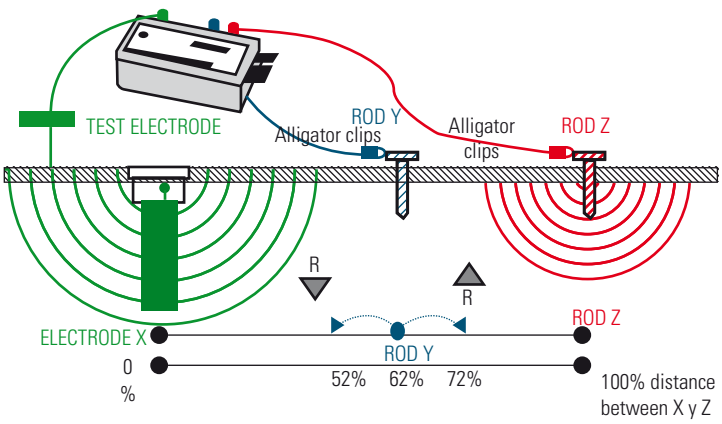
3.3. PREDICTIVE MAINTENANCE TO PHYSICAL GROUND NETWORK

3.3.1. *Electric Resistance at Physical Ground Network*

The measurement of electric resistance at the ground network must be carried out at least once per year, although it is advisable to do it every six months. Before carrying out the measurements, make sure that the conductor and ground rod are placed in the well or ground bus bar and the conductor and rod are united.

Measurements in the grounding system offer a parameter to guarantee that there is always a low value of electrical resistance. This facilitates the easy flow of the current in case of a fault due to

FIGURE 3: Ground Electric Resistance Measurement



atmospheric discharges and accidental contacts of live conductors with the equipment casing, therefore protecting the personnel from electrical shocks.

3.3.2. *Physical Ground Network Continuity Tests*

In the grounding system, it is necessary to check the continuity between the conductor and the grounded equipment. Also, make sure that the well has ground enhancement material and that the connection node is welded.

Plan annual tests to the ground network. If the value of the measurement is above five (5) Ohms, treat the ground with an enhancer product to reduce the electrical resistance, improve field resistance, and stabilize the total resistance of electrodes.

3.4. PREDICTIVE MAINTENANCE TO MOTOR

3.4.1. *Electrical Parameters Measurement and Analysis*

Carrying out continuous measurements to the motor enables users to detect problems that may be easily solved. The main problems may be the following:

- A different voltage than that of the motor design
- Voltage imbalance
- Current imbalance
- Power imbalance
- Harmonic distortion
- Low power factor

The following precautions must be observed when monitoring these parameters:

- *Keep minimum safety distances from energized or moving parts.*
- *Use safety clothing and equipment appropriate to the tensions supplied.*

Considering the measurements of required electrical power, calculate the load factor at which the motor is working. A low load factor (less than 40 percent) will mean low operation efficiency, and a high load factor (over 100 percent) will cause premature aging of the motor windings.

3.4.2. *Mechanical Vibration Measurement and Analysis*

The consequences of the mechanical vibrations are the increase in the efforts and tensions, power losses, and material wear. Even more consequential are the damages to equipment and increased noise at the working place. The measured vibration parameters are the frequency, displacement, speed and acceleration, and direction. These measurements must be taken yearly with a portable mechanical vibration measuring apparatus. An abnormal vibration may indicate the following:

- Loose motor anchoring
- Mismatch or misalignment of couplings, off-centered or unbalanced motor
- Bearing in bad condition
- Component wear and tear
- Lubrication problems

Some maintenance personnel have the necessary experience to distinguish the different noises generated by the motor and determine the cause of the problem. In these cases, the vibration meter may not be required.

3.4.3. *Winding Resistance Tests*

The main objective of coil resistance measurement is to detect faults. Recommendations to carry out these measurements are as follows:

- Take the measurements annually.
- Follow all necessary safety protocol.
- Measure motor windings resistance between each stator terminal pair.
- Connect the test terminals to the motor to measure the winding resistance to the ground; each phase to ground must be measured.
- If it is a star connection and the reading is phase to phase, divide it in half to obtain the ohmic resistance per phase.
- Measure and record the ambient temperature at which the measurement was made.
- Keep the casing connection to the ground.

3.4.4. *Thermographic Analysis*

The thermographic analysis measurements may be made with a thermographic camera or with an infrared thermometer. The following must be measured:

- Casing: any measurement of excessive heat implies a problem; it may be an overload or damage to windings.
- Ball bearings: high temperatures imply a problem, which may be inadequate lubrication, friction, or overload.

3.4.5. *Electrical Measurements in Capacitors*

If there are capacitor banks for power factor compensation, measure the current per phase every month to detect potential faults of any bank capacitors.

3.5. PREDICTIVE MAINTENANCE TO PUMP

3.5.1. *Pressure and Flow Measurement*

It is recommended to measure the pressure and flow every month, as well as to calculate the pumping head. If the pumping head and flow vary by more than 10 percent from those of the design of the pump, perform the corrective measures.

3.5.2. *Pillow Bushing*

Each time preventive or corrective maintenance is made to the pump, look for wear at the axis sleeve. If it is scratched or grooved, it must be changed.

3.5.3. *Stuffing Box*

The objective of a stuffing box is to eliminate liquid leaks at the pump and prevent airflows into suction spaces. When inspecting the stuffing box, look for any liquid leaks or minimal leaks. Note that there will typically be a small leak when stuffing boxes are used. This is acceptable. However, in regards to mechanic seals, there must *not* be any leaks.

3.5.4. *Mechanical Vibration Measurement and Analysis*

The consequences of the mechanical vibrations for pumps are similar to the ones mentioned above for motors. The parameters measured are the frequency, displacement, speed and acceleration, and direction. The increase in the values of the above parameters indicates wear and tear, misalignment, mechanical unbalance, ball bearing faults, inadequate lubrication, and so on. These measurements are made with a portable mechanical vibration meter and must be carried out at least once a year.

3.6. PREDICTIVE MAINTENANCE TO DISCHARGE PIPING

3.6.1. *Mechanical Vibration Measurement and Analysis*

The consequences of the mechanical vibrations for discharge piping are similar to the ones mentioned above for motors. Also, the same parameters should be measured. The respective measurements must be taken annually with a portable mechanical vibration meter. An abnormal vibration may indicate a loose pipeline, cavitation in valves or fittings, or pump vibration transmission. When the maintenance personnel have the necessary experience to distinguish the different noises and to determine the cause of the problem, the vibration meter is not necessary.

3.7. PREDICTIVE MAINTENANCE TO VALVES

3.7.1. *Visual Inspection of Valves*

It is recommended to visually inspect joints, connections, and packing or seal areas to detect leaks.

3.7.2. *Mechanical Vibration Measurement and Analysis*

The consequences of the mechanical vibrations for valves are similar to the ones mentioned above for the other components. The most important parameters measured in valves are the noise level and the frequency. Noise level may be caused by three reasons:

1. Mechanical vibration of packing
2. Liquid causing cavitation
3. Valve choking

3.8. PREDICTIVE MAINTENANCE TO WELL

3.8.1. *Level Measurement*

Static and dynamic levels of the well must be measured monthly. Draw down, or the difference between static and dynamic levels, must also be calculated. An increase in the draw down is usually due

to clogging in the well slots and/or gravel soils. If such an increase is observed, a video must be taken and maintenance of the well must be planned.

3.8.2. *Video Inspection*

To take a video, place a camera into the well to verify the condition of its casing and depth. This activity must be performed with specialized equipment and steps must be taken to prevent contaminating the well during the inspection. After preventive or corrective maintenance to the well, it is also recommended to take a video of the new condition.

Chapter 4

PREVENTIVE MAINTENANCE

Preventive maintenance for a pumping installation is the type of scheduled maintenance that is carried out to prevent faults. The main activities executed as part of preventive maintenance are inspection of the equipment, cleaning, lubrication, and the replacement of components.

4.1. PREVENTIVE MAINTENANCE TO TRANSFORMER

When performing any task with the transformer, make sure it is deenergized. Follow the disconnect procedures.

4.1.1. *Cleaning of the Area*

Once a week, the perimeter area of the transformer or substation must be cleaned. This includes removing fallen leaves, debris, and agents that may interfere in the correct operation of the transformer and/or equipment. Also, clean the grounding system register area and remove any obstructions.

4.1.2. *Cleaning of the Equipment*

Connect the terminals to the ground transformer to prevent any possible electrical contact during the monthly cleaning.

- Clean at least once a month with dielectric solvent or water or mild soap solutions. Do not use detergents or solvents. Comply with all safety measures such as providing potential detectors to the personnel, insulating gloves, and so on.
- Remove the accumulated debris with a brush, a piece of damp cloth, and pressurized air, if possible.
- Check that there are no damages or sparks due to bad fastening at the terminals or connections of the transformer.
- Check that there are no oil leaks in the valves, radiators, solders, packings, branch exchanger, or protections.
- Check the condition of the transformer paint.
- Check if the transformer makes abnormal noise or vibrations.

4.1.3. *Retightening of Bolts and Screws at Mechanical Nozzles and Terminals*

Every time the transformer is out of service, carry out “opportunity maintenance” by retightening the the mechanical nozzles and terminals.

4.1.4. *Dielectric Oil Purification and Filtering*

The dielectric oil purification and filtering consists of carrying out the appropriate preventive maintenance, prolonging the service life of the equipment, eliminating pollutants in the oil, and checking for color changes to determine oil pollution. It is advised to perform these purifications at least once a year. More frequent cleanings may be necessary if the oil presents a dielectric strength close to the lowest limit. A specialized laboratory must carry out this procedure.

4.1.5. *Ventilation*

If the transformer is indoors, make sure the building is well ventilated to prevent overheating. This will shorten the transformer's service life and reduce its efficiency.

4.2. PREVENTIVE MAINTENANCE TO MOTOR CONTROL CENTER

4.2.1. *Board Cleaning*

Maintenance of circuit boards must be performed on a yearly basis. This includes inspecting connection diagrams and manuals needed to carry out maintenance actions. It is crucial to duly ground the board or shunt bar during maintenance or cleaning.

The main board components are the following:

- Start and stop keypad
- Power contactors
- Overload relays
- Grounding system
- Breakers and starters

The cleaning process should go as follows:

- Clean input and output terminals of breaker and starter, and then refasten mechanically.
- Moisten burlap or cheesecloth in tetrachloride or dielectric solvent to clean board surfaces. Do not use abrasive products.
- Clean the motor control center room to eliminate debris and trash.

4.2.2. *Refastening of Bolts and Screws to Mechanical Terminals*

Refastening hardware at mechanical and electrical terminals prevents hot points due to high contact resistance. It is recommended to refasten at least once a year.

4.3. PREVENTIVE MAINTENANCE TO MOTOR

4.3.1. *Motor Cleaning*

Carry out the following preventive maintenance annually to guarantee a long service life of the equipment:

- Clean external surface and ventilation screen.
- Reset and adjust anchor bolts and screws.
- Remove rust and retouch and paint the casing if necessary. If the casing needs repainting, remove the old paint layer and make sure the new paint layer is thin.
- Clean the junction box.
- Readjust the ground cable of the junction box.
- Check the connections at the power cable terminals.
- Check alignment and wear and tear of the coupling pieces.
- Change dry and oilless grease.

4.3.2. *Ball Bearing Lubrication*

Ball bearing maintenance enables users to keep the equipment in good working condition and prevent unnecessary shutdowns. It is recommended to maintain the ball bearings weekly as follows:

- Check upper or non-drive end bearings.
- Check lower or drive end bearings.
- Remove, clean, and install the grease tube. Apply new grease until old grease starts to exit from the relief tube. This is applicable only to ball bearings that are not sealed.

In most small motors, the bearings are of the sealed type and should be changed based on the maximum operating hours stated by the bearing manufacturers. If lubrication of the ball bearings is made with oil, note that oil replacement must be made at least every three to six months, or when the inspection shows that the oil has lost its properties or is contaminated. The oil level must not exceed the stated maximum stand still oil level mark; otherwise the winding will be at risk.

4.3.3. *Axial Ball Bearings Change*

Unnecessary shutdowns are avoided by a timely and scheduled change of ball bearings. This contributes to good preventive maintenance practices. It is important to take into account equipment stoppages when scheduling the change of ball bearings. Bearings typically have long service lives, although it is better to change them before they show failures, which will require corrective maintenance. Mechanical vibration measurement is a method used to determine fault signs.

- Use adequate and appropriate equipment for the extraction of each type of ball bearing, and do not use additional attachments that may cause damage to the coupling shaft.
- Use the correct ball bearings for the application type, that is high temperature; vertical or horizontal position or; special bearings such as conic bearings. These bearings should be as stated on the motor name plate, or as indicated in the manufacturers specifications.

4.3.4. *Cover Adjustments*

Every day, an audio or visual inspection must be carried out on the covers to ensure there are no mismatches or wear due to broken or mismatched ball bearing parts. The following activities must be undertaken:

- Clean the area to guarantee proper equipment operation.
- If there is wear on the ball bearings, adjust them appropriately.
- Refasten and reposition the screws and bolts.

4.4. PREVENTIVE MAINTENANCE TO PUMP

4.4.1. *Change of Stuffing Box*

The objective of a stuffing box is to eliminate liquid leaks at the pump and prevent airflows into suction spaces. The stuffing box must be checked for leaks and also for air entering the pump suction intake. The packing of the stuffing box must be changed periodically. The frequency of this change depends on the number of operating hours of the pump as well as on material and quality of the packing. If the pump operates continuously, the packing must be replaced every three to six months.

4.4.2. *Bearings and Bearing Holder Lubrication*

Lubrication frequency depends on the conditions of the equipment and place where the equipment is operating. In general, the following must be performed:

- Change lubricants when they show color change or pollution by powder particles, water, metal particles, or decomposition by high temperature or moisture.
- Add a small quantity of grease every 400 hours of operation.
- The bearing housing must be one-third full (if applicable).
- Chlorinated solvents are not recommended to clean the bearings.
- Use the appropriate and standardized lubricants for each component according to working temperatures and the manufacturer's specifications.
- Refasten screws and bolts.

4.4.3. *Upper Shaft Lubrication*

The upper shaft is the part of the pump that has to transmit the torque received from the motor during the pumping operation; at the same time, the upper shaft holds the pump and other revolving parts. It must be inspected daily to best prevent damage and keep maintenance costs to a minimum. Maintain the upper shaft as follows:

- Use adequate and standardized lubricants; apply them with the frequency recommended by the manufacturer.
- Clean the shaft with burlap or cheesecloth and adequate liquids; do not use oxidizing agents.
- Check that all coupling parts are well clamped, and refasten them if they are not.

4.4.4. *Lubrication of Transmission Shaft*

Lubrication frequency will depend on working conditions and on the environment where the equipment is running; therefore, lubrication frequency must be scheduled according to experience. The activities to be carried out are as follows:

- Lubricants must be changed when contaminated with debris or moisture or when they are subjected to high temperatures.
- It is recommended to add a small quantity of grease every 400 hours of operation.
- The bearings housing must be one-third full of grease.
- To clean bearings without dismounting them, run hot light oil at 82°C to 93°C through the housing while the shaft is slowly turned.
- The use of chlorinated solvents is not recommended for cleaning bearings.

In the case of grease relubrication, take the following steps:

1. Carefully clean greasers and the exterior of the bearing housing.
2. Remove the purge or drain plug.
3. Inject new clean grease and push the old grease to the exterior.
4. Start the pump and keep it in operation for a period of time sufficient to drain excess grease.
5. Clean the excess grease with a piece of cloth and replace the purge plug.

In turbine type pumps with vertical motors, the pumped fluid lubricates the transmission shaft bearings.

4.5. PREVENTIVE MAINTENANCE TO DISCHARGE PIPING

4.5.1. *Revision of the Discharge Pipe*

Check the piping installation for problems with the seal and bearing, which may be due to poorly installed supports and anchors, thermal deformation, seal design, improper selection, dimensional variations, load in the pipe supports, or water hammer.

4.5.2. *Cleaning and Painting*

Cleaning and painting of the discharge piping must be done on an annual basis in compliance with the standards. First apply the anticorrosive layer, let it dry, and then paint with a secondary paint. Check that the mechanical or driving parts are not covered by paint spills. Remove dirt weekly to prevent debris from accumulating, which may attract moisture and cause corrosion.

4.5.3. *Packing Changes*

At least once a year, the packing between flange couplings, valves, gages, measuring apparatus, pressure maintenance valves, and control valves must be changed. They must be checked once a month, and all leaks and any changes to be made must be reported to avoid fees due to stoppages for emergency repairs.

4.5.4. *Chlorination Equipment Inspection*

Maintenance must be performed on a daily basis, and the corresponding safety precautions must be observed due to chlorine's high toxicity risk. The following items must be considered in the inspection of the equipment:

- The voltage supplied to the chlorinator does not exceed 10 percent of the allowed tension.
- The equipment is always free from dirt that may interfere in the operation.
- Analyze the chloride drip in accordance with the dosage in parts per million that must be maintained for each pumping system.
- Ensure that the chlorinator check valve is not closed.

4.6. PREVENTIVE MAINTENANCE TO VALVES

Valves are key components in the discharge piping; they avoid unnecessary spills and/or repairs caused by the breaking of network piping. It is recommended to check for leaks or anomalies once a week. The valves must not be motionless for long periods of time due to the risk of sediment accumulation and possible seizing of the valve. If possible, operate the valves at regular periods to ensure a correct and continuous operation.

4.6.1. *Lubrication*

In many cases, the frequency of lubrication of the valve is based on the experience of the maintenance personnel. However, it is recommended to lubricate the shaft bearing at least once a month. The type of lubricant will depend on the service conditions of the valve, such as temperature and fluid type.

4.6.2. *Adjustment of the Closing Diaphragm in Solenoid Valves*

Closing and opening of solenoid valves require accuracy in the adjustment of diaphragms. Perform this adjustment annually and report any occurring or potential faults. It must also be cleaned annually according to the specific instructions of the manufacturer.

4.6.3. *Packing Replacement in Outlet/Vent Valves and General Valve*

Frequency of the package change should be at the user's discretion based on operating experience. However, it is recommended to change the package annually.

4.6.4. *Inspection and Calibration of Pressure Gauges*

Inspection and adjustment of pressure gauges must be carried out once a year. Keep a record of maintenance, calibration, and faults.

4.6.5. *Cleaning of the Diaphragm Actuator Spring*

Actuators must be cleaned every month; precise adjustment of valve springs and actuators must be observed at every moment. Keep a record of maintenance and possible faults.

4.6.6. *Cleaning of the Valve Body*

Cleaning must be carried out every month, assuring that the opening and closing of the valve is not affected by any foreign object and that it is lubricated with the product recommended by the manufacturers according to its use and application.

4.7. PREVENTIVE MAINTENANCE TO WELL

Well preventive maintenance is carried out by flushing through the following steps:

- Remove any adhered material from the well casing.
- Application of clay scatterer to loosen setting in the slot.
- Swab after static level to clean and reaccommodate the gravel filter.
- Remove of all the sludge material accumulated on the bottom of the well.

Depending on the well's characteristics and water quality, maintenance should be performed yearly, every two years, or every three years.

Chapter 5

CORRECTIVE MAINTENANCE

Corrective maintenance is carried out in order to repair faults in the equipment; it includes the following types:

- Scheduled: Necessary repairs are known in advance, and therefore all the elements needed are at hand at the time of repair.
- Unscheduled: Required when there is a fault rendering essential equipment out of order. It is also known as emergency or "breakdown" maintenance.

Corrective maintenance is frequently carried out under emergency conditions and with the single purpose of reestablishing service.

5.1. CORRECTIVE MAINTENANCE TO TRANSFORMER

5.1.1. *Equipment Replacement*

The replacement of the transformer is recommended when, for some reason, it has lost efficiency or it is no longer reliable. The following are reasons why a transformer loses efficiency:

- High load factor – A high load factor makes the transformer work inefficiently, in addition heat caused by the current required by the load damages the oil properties and causes inefficiencies. High load factors may cause a short circuit and damage the transformer beyond repair.
- Voltage, current and power imbalance – In certain circumstances, it is better to replace the transformer when these cannot be fixed.

A defective protection system, combined with an electrical problem, may cause a destructive fault in the transformer and it may need to be replaced.

5.1.2. *Equipment Repair*

Equipment repair is necessary in the following cases:

- When the need to change the winding conductors is diagnosed as a result of the flash test (megger) or the test turn ratio (TTR);
- When high temperatures are detected during operation, which may indicate that the level of oil is low and needs to be refilled;
- When the transformer has physical damage due to an external cause; and
- When the transformer is damaged due to an electrical problem combined with a fault in the protection systems.

5.1.3. *Different Corrective Maintenance Actions to Transformers*

The following are corrective maintenance actions for the transformers based on different problems:

- Heat at junctions – Fasten screws and connections.
- Overload – Use another transformer to share the load or replace with one of adequate capacity.
- Abnormal temperature in transformer housing due to low or high oil level or poor ventilation – Replace oil level and ventilate.
- Change in oil properties – Filter or substitute the dielectric oil.
- Harmonic distortions – Install the harmonic filter.

5.2. CORRECTIVE MAINTENANCE TO MOTOR CONTROL CENTER

5.2.1. *Equipment or Component Replacement*

If equipment or components in the motor control center need replacement, take the following steps:

- Replace conductors that are damaged due to high temperatures in the insulation. If the problem was caused by loose contact in connectors, correct the problem by refastening nuts and bolts. If heating is due to the conductor's internal heating, replace it with a conductor of an adequate caliber that enables current conduction without damaging the insulation.
- Replace any keypad that is mechanically or electrically damaged.
- Replace the breaker if there is electrical noise due to arcing caused by bad contact in the breaker.

5.2.2. *Equipment Repair*

Replace damaged equipment if it can be repaired without affecting the equipment's overall reliability.

5.3. CORRECTIVE MAINTENANCE TO MOTOR

5.3.1. *Equipment Replacement*

The replacement of the electric motor is recommended in any of the following cases:

- If the motor runs for more than 4,000 hours per year, is of standard efficiency, or its efficiency has been reduced due to age and/or multiple rewinding, it must be replaced by a high efficiency motor of similar capacity.
- If the motor has operated for more than five years, runs for more than 3,000 hours per year, is of standard efficiency, or has been burnt due to a problem, it must be replaced by a new high efficiency motor of similar capacity.
- If the motor is running with a load factor less than 40 percent or higher than 100 percent, it must be replaced with a high-efficiency motor with similar capacity that will run with a load factor between 65 and 85 percent. If the new motor has less than 10 HP, the load factor must be between 75 and 90 percent.

5.3.2. *Equipment Repair*

Motor repair is required in any of the following situations:

- **Rewinding** – If the coil tests produce unfavorable results or there are significant current imbalances, the motor will need rewinding. If the motor has been rewound more than twice and the efficiency falls by more than 3 or 4 percent, it is better to replace it.

- **Ball bearings change** – When the bearing is worn, it must be replaced. At the time of the replacement, take into account that the bearing must not be touched with the bare hand since the acid from the skin may cause damage to the bearing and contaminate the grease or oil.

5.3.3. *Different Corrective Maintenance Actions to Motors*

The following corrective measures should be taken if there are deficiencies with the motor:

- Ball bearing:
  - If lubricant properties are inadequate for the application, replace the lubricant with one that has the desired features. There must not be any residue of the replaced lubricant.
  - If lubricant is inadequate, frequent lubrication is recommended, as determined by the type of ball bearing.
  - When there is an incorrect adjustment of bearing, make a correction if there is no damage; otherwise replace the ball bearing.
- When there are damages to coils, rewind or replace the motor.
- If operating speed is less than full load speed, check the voltage of operation and correct bearing or ball bearing problems or replace the motor.
- If overload occurs, correct the problem or replace the motor with one of higher capacity.
- Motor overload can be detected through the load factor calculation.
- If the supply voltage is different from the nominal voltage, identify the reason.
- If there is a voltage drop in the supply network, ask the energy provider to correct the problem. If the percentage of voltage is less than 5 percent, modify the TAP (voltage shunt) of the transformer, or ask the energy provider/owner of the transformer to do so.
- If there are imbalances in the voltage, current, and power, take the following steps:
- If there is imbalance in the terminals that connect to the transformer, ask the supplier to fix the problem.
- If there is imbalance in the transformer terminals in the vacuum, proceed with maintenance.
- If there is an imbalance due to the electric motor, replace the motor.
- If a low power factor is present, replace or install a capacitor bank.

5.4. CORRECTIVE MAINTENANCE TO GROUNDING SYSTEM

If the grounding system is malfunctioning, take the following steps:

- If the grounding conductor is disconnected, join it with aluminothermic welding.
- If the electric resistance is higher than five Ohms, it must be treated with ground intensifiers.
- A current in the grounded conductor indicates a power imbalance in the system. Identify the cause of the imbalance and correct it.
- Change the grounding conductor size if necessary.

5.5. CORRECTIVE MAINTENANCE TO PUMP

5.5.1. *Components Repair or Replacement*

The following steps must be taken to repair faults in the components:

- **Stuffing box:** In the case of a major leak, replace packing or mechanical seals.

- **Pillow bushing:** Remove old packing completely with a packaging extractor. Check and clean the stuffing box as well as the cooling ducts. Verify the attachment and the clearance to sleeve or shaft, which must not exceed 0.762 mm.
- **Impeller:** If the flow and head vary by more than 10 percent from their design values, it is a signal that the impeller is worn. In this case, replace the impeller(s).
- **Suction tube:** When the suction tube has advance corrosion, replace it to avoid a water leak that can affect the operations of the system.

5.5.2. *Pump Replacement*

Pump must be replaced in any of the following cases:

- The body of the pump shows severe damages from corrosion, clogging, water hammering, or friction.
- The running conditions do not match the design characteristics of the pump, resulting in low operation efficiency.

5.6. CORRECTIVE MAINTENANCE TO VALVES

If the valve has suffered damages in any of its components, recondition it through the following steps:

1. Disassemble the valve and clean the components with chemical products or by grit or sand blasting.
2. Carefully inspect the components, and decide to repair or replace the worn parts.
3. Weld to refill worn surfaces or produce new surfaces; semifinished and repaired parts (spare parts) must be stored to produce new parts.
4. Assemble the valve with new packing and if required, with new bolts.
5. Test the reassembled valve against the new valve specifications.

Chapter 6

MAINTENANCE PLAN

6.1. EQUIPMENT AND FACILITIES INVENTORY

The first step to build a maintenance plan is to prepare an inventory of the facilities and equipment, which must contain at least the following information:

Electrical facilities

- Update or create a single line diagram.
- Include information regarding the length and caliber of the electric conductors in each section. Also indicate if the electric conductors run in conduit or tray and the number of conductors that can be carried in the conduit or tray.
- Include the identification of each transformer and all board data.

Include the following data about the equipment:

Electric motors

- Motor identification
- Motor manufacturer
- Year of manufacture/installation
- Manufacturer power rating, voltage, current, revolutions per minute (rpm) and cos phi
- Age, dates, and number of rewindings the motor has undergone and a general description of the repairs made to the motor
- Ball bearing specifications, including the date of last replacement
- Control system specifications, including starter, breaker, and protection characteristics
- Control system diagrams and dates of modifications

Pumps

- Pump identification
- Pump manufacturer
- Year of manufacture/installation
- Pump specifications, including model, material, operating speed, and characteristic curves
- Design data, such as total dynamic head (TDH) and flow
- Impeller specifications, such as type and diameter and the date of installation
- Ball bearings, stuffing box, and mechanical seals specifications, including the date of last replacement
- Diagram of water supply, discharge piping, and valves

Tanks

- Identification
- Dimensions and capacity
- Construction material and age

- Scheme or diagram
- Control or level system

Water system

- Water system diagram, including length, diameters, and pipe material, and the location of the valve boxes
- Age of pipe and the statistics of breaks/leaks
- Valve inventory, indicating the specification of each one and its location

6.2. ACTIVITIES AND FREQUENCY

In order to prepare the maintenance program, preassign the frequency with which preventive or predictive maintenance will be carried out, which will be based on the experience of the maintenance staff, the environmental conditions and location of the equipment, and the recommendations of the equipment suppliers. Table 1 shows the frequency recommended to perform the different activities. This table can be used as a guide, which must be adapted to the specific conditions of the company and the equipment.

TABLE 1: Maintenance Frequency

Subsystem	Equipment	Recommended action	Maintenance frequency				Notes
			Daily	Weekly	Monthly	Annual	
Electrical	Transformers	Equipment cleaning			X		
		Area cleaning		X			
		Retightening of nuts and bolts in nozzles and mechanical terminals			X		
		Dielectric oil purification and filtration, consisting in centrifugation, filtering, dewatering, and degassing contents in the transformer				X	
		Measurement and analysis of electric parameters			X		
		Physiochemical analysis of oil				X	
		Test Turn Ratio (TTR)				X	
		Electric tests (Megger)				X	
		Thermographic analysis				X	
	Motor control center	Board cleaning with dielectric solvent				X	
		Cleaning and lubrication of mechanical drives (e.g., springs, keypads)				X	
		Refastening nuts and bolts to terminals and electrical connectors				X	
		Measurement and analysis of electrical parameters			X		
		Electric endurance tests in the physical grounding network				X	
		Continuity tests in the physical grounding network				X	
		Thermographic analysis				X	
	Electric motors	Winding cleaning with dielectric solvent				X	
		Ball bearings lubrication			X		
		Axial ball bearings change				X	
		Cover adjustments				X	
		Casing sanding and painting				X	
		Measurement and analysis of electric parameters				X	
		Mechanical vibration measurement and analysis				X	
		Flash test				X	
		Endurance test to winding				X	
		Thermographic analysis				X	
Mechanical	Pumps	Bearings and bearing holder lubrication			X		
		Upper shaft lubrication		X			
		Change of cup bushing					*
		Rectification of intermediate cup seats					*
		Change of suction cup bushing					*
		Rectification of line shaft					*
		Change of upper shaft					*
		Journal bearing change					*
		Change of pillow bushing					*
		Rectification of cup shaft				X	
		Mechanical vibration measurement and analysis				X	
		Measurement and analysis of delivery pressure and pumping head			X		
		Flow rate measurement and analysis			X		
		Pillow bushing inspection		X			
		Stuffing box inspection	X				
	Discharge piping	Discharge piping cleaning and inspection		X			
		Discharge piping painting				X	
		Change of broken packing between the flange couplings, valves, measuring apparatus, and check pressure sustainers			X		
		Valve change					*
		Functioning and calibration inspection of macro measuring apparatus				X	
		Inspection of chlorination equipment	X				
		Solenoid and air-bleed valves cleaning			X		
		Mechanical vibration measurement and analysis				X	
	Valves	Cleaning and evaluation of diaphragm					*
		Cleaning and evaluation of the diaphragm driver spring				X	
		Cleaning of anti-dust joint				X	
		Shaft bearing lubrication			X		
		Cleaning of the valve body			X		
		Solenoid cleaning				X	
		Change of control electric conducts					*
		Mechanical vibration measurement and analysis			X		

* Only when required.

6.3. MAINTENANCE PROGRAM

Once the equipment inventory has been taken and the frequency of the different activities to be performed has been set, the next step is to implement a maintenance program, which should include a matrix with dates on one axis and activities on the other. It is important to determine the person or persons responsible for each activity. Once the tasks have been carried out, maintain an accurate equipment history, which will be the basis for necessary improvements to the plan. Table 2 provides an example spreadsheet for recording the data required for the maintenance program.

TABLE 2: Maintenance Program

Plant or system	Equipment	Activity	Person in charge	Date:																											
				Week 1					Week 2					Week 3					Week 4					Week 5					Week 6			

Chapter 7

PROBLEM IDENTIFICATION

This section provides a detail of the activities necessary to carry out problem identification, which involves determining specific issues or deficiencies with the maintenance of the system's various components in order to provide a timely solution.

7.1. SENSORY INSPECTION (SEE, FEEL, SMELL, HEAR)

Identify problems with the existing maintenance of equipment or facilities through sensory inspection Pay attention to the following main activities and aspects:

7.1.1. *Electric System*

Transformer

- Listen for abnormal sound or vibration.
- Make sure the paint is in good condition.
- Ensure that the grounding conductors are properly grounded.
- Make sure there is no leak in the dielectric oil.
- Check for damages to nozzles.

Breaker

- Make sure there are no electric noises.
- Check for smell of burning or overheating.
- Look for signs of cracks on the surface.
- Feel for overheating on the surface.

Conductors

- Look for damages to the insulation.
- Check for smell of burning or overheating.
- Feel for overheating on the surface.

Motor

- Listen for abnormal sound or vibration.
- Check for smell of burning or overheating.
- Feel for overheating on the surface.

7.1.2. *Water System*

Pump

- Listen for abnormal sound or vibration.
- Make sure there are no loose bolts.
- Look for signs of corrosion.

• Check for leaks in seals and stuffing boxes.
• Look for signs of metal cuttings around the stuffing box.

Discharge head

• Make sure the measuring equipment including the gauges and manometer are running.
• Check for leaks.
• Make sure the air ejector valve is running.
• Look for physical damages to the components.

7.2. ANALYSIS OF THE ELECTRICAL SYSTEM

7.2.1. *Single Wire Diagram*

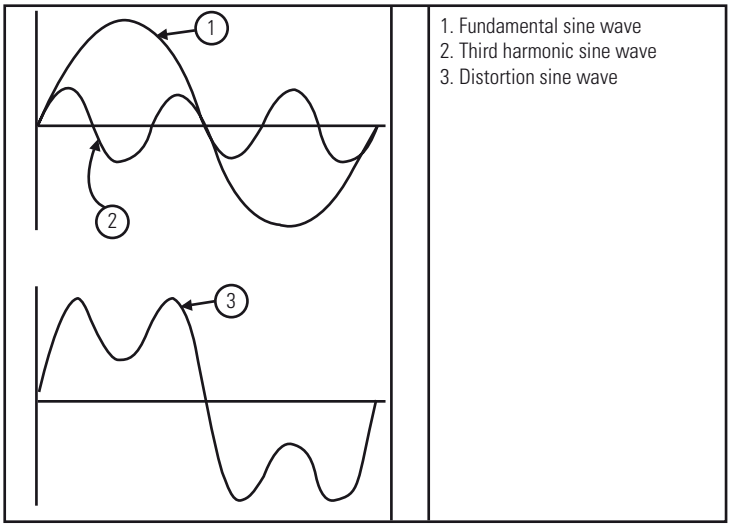
The single wire diagram of an electrical installation is a useful tool for many maintenance actions. As such, this diagram must be maintained and updated as part of the program analysis. Record the date of the last update and the contact information for the person who performed it.

7.2.2. *Harmonic Distortion Analysis*

To protect the equipment from damage, it is necessary to perform a minimum 24-hour monitoring (recommended for at least seven days) of the total harmonic distortion in voltage and current to make sure values do not exceed 4 percent in voltage and 20 percent in current.

• **Electric motor:** Harmonics cause distortion to the voltage sine wave (see Figure 4), producing noise in the motor. This occurs because the magnetic field does not correctly connect the rotor, and as a result there is a decrease in the service life. Moreover, negative sequence harmonics such as the second, fifth,

FIGURE 4: Sine Wave Distortion



eighth, and so on cause a counter-torque in the motor, which reduces its capacity to deliver power and eventually may cause the motor to burn out.

- **Capacitors**: High order harmonics such as the ninth, eleventh, thirteenth, and so on may be in resonance with the capacitor, which can cause damage and possible injury to personnel.
- **Electric conductors:** In three-phase systems such as the ones in pumping facilities, the zero-sequence harmonics are added in the neutral conductor and cause high current in the neutral wire. If the neutral conductor is not designed to manage those high currents, it can be overheated and could potentially catch on fire.

Nonlinear loads in the electrical system cause harmonic distortion. In pumping facilities, these loads may be the solid state speed shifters. Install harmonic filters to solve this problem.

7.2.3. *Analysis of the Electrical Measurements*

The analysis of the electrical measurements helps to identify the following problems:

Supply voltage differs from nominal voltage – VDN

An electric motor supplied with a voltage different than that of the plate or nominal voltage decreases its operation efficiency. The tension deviation percentage regarding the nominal voltage is calculated according to the following formula:

$$VDN = \frac{\left(V_{prom} - V_{placa}\right)}{V_{placa}} * 100$$

Where:

VDN = Percentage difference between the value of the supply voltage and the plate data of the nominal voltage (–)

V_{prom} = Average voltage between phases (V)

V_{placa} = Value of nominal voltage supply as shown on the plate (V)

The origin of this problem can be external, for example, if the supply is provided with a voltage different than that of the nominal or internal voltage. A transformer that is not operating efficiently, that is undersized, or that has an inadequate transformation relation may cause the internal problem. Another cause may be a large voltage drop in the electrical conductors. To solve this condition, the following measures can be taken:

- If it is an external problem, it is probable that if the transformation relation (turns ratio) of the transformer is modified with the “TAPS,” which can be fixed or the effect can be diminished. The electric supply company must be notified so that it can provide a solution if the deviation is considerable or there are significant voltage variations.
- Maintenance or replacement will be necessary if the problem is due to the poor operating condition of the transformer.
- If the transformer is undersized, it should be replaced.
- If the transformation relation is not correct, it must be modified with the “TAPS.”
- If the problem is a considerable voltage drop in the conductors, replace those conductors with larger ones.

Note: TAPS from a transformer are mechanical selectors that add a number of turns to the primary winding so that the output voltage is adequate according to the tension regulation.

Voltage imbalance – DBV

An electric motor supplied with unbalanced voltage will reduce its capacity to convert electrical power into mechanical power, and will also reduce its transformation efficiency. To detect an unbalanced supply voltage to a motor, carry out measurements of voltages between phases and calculate the imbalance with the following equation:

$$DBV = \frac{max\left((max\,(V_{A-B}, V_{B-C}, V_{C-A} - V_{prom}), (V_{prom} - mín\,(V_{A-B}, V_{B-C}, V_{C-A})\right)}{V_{prom}}$$

Where:

DBV = Voltage imbalance (–)
V_{A-B} = Voltage between phases A and B (V)
V_{B-C} = Voltage between phases B and C (V)
V_{C-A} = Voltage between phases C and A (V)
V_{prom} = Average voltage between phases (V)

If the unbalanced supply voltage to an electrical motor is caused by a problem external to the motor, identify the origin. The main causes of the motor imbalance are the following:

- Imbalance of loads within the same installation
- Transformer problems that cause the relations of the transformation per phase to differ
- Load imbalance in the supply line of the installation (if this problem occurs, contact the electric supplier for solution)

Current imbalance – DBI

When the currents required for each motor phase are different, this indicates a current imbalance, which indicates possible damage to the motor coils or problematic coil differences. The current imbalance is calculated from the current measurements per phase through the following equation:

$$DBI = \frac{max\left((max\,(I_A, I_B, I_C) - 1_{prom}), (I_{prom} - mín(I_A, I_B, I_C))\right)}{I_{prom}}$$

Where:

DBI = Current imbalance (–)
I_A = Phase A current (A)
I_B = Phase B current (A)
I_C = Phase C current (A)
I_{prom} = Three-phase average current (A)

The most common causes of current imbalance are the following:

• Contact of turns of the same winding in any of its phases caused by damage to the electric insulation.
• The motor has been repaired or rewound, but the original number of turns in the motor has not been placed.

Power imbalance – DBP

When power measurements per motor phases differ, there is power imbalance. This is typically the result of current imbalance. Power imbalance similar or higher than current imbalance is a sign that the problem is the motor and the causes are those indicated in the current imbalance section above.

If there is no power imbalance but there is current imbalance, it is very probable that the problem is a voltage imbalance not related to the motor. The power imbalance is calculated from the power measurements per phase through the following equation:

$$DBP = \frac{max\left((max\,(P_A, P_B, P_C) - P_{prom}), (P_{prom} - mín(P_A, P_B, P_C))\right)}{P_{prom}}$$

Where:

DBP = Power imbalance (–)
P_A = Phase A power (kW)
P_B = Phase B power (kW)
P_C = Phase C power (kW)
P_{prom} = Three-phase average power (kW)

Load factor – LF

The load factor of the electric motor indicates the percentage of mechanical power supplied in relation to the nominal capacity. A load factor above 100 percent indicates that the motor is overloaded, which results in overheating of the winding and a decrease in the operating efficiency and its service life. The load factor recommended for motor operation is between 65 and 80 percent. This is calculated with the following equations:

$$LF = \frac{\left(P_e / \eta_m\right)}{HP_{nom} * 0.746}$$

or

$$LF = \frac{\left(P_e / \eta_m\right)}{P_{nom}}$$

Where:

LF = Load factor of motor operation (–)
P_e = Electric power required by motor in kilowatts (kW)
η_m = Efficiency of motor operation (–)
HP_{nom} = Motor nominal power in horsepower (HP)
P_{nom} = Motor nominal power in kilowatts (kW)

The service factor indicated on the motor plate states up to what point the motor is capable of resisting overloads. Thus, a service factor of 1.15 means that the motor is designed to operate with a 15 percent overload more than its nominal power. This should only be done for a short period as constant operations of a motor at 15 percent overload will shorten the life of the motor and damage the winding insulation.

Capacitor current

The measurement of the capacitor current per phase indicates whether or not the phases are operating correctly. The current in each phase must be the same. If different currents are detected, it is a sign that the capacitor bank is not operating efficiently and must be repaired or replaced.

The capacity of the capacitor bank must be selected to reduce the reactive currents circulating through the electric conductors to the minimum; for example, the capacitor bank capacity must be selected to obtain a power factor close to the minimum value required by the electricity provider. The bank must be installed as close to the load as possible.

7.2.4. *Analysis of the Grounding System*

A good grounding system provides safety and security to the staff that works for the water and sanitation company and protects the equipment. Having the equipment grounded guarantees that if there is any contact with the energized electric conductors or the equipment structure, the current is drained to the grounding system. If there is an atmospheric discharge, this ensures that there will be no current flow in case there is human contact with the equipment. The parameters to analyze the grounding system include the following:

- **Continuity and electric resistance:** The first step is to see that there is a physical connection of the grounding conductor with the grounding system and that there is no sulphation in the welding. If the previous conditions are fulfilled, the measurement must be taken with a megohmmeter, and the value of the electric resistance of the grounding system must not exceed five Ohms.
- **Current:** If a current that flows from the neutral level to the ground is measured in the grounding system, it indicates that there is a power imbalance in the equipment.

7.3. ANALYSIS OF THE WATER SYSTEM

7.3.1. *Pump Analysis*

The water analysis of the running pump determines the variation of the pump from its design point. When the flow and head of operation are different from the design values, it may be due to one or several of the following causes:

- Bad adjustment of the impeller, which means that the impeller does not work at the design point.
- Worn impeller, which means that the impeller drives the water out of the well or sump; if there is a large amount of wear, the drive is weaker and results in less head and lower flow rate.
- Operational speed differs from that of the pump design; if the pump speed varies, the pump curve, head, and flow speeds will vary as well.

The above implies higher energy consumption, since pump efficiency decreases considerably.

Determination of hydraulic head deviation with respect to the design data

$$DH_b = \frac{H'_b - H_b}{H_b} *100$$

Where:

DH_b = Hydraulic deviation as compared to design head (–)
H_b = Hydraulic pump design head (wcm)
$H'_b H'_b$ = Hydraulic head pumping measure (wcm)

Determination of flow deviation

$$DQ_b = \frac{Q'_b - Q_b}{Q_b} *100$$

Where:

DQ_b = Flow deviation as compared to design flow (–)
Q_b = Hydraulic flow of pumping design (l/s)
Q'_b = Pumping hydraulic metered flow (l/s)

7.4. TEMPERATURE ANALYSIS

7.4.1. *Temperatures in the Transformer*

High temperature in the transformer is a symptom of a problem in the transformer. The following are the main problems that can be detected by measuring the temperature in the transformer:

- **High temperature in the feeder or primary terminals:** Indicates a mismatch at the terminals; in this case, contact resistance occurs and causes heating and bad contact. An overcharged transformer can also be a cause.
- **High temperature at the terminals of the secondary:** Indicates mismatch at terminals; in this case contact resistance occurs and causes heating and bad contact. An overcharged transformer can also be a cause.
- **High temperature in the transformer body:** Indicates heat removal problems that can be due to overload, high or low oil level, worn oil, or oil contaminated by moisture or oxygen.
- **Differential temperature between the lower and upper part of the radiator:** Indicates that there are heat removal problems.

7.4.2. *Temperatures at the Control Equipment*

Increased temperature at the different components is mainly due to unfastened screws in the conductor terminals and to motor overload. Monitor the temperature of the following components: breaker input, breaker output, starter input, and starter output.

7.4.3. *Motor Temperature*

Ball bearings

Temperature in motor ball bearings must not exceed 60 to 65 percent of the room temperature. When these temperatures are exceeded, there is a problem in the ball bearings. The following could cause the problem:

- Inadequate lubricant properties or lubricant with properties different from those of the original design
- Inadequate motor bearing lubrication or lack of lubrication in the bearing
- Overload of the ball bearings, whose temperature is directly related to the winding's temperature
- Incorrect adjustment of the bearings, which will cause greater friction and heating
- Misalignment of pump and motor

Casing

Abnormal temperature in the motor can be due to the following:

- Damaged coils
- Operational speed below full load speed; when speed is lower, greater current is generated in the winding, causing heating and damage to the insulation
- Overload, which produces heat by the current circulating inside the motor
- Damaged motor cooling fan

When a frequency shifter operates the motor, slower revolution reduces forced ventilation and therefore temperature increases. It is recommended to use specially designed motors for this type of equipment.

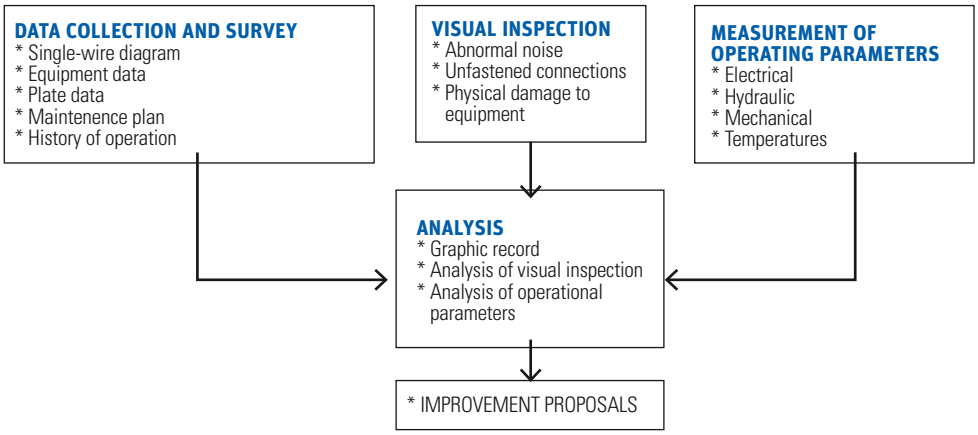
EXHIBIT

1. METHODOLOGY FOR MAINTENANCE AUDIT

A maintenance audit (MA) in a water pumping system is a process to evaluate the way in which the maintenance of the electrical, mechanical, and water components is carried out. It consists of collecting the data, measuring the equipment and operation parameters, and analyzing the information collected to identify areas of opportunity for improvement. In addition, the final objective is to make specific proposals to improve and integrate the maintenance plan into the company. Proper maintenance plans contribute to an increase in operational efficiency, equipment availability, and in overall productivity.

For best results, an orderly sequence must be followed during the MA for a water pumping system, which requires both field and office work. Figure A1 indicates the key activities, both in the field and office, necessary to carry out an effective audit.

FIGURE A1: Methodology to Perform a Maintenance Audit



1.1. FIELD ACTIVITIES

Data Collection

Data collection is necessary in order to become familiar with the basic equipment in the pumping systems, such as transformers, control systems, motors, pumps, water pipelines, electric conductors, and capacitors. Moreover, in this stage of the audit, information related to the existing maintenance plans and programs of the company must be collected.

Field Measurements

As part of the fieldwork, a measurement campaign of the electrical, hydraulic, mechanical, and temperature parameters must be carried out; the results will indicate the equipment condition and need for repairs or replacements. The following measurements are necessary:

Electrical parameters

- Measurement of harmonics in the feed line
- Voltage, current, power, and power factor measurements in the electric motors

- Current measurement in the capacitors
- Transformer tests
- Measurements in the grounding system

Hydraulic parameters

- Measurements of flow in pumps
- Pressure measurements in pump suction and discharge
- Measurements of water levels and necessary parameters to determine the pumping head
- Measurements of piping length and diameter

Temperature measurements

- Temperature measurements of feed terminals and low-tension terminals, and in the container and radiator of the transformer
- Temperature measurements of the connection terminals (of starters and breakers) in the motor control system

1.2. OFFICE ACTIVITIES

Analysis of Maintenance Information and Assessment

Analyze the information from the field activities to identify the areas of opportunity for improvement. The analysis should focus on two aspects: the correction of specific problems identified during fieldwork and the proposal of improvements to the maintenance plans and programs of the company.

Improvement Proposal

Propose areas of opportunity for improvement in predictive and preventive maintenance, as well as in the specific corrective maintenance actions derived from the problems discovered during fieldwork. In making the proposals, consider the following:

- ***Improvement to preventive maintenance***
  The proposed actions must be oriented to a good preventive maintenance program, with the purpose of preventing faults or failures in the equipment.

- ***Improvement to predictive maintenance***
  The proposed actions must be oriented to a good predictive maintenance program, with the purpose of anticipating fault occurrences or equipment failures.

- ***Improvement to the corrective maintenance***
  The proposed actions must be oriented to establish good corrective maintenance practices.

- ***Correction of identified problems***
  Whenever specific problems are identified as part of the field activities, recommendations for corrective actions should be proposed.

2. DATA COLLECTION

An MA cannot be carried out without collecting the necessary data. Most of the information will be found in the equipment inventory, datasheet, or purchase order. Information that cannot be gathered through these means must be obtained through fieldwork. This section provides a description of the basic data needed as well as where to find it.

2.1. ELECTRICAL SYSTEM

Single-Wire Diagram

The single-wire diagram of the system is used to carry out any type of maintenance and must include the following: equipment, connector, wiring, transformer, and the main breaker, and must indicate whether or not it has a starter.

Transformer

Regarding the transformer, the following information is needed:

- **Type:** The type of transformer that feeds the equipment or a description of the elements that feed the transformer in a low-tension system.
- **Capacity:** The capacity of the transformer or transformers; if more than one transformer provides the supply, state the capacity of each of them (kVA).
- **Transformation relation:** The input and output voltage of the transformer, or the relation of transformation voltage, must be stated in volts (V) separated by a slash, for example 13200/415/220V. If the transformer has more than one output voltage, state the voltage at which the transformer is currently operating.

Main Breaker

Collect the following data regarding the main breaker:

- **Trade name:** Record the breaker trade name or manufacturer.
- **Capacity:** Note the nominal capacity of the breaker in amperes (A).
- **Adjustment:** State nominal capacity to which the breaker is adjusted (if it is the adjustor type) in amperes (A).
- **Voltage:** Provide the maximum voltage at which the breaker should operate (V).

Starter

Collect the following data regarding the starter:

- **Type:** Provide the trade name or manufacturer.
- **Capacity:** Record the capacity of the starter (HP) or (kW).
- **The starting method:** State the starting method, which include across-the-line, autotransformer, star-delta (Y-D), soft starter, among others.

Thermal Protection

Collect the following data regarding the thermal protection:

- **Trade name:** Provide the manufacturer or trade name of the thermal protection element of the motor.
- **Capacity:** State the calibration range of the thermal element in amperes (A)
- **Adjustment:** Record the calibration point of the thermal element.

Capacitors

If the equipment has a capacitor bank, state the total capacity of the bank (kVAr).

Grounding System

Register the grounded and ungrounded equipment, and state the wire gage.

Electric Conductors

The conductor data must be gathered from the following sections: from the transformer to the control equipment and from the control equipment to the motor. The data to gather are the following:

- **Gage:** Provide the conductor gage (mm^2) or (AWG), which is indicated on its insulation.
- **Length:** Record the total length of the conductors in the described section.
- **Wiring and grouping:** Describe how the conductors are grouped, the wiring means used, and its measures. This is important because it indicates the ventilation that the the electrical conductors have.
- **Design temperature:** Note the design temperature of the insulator.

2.2. MOTOR DATA

Plate Data

- **Trade name:** Provide the motor trade name or manufacturer.
- **Capacity:** State the nominal capacity of the motor (HP) or (kW).
- **Speed:** Provide the operating speed of the motor in revolutions per minute (RPM).
- **Tension:** Record the nominal tension of the motor in volts (V).
- **Current:** Record the nominal current of the motor in amperes (A).
- **Efficiency:** State the efficiency of the manufacturer of the new motor in percentage (–).
- **Type:** Provide the motor type.
- **Casing:** Record the type or number of frame of the motor.
- **Service factor:** Provide the service factor information.

Operation Data

- **Age:** Provide the number of years the motor has been working since the first installation.
- **Operation:** Record the average working hours of the motor in a year (hr/year).
- **Number of rewindings:** State the number of rewindings that have been made to the motor during its service life.

2.3. PUMP NOMINAL DATA

This section provides details about the pump plate data that must be recorded.

Data of the Pump Body

The following data regarding the pump body must be obtained:

- **Trade name:** Provide the motor trade name or manufacturer.
- **Type:** Record the type of pump, such as, submersible, vertical turbine, horizontal, and centrifugal, among others.
- **Model:** Note the pump model according to the manufacturer.
- **Age:** Record the number of years the equipment has been operating since its installation.

Impeller Data

The following data corresponding to the pump impeller must be obtained:

- **Type:** Provide the type of pump impeller.
- **Material:** Note the material with which the impeller is manufactured.
- **Diameter:** Record the nominal diameter of the impeller (m).
- **Age:** Record the number of years the impeller has been in operation. Note that the impeller's age could be different from that of the pump, if the impeller has been changed during the life of the pump.

Design Data

Provide the hydraulic design features that were used to select the equipment:

- **Head:** design head (wcm)
- **Flow:** design flow (l/s)

2.4. VISUAL AND HEARING INSPECTION

Make basic observations during the inspection of the following equipment:

Electrical System

- **Transformer:** Provide any pertinent information on the ground connection, abnormal noise or vibration, paint condition, dielectric oil leaks, and damage to nozzles.
- **Breaker:** Listen for any noise due to arcing because of contact wear and tear.
- **Conductors:** Note any damaged insulation.
- **Motor:** Listen for any abnormal noise or vibration due to ball bearings, unbalanced components, or motor misalignment.

Hydraulic System

- **Pump:** Listen for any abnormal noise or vibration due to sediments, loose or unbalanced impeller, and/or loose head bolts if the pump is a vertical turbine.

2.5. DATA COLLECTION AND FIELD MEASUREMENT FORMS

In order to achieve the objectives in a clear and orderly way, use organized forms to record the characteristics of the electromechanical system and the nominal data of the pump and the motor. Tables B1, B2, and B3 provide examples for recording these characteristics. Tables B4, B5, and B6 present the form that can be used in hydraulic, electric, and temperature parameters of the pumping equipment. Organized forms for the collection and measurement of the different parameters are essential for a quick audit.

TABLE B1: Electrical System Data (example)

NECESSARY DATA

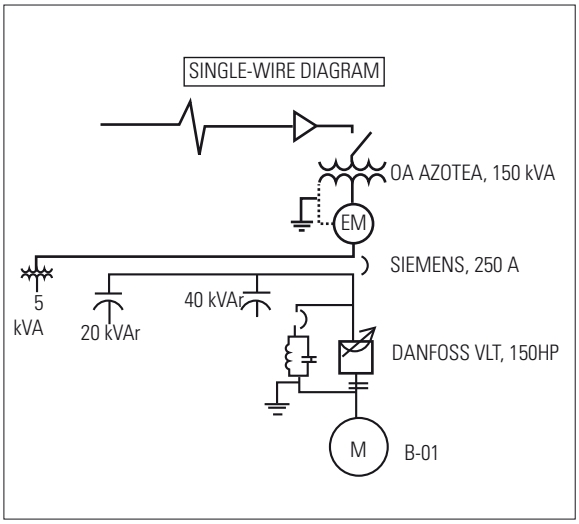
POWER SUPPLY	
Supplier:	----------
Service (power meter) No.:	----------
Subscribed tariff:	----------

TRANSFORMER		
Type:	OA (AZOTEA)	
Capacity:	150	kVA
Transf ratio:	13200/440/254	V.

MAIN BREAKER	
Trade name:	SIEMENS
Capacity:	250 A
Adjustment:	1100-2500-50%

STARTER:	
Type	DANFOSS VLT AQUA
Capacity:	150 HP
Starting method:	Star-Delta (Y-D)

PROTECTION	
Trade name:	BY SHIFTER
Capacity:	
Adjustment:	



CAPACITORS	
Capacity:	40/20 kVAr

CONDUCTORS	
Transformer – Starter	
Gage:	1HXF-4/0
Length:	7 m.
Grouping:	C-3H+1N4
Starter – Motor	
Gage	1HXF-4/0
Length:	9 m.
Grouping:	C-3H

GROUNDING SYSTEM				
Is there a grounding system?	Yes↙	NO		
Are neutral and ground separated?	Yes	NO↙		
Is the transformer grounded?	Yes↙	NO	Gage:	8
Is the starter grounded?	Yes↙	NO	Gage:	4
Is the motor grounded?	Yes	NO↙	Gage:	–

NOTES: _____

TABLE B2: Electric Motor Data (example)

PLATE OR NOMINAL DATA							
Brand:	General Electric		Tension:	440	V	Type:	T speed
Capacity:	150	HP	Current:	180	A	Frame:	1445TP
Speed:	N/A	RPM	Efficiency:	N/A		S.F.	1.15

HISTORY					
Age:	20 years	Operación:	8760 hrs/yr	No of rewinding	2
NOTES:	Model 14KA154				

TABLE B3: Pump Data (example)

PUMP DATA

BODY				**IMPELLER**		
Trade name:	N/A			Type:	almost open	
Type:	T. Vertical			Material:	N/A	
Model:	N/A			Diameter:	N/A	m
Age:		years		Age:	N/A	years
DATE	Diameter:	N/A	inches	Length:	N/A	m
DESIGN DATA:	Head:	158	wcm	Consumption:	14	l/s
NOTES						

TABLE B4: Electrical Measurements (example)

ELECTRICAL MEASUREMENTS

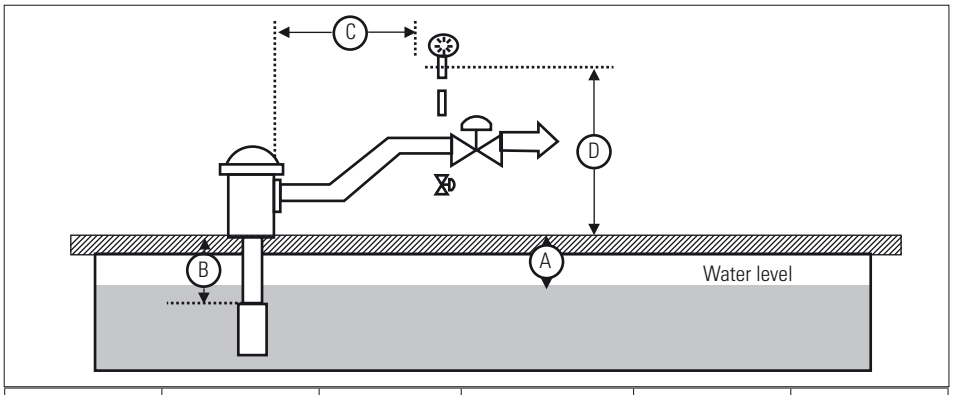
VOLTAGE AMONG PHASES (V)	Vab:	461	Vbc:	462	Vac:	460
CURRENT PER PHASE (Amps):	Ia:	71.7	Ib:	71.5	Ic:	69.2
ACTIVE POWER (kW):	Pa:	14.9	Pb:	14.9	Pc:	14.3
POWER FACTOR:	Fpa	–0.78	FPb:	–0.76	FPc	–0.78
HARMONIC DISTORTION	THD-V	1%	THD-I	32.60%		
Measurement point:	In the output contactor to the motor in the shifter.					
CAPACITOR CURRENT (Amps):	Ia:	58,1	Ib:	54,4	Ic:	38.5
GROUNDING system:	Continuity	~~SI~~ / NO	Current	30.32 mA	Resistance:	10.36 Ω
NOTES:	Capacitor bank oversized and capacitor C phase damaged .					

TABLE B5: Form for Collection of Hydraulic Measurements

HYDRAULIC MEASUREMENTS

LEVELS:

Top of water level (A)	150	m.	Length of suction piping (B)	158.60	m.
Discharge distance to manometer (C)	1	m.	Height discharge manometer (D)	0.1	m.



	Diameter	Material	Pressure (kg/cm²)	Flow (l/s)	Speed (m/s)
Suction	0.2032	AC	–	12.6	0.3885
Discharge	0.2032	AC	0.61	12.6	0.3885

NOTES

TABLE B6: Form for Collection of Temperature Measurements

TEMPERATURE MEASUREMENTS

Control equipment (temperature in °C)	Breaker input			Breaker output			Starter input			Starter output		
	A	B	C	A	B	C	A	B	C	A	B	C
	34	34	32	34	33	33	33	33	33	31	33	34

MOTOR			TRANSFORMER										
Casing	Ball bearings		Feeder terminals			Low-tension terminals				Container		Radiator	
	Upper	Lower	X1	X2	X3	X0	X1	X2	X3	Upper.	Lower	Upper.	Lower
37	37	36	-	-	-	34	36	36	35	38	31	36	32
NOTES: There is a dielectric oil spill in low voltage side of the transformer.													

2.6. FORM FOR MAINTENANCE PLAN AUDIT

List appropriate actions taken regarding the pumping equipment maintenance. The water company provides this information (see Table B7).

TABLE B7: Maintenance Plan Audit (example)

Subsystem	Equipment	Recommended action	Maintenance frequency				Not pre-formed
			Daily	Weekly	Monthly	Annual	
Electrical	Transformers	Equipment cleaning					
		Area cleaning					
		Retightening of nuts and bolts in nozzles and mechanical terminals					
		Dielectric oil purification and filtration, consisting in centrifuge, filter, dewater, and degassing contents in the transformer.					
		Measurement and analysis of electric parameters					
		Physiochemical analysis of oil					
		Test Turns Ratio (TTR)					
		Electric tests (Megger)					
		Thermographic analysis					
	Motor control center	Board cleaning with dielectric solvent					
		Cleaning and lubrication of mechanical drives (springs, keypads)					
		Refastening nuts and bolts to terminals and electrical connectors					
		Measurement and analysis of electric parameters					
		Electric endurance tests in the physical grounding network					
		Continuity tests in the physical grounding network					
		Thermographic analysis					
	Electric motors	Winding cleaning with dielectric solvent					
		Ball bearings lubrication					
		Axial ball bearings change					
		Cover adjustments					
		Casing sanding and painting					
		Measurement and analysis of electric parameters					
		Mechanical vibration measurement and analysis					
		Flash test					
		Endurance test to winding					
		Thermographic analysis					

TABLE B7: Maintenance Plan Audit (continued)

Subsystem	Equipment	Recommended action	Maintenance frequency				Not pre-formed
			Daily	Weekly	Monthly	Annual	
Mechanical	Pumps	Bearing and bearing holder lubrication					
		Upper shaft lubrication					
		Change of cup bushing					
		Rectified of intermediate cup seats					
		Change of suction cup bushing					
		Rectification of line shaft					
		Change of upper shaft					
		Journal bearing change					
		Change of pillow bushing					
		Rectification of cup shaft					
		Mechanical vibration measurement and analysis					
		Measurement and analysis of delivery pressure and pumping head					
		Flow rate measurement and analysis					
		Pillow bushing inspection					
		Stuffing box inspection					
	Discharge piping	Discharge piping cleaning and inspection					
		Discharge piping painting					
		Change of broken packing between the flange couplings, valves, measuring apparatus and check pressure sustainers.					
		Valve change					
		Functioning and calibration inspection of macro measuring apparatus					
		Inspection of chlorination equipment					
		Solenoid and air-bleed valves cleaning					
		Mechanical vibration measurement and analysis					
	Valves	Cleaning and evaluation of diaphragm					
		Cleaning and evaluation of the diaphragm driver spring					
		Cleaning of anti-dust joint					
		Shaft bearing lubrication					
		Cleaning of the valve body					
		Solenoid cleaning					
		Change of control electric conducts					
		Mechanical vibration measurement and analysis					

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