

Electrical Submersible Pump Dismantle, Inspection and Failure Analysis

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Electrical Submersible Pump Dismantle, Inspection and Failure Analysis

1 Scope

This recommended practice (RP) covers the processes and procedures of collecting required information to complete a root cause failure analysis of an electrical submersible pump (ESP) system. These include:

- Procedures for disassembly, inspection, final report, failure classification and corrective actions. Items covered by this recommended practice include pumps, intakes, gas separators, gas handling devices, seals/protectors, motors (induction and permanent magnet motors), gauges, sensors, motor lead extensions, potheads, and power cables. Tooling and test equipment may differ between suppliers; however, the typical assembly and inspection procedures and principles are generally applicable for most ESP systems.
- Information that should be collected prior to equipment dismantle and inspection as well as specific observations that should be recorded during equipment inspections/teardown/disassembly.
- General equipment drawings which may aid in identifying equipment components. It should be noted that these drawings are for generic equipment components, and there may be differences between manufacturers on the exact description or configuration of the assemblies. The user should refer to the manufacturer's specific drawings as needed.

This RP does not include gauge surface electronics, system grounding, alternative deployed systems, chemical injection systems, motor oil injection from surface, remote gauges, generators, power supply, wellhead, trees and valves, tubing, tail-pipe systems, operation maintenance and troubleshooting, pump testing, installation, sizing and selection, application of ESP cable systems, testing of ESP cable systems, application and testing of seals/protectors, sand handling devices, ESP system vibrations or items covered by other API recommended practices.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

ASTM D877/D877M, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*

ASTM D1533, *Standard Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration*

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

bag chamber

A seal/protector chamber that relies on an elastomer barrier (bag) to isolate seal fluid from the well fluid.

NOTE The seal/protector may include multiple chambers connected in parallel or series.

3.1.2

balance ring

On a mixed flow stage, this ring projects upward from the upper shroud and seals off the top of the impeller from its discharge. It can also function as a radial bearing surface or a place to drill holes when physically balancing the impeller, or both. Balance rings and balance holes are only used on the higher flow rate stages within a series.

3.1.3

bands

The material used to secure the cable to the tubing.

3.1.4

cable splice

The joining of two sections of power cable as required for the full length to electrical submersible pump (ESP) set depth.

3.1.5

center tandem motor

CT Motor

A motor with a head designed to connect to the bottom of an upper tandem, or center tandem motor and a base designed to connect to another center tandem motor, a lower tandem, or a universal base. All flange connections have provision for connecting the corresponding windings to those of the adjacent motors.

3.1.6

center tandem pump

CT Pump

A pump with flange connections which allow any number of sections to be connected in tandem. Also, a discharge head, intake or gas separator may be attached to the pump.

3.1.7

compression

All impellers are locked hub to hub and to the shaft. All stage and shaft thrust are transferred to the seal/protector thrust bearing. Typically applied when abrasives are present, when low lubricity fluids (Propane and NGL) are being pumped and in pump series larger than 538 series.

3.1.8

compression nut

The nut used on a bottom floater or compression pump to lock/compress the impellers hub to hub.

3.1.9

compression tube

A tube, generally stainless steel, closely fit to the inside of the pump housing located between the head and the upper diffuser. The compression tube is "cut-to-fit" such that the length is longer than the space between the pump head and top diffuser. The length will compress the diffusers and lock them in place to prevent rotation. The length is unique for each stage type and manufacturer.

NOTE A typical value may be 0.0015 in. to 0.002 in. of additional length per pump stage in the pump.

3.1.10

coupling

A device which connects one shaft to another shaft, usually to transfer torque from one to the other.

3.1.11

diffusers

The stationary part of the stage that converts the velocity head generated by the impeller into static head (pressure) and guides the fluid into the next impeller.

3.1.12**discharge head**

The component connected the upper pump that allows the ESP to be connected to the tubing.

3.1.13**down tube**

A component (communication tube) in a seal/protector.

3.1.14**down-thrust washer**

A washer used as the bearing surface on the bottom of the impeller.

NOTE This is generally fabric-filled phenolic material, however other materials are sometimes used.

3.1.15**encapsulated stator**

A method of stabilizing, protecting, insulating the motor windings.

NOTE The encapsulating material will vary between manufacturers.

3.1.16**head**

Pressure, generally expressed in feet of lift, of produced fluid.

3.1.17**head and base**

The machined part that finishes the top and bottom of each equipment (DMS, motor, seal/protector, gas separator, pump).

3.1.18**impeller**

The rotating part of the stage that adds velocity and head to the pumped fluid using centrifugal force.

3.1.19**junction box**

The connection point for the cable from the switchgear to the surface cable.

3.1.20**labyrinth chamber**

A seal / protector chamber designed for wells where the well fluid is denser than the motor oil and relies on the difference between their densities and their relative immiscibility.

NOTE The seal/protector may include multiple chambers connected in series.

3.1.21**loss of lubricity**

The oil-film between the runner and associated thrust bearing.

3.1.22**lower pigtail splice**

The splice from the pigtail (typically connected to the wellhead penetrator at the lower end of the tubing hanger to the main power cable.

3.1.23**lower tandem motor****LT motor**

A motor with a head designed to connect to the bottom of an upper tandem or center tandem motor and an integral “Y” connection at the bottom connecting the windings together.

3.1.24**lower tandem (LT) pump****LT Pump**

A pump with a built-in intake.

3.1.25**magnet wire****mag wire**

Copper wire used to wind and form the motor stator coils.

3.1.26**manufacturing quality**

The manufacturer’s specific quality and quality program.

3.1.27**mixed flow**

Fluid flowing through mixed flow stages moves both radially and axially at the same time.

3.1.28**motor lead extension****MLE**

A special clearance parallel conductor cable used to go alongside the pump and protector to the motor and is spliced to the main power cable above the pump discharge head. The MLE will have the pothead incorporated on the lower end.

NOTE Also see “Flat Cable Extension (FCE)” in Annex A.

3.1.29**O-ring**

A doughnut-shaped rubber ring seal between two pieces of equipment.

3.1.30**O-ring boss**

The area where the O-ring engages and provides a seal.

3.1.31**O-ring groove**

The groove that holds the O-ring in place.

3.1.32**O-ring surface**

The mating (sealing) surface used to compress and seal against the O-ring.

3.1.33**Phase-to-ground**

The electrical reading used to measure electrical insulation resistance for an ESP motor, cable, or overall ESP system. Expressed in a value of ohms (Ω), mega ohms (M Ω) or giga ohms (G Ω).

3.1.34**phase-to-phase**

The electrical reading used to measure resistance between motor, or motor with cable connected phases (A-B, A-C, and B-C).

3.1.35**proportional integral derivative****PID**

A control method used in variable speed drives (VSDs) to automatically control the ESP to maintain a target operating parameter.

3.1.36**pigtail**

The clip-on extension leads used in performing electrical tests.

3.1.37**pitting**

Voids in the material, usually caused by rust and corrosion.

3.1.38**porosity**

Voids or bubbles in a casting, typically the impeller or diffuser.

3.1.39**pothead**

The connector on the lower end of the MLE (Motor Lead Extension) that makes the mechanical and electrical connection to the motor.

3.1.40**pull report**

The document filled out by a field service technician that documents the removal of an ESP system.

NOTE Also see "Pull and Run Report" in Annex A.

3.1.41**pump stage**

A combination of the impeller and diffuser.

3.1.42**rotor**

The part of the rotating assembly in the motor that provides a magnetic field generated either by an electromagnetic circuit (example: squirrel-cage or wound rotor) or by permanent magnets. The torque produced at the shaft is a result of the interaction between that magnetic field and the one produced by the stator.

3.1.43**rotor bearings**

Bearing race for shaft sleeve used at each end of each rotor to center the rotor in the bore of the stator.

3.1.44**rotor end ring**

An electric conductive ring at both ends of the induction motor's rotor, which connects the rotor bars end together.

3.1.45**seal/protector**

The component used in an ESP to protect the motor, prevent well fluid entry, and equalize pressure from the motor to the wellbore.

3.1.46**shaft play**

The movement of a shaft (typically axial but may also be radial movement).

3.1.47**shaft setting**

The amount of movement and shaft end location of the shaft as per manufacturing guidelines.

NOTE May also be described as axial play.

3.1.48**shaft tube**

The tube that covers the shaft in a seal/protector.

3.1.49**stage**

A single impeller and a diffuser set.

3.1.50**standard intake**

Provides intake holes and screens for center or upper tandem pump sections (which end with a simple male flange).

3.1.51**stator**

The stationary part of the motor comprising the stator lamination and the stationary three-phase magnet wire windings and winding leads (brush wire).

3.1.52**stator lamination****lams**

Thin steel plates stacked together to form along with the three-phase stator winding, the stator's magnetic circuit.

3.1.53**time domain reflectometer****TDR**

A method used to determine electrical fault location(s).

3.1.54**thrust bearing**

The bearing that carries the axial load.

3.1.55**trend analysis**

The method for analyzing ESP performance using operating parameter trends over a period. Generally, consists of multiple parameters.

3.1.56**two-piece coupling**

A coupling that comprises two pieces so that different shaft diameters are coupled together.

3.1.57**two-piece ring**

A split ring used in various forms in many different pieces of equipment where high thrust loads are to be transmitted to or from the shaft.

3.1.58**universal base**

A base which bolts onto the bottom of an upper tandem or center tandem motor to make the “Y” connection at the bottom connecting the windings together and to isolate the motor from the well bore fluid.

3.1.59**upper shroud**

The portion of the impeller which forms the top of the flow passages.

3.1.60**upper tandem motor****UT motor**

A motor with a head made to accept the power cable connection on top and either a center tandem motor, lower tandem motor, a DMS or universal base on the bottom.

3.1.61**upper tandem pump****UT Pump**

A pump with a built-in discharge head.

3.1.62**variable speed drive****VSD**

Allows the user to vary motor and pump rotating speed by varying the Hz/frequency of the motor electric frequency provided to the motor, even if the energy comes from a constant frequency power supply.

NOTE Or Variable Frequency Drive (VFD).

3.2 Abbreviations

BHT	Bottom Hole Temperature
DIFA	Dismantle, Inspection and Failure Analysis
ESP	Electrical Submersible Pump
FTP	Flowing Tubing Pressure, at surface
FTT	Flowing Tubing Temperature, at surface
MLE	Motor Lead Extension
PI	Productivity Index, barrels per day (BPD)/psi
PID	Proportional Integral Derivative
PIP	Pump Intake Pressure
POOH	Pull Out of Hole
Pr	Reservoir Pressure (static and flowing)
PSI	Pounds Per Square Inch
RIH	Run in Hole
SC	Silicon Carbide
SCADA	Supervisory Control and Data Acquisition
SS	Stainless Steel
SSHB	Stainless Steel Head and Base
T	Temperature

Tr	Reservoir Temperature
TDR	Time domain reflectometer
VSD	Variable Speed Drive

4 Health Safety and Environmental (HSE)

4.1 General

Health, safety, and environmental hazards and procedures are not part of the scope of this RP and will not be addressed except in certain special cases. It is the responsibility of the entity performing the inspection and failure analysis to ensure that appropriate HSE, regulatory, and governmental guidelines are adhered to. Be sure to perform a tailgate safety meeting prior to dismantle.

Caution—Common hazards that may be identified include but are not limited to:

- Inhalation injury from Hydrogen Sulfide (H_2S)
- Naturally Occurring Radioactive Material
- Poison from inorganic hazards such as arsenic or others
- Physical injury from trapped pressure
- Burns or eye injury from flying sparks during cutting
- Electric shock during electrical tests
- Laceration from sharp ESP parts and cutting equipment
- Impact from highly torqued components having stored energy

At all times, the user should adhere to safe practices regarding these hazards and closely follow the supplier/manufacturer's guidelines and policies. All appropriate safety precautions should be undertaken.

4.2 Lifting and Handling

To avoid injury, use appropriate lift aids and techniques. Suppliers/manufacturers established practices should be reviewed and followed in all cases.

4.3 Clear and Clean Work Areas

A properly organized work area ensures safety of the workers present and an accurate assessment of the failed equipment.

4.4 Personal Protective Equipment (PPE)

PPE should always be worn in designated areas and as directed by worksite facility personnel. Different facilities may have different requirements for PPE so coordinate with local HSE representative(s) for specific requirements. At a minimum, hand protection, eye protection and H_2S and radiation monitors should be used.

4.5 Dedicated Work Areas

It is recommended that a dedicated workspace be provided for dismantle and inspection along with the appropriate tooling and personnel. Additionally, it is recommended that a dedicated office space be provided to the users.

5 ESP Pulling—Activities and Observations

5.1 General

Observations, evidence, and data collected during the ESP pulling activity can be very important as part of the overall failure analysis. When pulling the ESP from the well the following processes/procedures are recommended.

5.2 Pre-pulling Procedural Guidelines

The following should be completed prior to pulling the ESP from the wellbore:

- Ensure that all required safety processes and procedures are being followed.
- Ensure that all ESP manufacturer recommended practices are observed during operations.
- Take care in ESP cable spooler and sheave placement to ensure that ESP cable is not damaged during pulling operations.
- Cable clamps or bands, or both, should be properly removed and stored for possible additional inspection. Cable clamps and bands shall be counted, and counts compared with installation report. Any missing clamps shall be noted, including location (measure depth or joint count) where clamp should have been. Any damage to cable clamps/bands shall be noted including the measure depth or joint count where damage was observed.
- ESP power cable(s) shall be visually inspected, and any damage noted including the measure depth or joint count where damage was observed.
- ESP equipment should be pulled out of hole at a safe speed. Speeds in excess of 1000 ft/hour should be closely monitored. If cable decompression is observed during pulling operations (noted by “popping” sounds from the cable) then pulling speed should be slowed.
- Take photographs of any unusual findings during pulling operations.
- During ESP equipment dismantle ensure that all accessories including couplings are kept for evaluation. Couplings, where possible, should be left installed on the base of the equipment and secured with a shipping cap.

5.3 Recommended Observations During Pulling Operations

To support the failure analysis process, it is important to ensure good observations of the pulled ESP equipment taken as the equipment comes out of the well and is laid down on the rig floor. Observations to be taken include the following:

- Record unique identifiers (i.e. serial numbers) and system location of each ESP component.
- Wellhead Penetrator/ Lower Connector—Obtain and record electrical conductivity readings phase-to-phase and insulation resistance phase-to-ground for all three phases. Ensure that penetrator and lower connector are tagged and shipped back with ESP components for further inspection.
- Packer Electrical Penetrator Mandrel Connectors—Obtain and record electrical conductivity readings phase-to-phase and insulation resistance phase-to-ground for all three phases. Ensure that mandrel and connectors are tagged and shipped back with ESP components for further inspection.
- Any significant mechanical damage (i.e. drag marks, impacts, vibration marks, bent housings or necks). Include photographs.

- Indications of leaks at joints or plugs including flange connections, or both, noting any observed improper make-up of connections.
- Scale or substance build-up on or in equipment. If possible, collect samples and store in properly identified container to be forwarded with equipment.
- Debris or foreign material buildup in or on equipment openings or housings.
- Any signs of external corrosion
- Any signs of damage/breaches in production tubing or capillary lines, or both.
- Any signs of excessive heat on ESP equipment housings.
- Examine O-rings and other seals at flange connection points and record any signs of leakage, deformation, or damage.
- Intake Screens: If the ESP component has an intake screen, observe its condition noting any signs of foreign material, deformation, or damage.
- Rotate equipment shafts to determine if rotation is free, shafts are intact and noting any significant side play. Shaft rotation should be checked from top of ESP system while still assembled (hanging in rig) and then again when components are disassembled after laying down.
- Pumps: When shaft shims are used, ensure that all shims are collected, bagged, or otherwise secured, component location identified and placed in the base of the component along with the component coupling. If shim bolts are used, they should remain in place and not removed.
- Motor Protectors/Seal Chamber Sections—Where/when possible and if safe to do, collect fluid samples from each chamber. Identify the location of the collection point and label sample bottle with identifying information (i.e. well location, equipment serial number, chamber, date). Fluid samples shall be returned with equipment for further inspection. If/when plugs are removed to collect samples observe presence of and condition of seals for damage (i.e. over-compression).
- Motor(s)—Cut off motor lead extension (MLE) ~12 in.–24 in. above the pothead and DO NOT disconnect from motor. Ensure the MLE “stub” is laid flat onto the motor housing and secured to avoid damage.
- Motor(s)—Obtain and record electrical conductivity readings phase-to-phase and insulation resistance phase-to-ground for all three phases from the cut-off MLE location or the head of the center/lower tandem motor terminals.
- Motor(s)—Where/when possible and if safe to do, collect fluid samples from each chamber. Identify the location of the collection point and label sample bottle with identifying information (i.e. well location, equipment serial number, chamber, date). Fluid samples shall be returned with equipment for further inspection. If/when plugs are removed to collect samples observe presence of and condition of seals for damage (i.e. over-compression).
- Cable(s)—Obtain and record electrical conductivity readings phase-to-phase and insulation resistance phase-to-ground for all three phases.
- Cable(s)—Visually inspect and note any damage (mechanical or electrical) along cable and including splice locations. Note and record any observations including the measure depth or joint count where damage was observed.
- Ancillary Equipment (i.e. shrouds, de-sanders): Note and record any observations relating to damage, scale or substance build-up or deposits, or a combination thereof.

An ESP pulling checklist can be found in Annex B for further reference and to assist in developing applicable ESP pulling procedures.

6 General Pre-inspection Information Gathering and Guidelines

6.1 General

Sections 6.2, 6.3, and 6.4 are intended to assist the user in a comprehensive review to determine root cause. While the ultimate root cause may not be fully identified, a thorough review of the data will allow the user to list the most likely causes for failure. These causes can then be used to improve overall ESP performance.

NOTE Most often, all the ESP equipment is prepared for dismantling although there is frequently not time to do the entire string as the focus is on failed component(s) and then to scrap the rest. By looking intensively at components after short run, specific of failure modes for that component and in that well can be identified. A broader look at all ESPs in a particular field might gain a better perspective of failure issues, however. The majority of ESPs do not go through any inspection process other than to separate components by scrap bin. We are living in data intensive times which helps us to learn the life cycle of ESPs to better understand potential lessons learned. Collecting data on this very last step of ESP life cycle is worth the effort to tie back to collected data on an ESP's operation. Each ESP vendor does DIFAs and scrap differently so it is important to see what each can offer in a "DIFA-lite" option(s) for pumps sent directly to scrap.

6.2 Preparation

6.2.1 General

Electrical submersible pumping systems may stop operating, or not operate as expected, for a variety of reasons. Improper identification of the root cause(s) in many cases can result in frequent and repeat failures. This may be due to many factors that are not investigated, misinterpreted, or are not properly documented. Unfortunately, the initial problem, or a failed component discovered during the failure investigation of an ESP system, may be prematurely assigned full "responsibility" for the failure although it is not the "root cause" or basis of the problem but the result of the root cause(s). It is imperative to not only identify the root cause(s) of failure but also to identify the lagging failures. Lagging failures are issues that would have led to a subsequent failure had the primary root cause not been present.

Schedule the dismantle and inspection as soon as possible after the ESP is pulled to minimize loss of information. The root cause investigation process can take days or weeks. Many factors impact the timeliness of determining the root cause. Factors that should be considered are (but not limited to):

- a) Application and design.
- b) Materials selection.
- c) Manufacturing practices and quality
- d) Shipping and handling.
- e) Installation practices.
- f) Startup practices and procedure.
- g) Production operations.
- h) Operating practice.
- i) Optimization.
- j) Pulling practices.

- k) Transportation to DIFA facility.
- l) Pre-DIFA data capture.

Proper preparation is required for effective failure analysis. The following information should be collected and available during the process. This recommended practice recognizes that all items may not be available for each failure analysis.

6.2.2 ESP Design and Application

Well and ESP system compatibility and design parameters:

- a) Operator design request and information provided that the design was based on.
- b) Supplier detailed design report and recommendations.
- c) Well and ESP system model alternatives for time intervals with expected well condition changes as appropriate.
- d) Technical specification for ESP components.
- e) Wellbore survey (dogleg/deviation survey).

6.2.3 ESP Manufacturing

Manufacturing factory acceptance testing reports:

- a) Pump performance test.
- b) Motor performance test.
- c) Protector/seal performance test.
- d) Other relevant test and assembly check list compliance reports.
- e) Manufacturing quality records, as may be applicable including confirmation of component shaft settings.

6.2.4 Shipping and Handling Information

Shipping and handling information as listed below:

- a) Information regarding package and transport methods.
- b) Information describing how the equipment was secured for transport such as: in shipping box, strapped to truck/trailer bed, loaded in containers, or properly loaded in shipping baskets.
- c) Handling methods including procedures used for loading and unloading equipment such as lifting points, cranes, forklift, spreader bars, or other equipment.
- d) Information related to the shock sensors, if used.

6.2.5 Rig Operations

The following information should be observed during rig operations. However, prior to the start of rig operations, check for dangerous voltages prior to testing for resistance values, even if the VSD is isolated. Some ESP systems such as those with permanent magnet motors have electric shock potentially injurious to service personnel.