AN OVERVIEW OF RECOMMENDED PRACTICES RELATED TO INSTALLATION AND OPERATION OF ELECTRIC SUBMERSIBLE PUMPS

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ABSTRACT

Electric Submersible Pumping Systems are being specified more frequently as the means of artificial lift for both new and existing wells. With this increased use, many operators may not understand the proper selection, installation, operation, maintenance and troubleshooting related to the Electric Submersible Pumping System. This understanding is important in assuring a successful Submersible Pump operation.

The purpose of this paper is to give an overview of some of the recently published Recommended Practices on Electric Submersible Pump installations and also to comment on additional work currently being done in this area.

INTRODUCTION

The installation of Electric Submersible Pump equipment (Figure 1) in oil wells is becoming almost as common today as running sucker rod equipment. However, unlike sucker rod installations, the Electric Submersible Pump equipment requires greater attention to care and handling during its transportation to a well, and while it is being run into the well bore. For a successful installation the operator must give proper attention to each phase of selecting, handling and installing an Electric Submersible Pump System.

Although many companies have their own recommended practices and procedures for installing Electric Submersible Pump equipment, it is becoming necessary to review these practices and develop guidelines covering all phases of handling and installation to insure successful pump operation.

In keeping with this need, an API Task Group has completed two Recommended Practices (RP). The first, API RP 11R, is "Electrical Submersible Pump Installations", and the second, API RP 11S, is "Operation, Maintenance, and Troubleshooting of Electric Submersible Pump Installations". The Task Group is working on a third RP on "Sizing and Selection of Electric Submersible Pumps". The key points in these publications will be reviewed and the need for further work in this area discussed.

TRANSPORTATION AND HANDLING

Once Electric Submersible Pump equipment has been specified for a well, each step including transporting, handling and installing the equipment is of significant importance in assuring a successful installation.

All Electric Submersible Pump equipment should be transported and handled with the care normally given fine machinery or precision

equipment. This includes the Electric Submersible motor, seal section and pump as well as the motor lead cable and power cable. Also, surface equipment such as the motor control panel, junction box and transformers must be properly transported and handled. The success of an Electric Submersible Pump installation is often jeopardized before the rig arrives on location to run the equipment.

ELECTRIC SUBMERSIBLE MOTOR, SEAL SECTION AND PUMP

The Electric Submersible motor, seal section and pump are normally shipped in metal shipping boxes, provided by the equipment manufacturer to properly support and provide mechanical protection for the equipment during shipment. These shipping boxes should be handled by lifting them with a two point lift that allows them to be moved while maintaining the box in a horizontal position.

When Electric Submersible Pump equipment is being transported to the lease location, the truck or trailer bed used to transport the equipment must be of sufficient length to properly support the total length of the shipping box. No more than a three foot overhang should ever be allowed, and the shipping boxes must be in a horizontal position. The shipping boxes are marked by the manufacturer to show which end is to be placed toward the wellhead when off loading. This should be considered when loading the equipment on the truck to take it to the well site.

If support blocks are used under the shipping boxes, they must be properly spaced to provide enough support points to prevent bending. Also, the boom chains or ropes that are securing the boxes must be located directly over the support blocks so that they secure the load without bending.

The same care must be exercised when unloading Electric Submersible Pump equipment as has been stated for loading it. The two point lift system should be utilized and care must be taken not to bounce or drop the boxes. The shipping boxes provide protection for normal handling and cannot prevent damage when handled improperly.

All boxed Electric Submersible Pump well equipment should be placed as close to the wellhead as practical, and with the properly marked end toward the wellhead. This will insure proper removal from the shipping boxes and easy assembly, while minimizing the risk of damage.

MOTOR LEAD CABLE AND POWER CABLE

The motor lead extension cable (flat cable)(Figure 1c)is normally already spliced onto the round power cable(Figure 1b) before delivery to the well site. While on the power cable spool, the flat cable should be tied down at the pot head, as well as at the flat cable-round cable splice to provide protection during shipment.

When spooled, the cable should allow a minimum of a four inch inset between the last outer cable wrap and the O.D. of the cable reel flange to protect the cable (Figure 2).

When unloading a spool of cable, a cable power spooler or a spreader bar lift system should be used. Never lift a cable spool

using a sling without a spreader bar since this is likely to damage both the spool and the cable.

The spool should be placed 75 to 100 ft. from the wellhead and in the rig operator's direct line of vision. Placement should not be such that it allows the cable to pass over his head. In addition, the reel should be set so as to allow the cable to spool onto or off of the top of the spool which minimizes cable tension and therefore, reduces the chances of cable damage.

TRANSFORMERS, MOTOR CONTROLLER AND JUNCTION BOXES

Transformers

Each transformer is provided with lifting hooks or pick-up lugs for handling. If a crane is available, the lifting hooks should be used utilizing a spreader bar lift system. If a crane or hoist is not available, lift the transformer by jacking it up using the jack-up lugs and then use rollers under the transformer to move it. Regardless of the method used to move transformers, they should be handled carefully and only in a vertical position.

Motor Controllers

Although electrically durable, motor controllers (control panels) (Figure 3) can be damaged by excessive vibration. It is therefore important that the controller is firmly secured while being transported to minimize movement, tipping and vibration. Other equipment being transported should not be stacked on top of the controller.

When lifting the motor controller, the lifting hooks must be used, and it should not be placed closer than 50 ft. from the wellhead. Uncrating a motor controller should be done with a pry bar (crow bar) and not with a hammer.

Junction Box

The purpose of the junction box is to allow any gas migrating up the well power cable to be vented to atmosphere, thereby preventing it from reaching the motor controller. It should be located no closer than 15 ft. from either the wellhead or from the motor controller. A cable vapor seal should always be used on the cable connecting the junction box with the motor controller (Figure 4).

INSTALLING AND PULLING EQUIPMENT

When an Electric Submersible Pump is being run into or pulled from a well, various auxiliary equipment is used to insure a successful installation. The condition of this equipment and the method that it is used may be detrimental to the life of the Electric Submersible Pump equipment. For this reason, a brief discussion of this equipment is warranted.

Tubing Spiders, Slips and Back-Up Tongs

The tubing spider doors should be slotted or the "cut-out" type to permit passage of the power cable. This should be periodically checked for alignment so as to minimize interference with the power cable and risks of damage to the cable.

The slips are to be of the proper size for the tubing being used, and must be sharp and clean, and capable of accommodating the size power cable being installed.

Back-up tongs must always be used to prevent tubing rotation during make-up or when breaking joints. Tongs must be kept clean and in good condition so that the power cable will not be damaged due to the tubing slipping.

WELL SERVICING RIG

The pulling unit used must be of adequate capacity, be in good operating condition, and have sufficient mast height to accommodate the Electric Submersible Pump equipment being run. The rig crew must be made aware of the precision type of equipment that is being installed or pulled, and that slow running or pulling speeds are required.

Also, the rig should be spotted perfectly over the well bore so as to minimize any possible snagging of the power cable or cable bands.

CABLE SPOOLER (REEL) AND GUIDE WHEEL

As mentioned before, the power cable spooler should be located 75 to 100 ft. away from the wellhead when running or pulling equipment. If a power spooler is not used, a cable reel stand of adequate size should be used and manned by two people for proper control. When ambient temperatures require heating the cable for running, a suitable shelter with heaters should be utilized.

A guide wheel should always be used when running or pulling Electric Submersible pump equipment. The recommended guide wheel diameter is 54 inches and it should have sufficient frame clearance to prevent power cable damage.

When preparing to feed the cable through the guide wheel, the wheel should be supported about 10 ft. above the ground. After the flat cable to round power cable splice has passed through the wheel and the splice has been securely banded to the tubing, the guide wheel should then be raised to a running position approximately 30 to 45 ft. above the ground. At this time, it should be secured as close in alignment with the traveling block as possible. Care must be taken not to align the guide wheel by pulling on the power cable.

It is important to hang the wheel from a primary hanging device, and also from a secondary safety line. The safety line should not have any load on it during normal running operations.

RUNNING EQUIPMENT INTO WELL

Installation Equipment

As reviewed in the previous sections, equipment that is going to be used to run the Electric Submersible Pump equipment into the well must be checked to make certain that it is serviceable, in good working condition, and properly positioned or installed.

Electric Submersible Equipment

Prior to setting up to run the Electric Submersible equipment, all equipment delivered to the well site should be carefully checked to insure:

1. That is it the proper size and type.

2. That all equipment needed for the installation has been delivered, including cable bands and other accessory equipment.

3. That equipment Serial Numbers are recorded for the well records, and equipment O.D. measurements are recorded.

4. That equipment has been properly located relative to the wellhead to facilitate pick-up and handling.

Casing Check

The casing should be gauged with a full gauge tool to a depth of at least 60 ft. below the intended motor setting depth. This should always be done prior to equipment installation in a new well, or in a well where any evidence of equipment or cable damage was found when equipment was pulled.

Wellhead Preparation

The casing head and wellhead should be carefully inspected to make certain they are of sufficient I.D. size to allow proper passage of the Electric Submersible equipment, and that there are no burrs or sharp edges that might damage the equipment or power cable.

Running Electric Submersible Pump Equipment

All lifting equipment should be safety checked just prior to proceeding with installation. Make certain that all slings, chains, and cables are in good condition, and that lifting hooks have safety bails.

The Electric Submersible motor is the first piece of equipment to be installed. Shipping caps must not be removed from the equipment until it is in a vertical position over the wellbore and ready to be coupled to another component. Using a nylon sling, the motor end head end should be raised enough to allow installation of the motor clamp. The motor can then be raised using the Rig Elevators and the proper lift equipment. Care must be taken when lifting the

motor or any Electric Submersible equipment out of their shipping boxes, that the bottom end of the equipment does not swing into the wellhead or rig floor area endangering personnel or possibly damaging the equipment.

Each component of the Electric Submersible pumping equipment should be checked prior to running it into the well to be certain:

1. That all units rotate freely.

2. That electrical checks are made where applicable and that all fill, vent, and drain plugs are checked for tightness.

3. That pressure checks and other equipment checks are made per the manufacturer's instructions.

Lifting the completely assembled Electric Submersible Pump unit should be done using a lifting or handling sub that has been properly installed in the pump discharge head. An assembled or partially assembled unit should not be allowed to stand in the derrick due to the possibility of damaging equipment alignment.

Cable Splicing

Splicing the motor lead cable to the power cable or other splicing that may be required, can be accomplished by cable splicing procedures recommended by the Submersible Pump manufacturer for the particular cable being used and the expected well bore conditions being encountered.

Cable Banding

The quality of the cable banding job done will be very dependent on the banding tools used. Make certain that the banding tools are in good operating condition, and that the personnel using the tools are properly trained and supervised. Some important cable banding procedures and techniques are:

1. Never install a band across a cable splice. The splice should be located at least 3 to 4 ft. above the closest collar so that adequate space is available for proper banding. Double band immediately above and below the splice to prevent any cable load being transferred to the splice.
2. Recommended minimum banding is two bands per tubing joint, with one band in the middle of the joint and the other band 2 to 3 ft. above the collar.

3. Consideration should be given to installing multiple cable bands (5 or more) slightly above the deepest point in the tubing string where tubing cut off would occur if a fishing operation was required.

4. When running unarmored cable, cable band saddles must be used, and the bands should be tight enough to prevent any slippage of the cable or saddle.

5. On armored cable, bands should be tightened until armor is slightly distorted but not crushed.

Check Valves and Drain Valves

A check valve may be installed in the tubing string above the pump discharge to prevent fluid "fall back" when the pump stops operating, resulting in reverse rotation of the pump unit. The danger without the check valve is restarting the pump while it is in reverse rotation, which can result in electrical or mechanical damage. At least 30 minutes should be allowed after a pump shuts down before trying to restart it. This allows sufficient time for the well fluids in the tubing to drain back through the pump.

If a check valve is installed it should be a minimum of 6 to 8 joints above the pump. The check valve requires that a bleeder or drain valve be installed one joint above the check valve so that the tubing will not have to be pulled wet.

Important Running and Pulling Practices

After the Electric Submersible Pump equipment has been started into the well, the primary concern then becomes proper handling of the power cable. The majority of cable damage occurs due to mishandling or improper running procedures. Attention to the following running practices is extremely important:

1. When running or pulling tubing, all starts and stops must be "slow and smooth". Rapid acceleration or deceleration is the primary cause of cable damage due to the tension imposed on the power cable. Minimum tension must be maintained on the cable between the cable reel and the guide wheel.

2. One rig crew member must be made responsible for insuring that the cable stays aligned with the slot or cut out in the tubing spider doors.

3. Cable and motor electrical continuity and insulation resistance checks should be made periodically (a minimum of once every 2000 ft.) and when the pump is landed on bottom.

4. The Submersible pump should be landed with the motor above the well perforations. If the pump is set with the motor below the perforations, a means must be provided to insure adequate fluid flow by the motor to obtain proper motor cooling. (Motor shroud, etc.).

Surface Completion

After reaching pump setting depth, the tubing should be landed and the wellhead made-up according to proper procedures for the type of wellhead used. The only piping required is the connection of the well production tubing to the flow line. Make certain that all fittings, valves and piping are of sufficient pressure rating to allow

safe operation at maximum pump discharge head (possible if casing is full).

The electrical connection from the wellhead to the junction box should be completed assuring that the leads are properly secured mechanically, electrically, and as relates to phase order. Also, all surface units, junction box, motor controller and transformers must be properly grounded.

START-UP PROCEDURES

Checks Before Start-Up

After the Electric Submersible pump installation is completed and before start-up, the following must be checked:

1. Make certain the flow line connection is properly completed, valves are correctly installed and in proper operating position for start-up (open or closed as appropriate).

2. Check electrical connections and make certain they are properly completed and secured, and that all electrical controls are properly set or adjusted for start-up. Specifically, check the overload and underload adjustments for proper start-up settings according to the manufacturer's recommendations.

Equipment Start-Up

Having completed all pre-start-up checks, the serviceman or user personnel should complete the start-up procedure. This includes:

1. Starting the unit. The pump should not be started against a closed choke or valve, but can be throttled to control pump discharge rate within range specified on the pump performance curve. In large horsepower units (above 250 HP) regardless of setting depth, and low capacity units set deep (static fluid level below 7000 ft.) tubing fill up is recommended before start-up.

2. Making initial operational checks to insure that equipment is operating properly. Pump rotation should be verified as soon after start-up as possible. Use "pump-up" time, wellhead tubing discharge pressure and flow rate, production test, or other methods recommended by pump manufacturer or operating company procedures.

3. After well production stabilizes, reset or adjust:

   a. Overload relay - normally set at 120% of motor name plate amperage.

b. Underload relay - generally set at 80% of motor normal operating amperage.

c. Time delay restart - generally set at 10 minutes per 1000 ft. of operating fluid level, but not less than 30 minutes.

4. Scheduling well testing to provide production and operating information as soon after start-up as possible.

Operating Data Gathering

Obtaining and recording accurate operating data is extremely important because:

1. It is required for comparison to monitor the system against under normal operating conditions.

2. It will provide information that will be useful in troubleshooting the installation under abnormal operating conditions.

3. It will provide accurate data for equipment reference and analysis and should include:

a. Start-up ammeter chart.

b. Well test data sheets with corresponding ammeter chart attached.

c. Most recent ammeter chart.

d. Other pertinent well and equipment data.

Operating data should be taken on a periodic basis, with a monthly schedule recommended under normal operating conditions. As indicated before, most frequent checks and well tests should be made at start-up and until the well stabilizes.

Use Of Operating Data

Operating data is obtained to:

1. Allow evaluation of the system after initial installation start-up to insure that it is functioning properly.

2. Provide a basis for monitoring system operation over the life of the equipment.

3. Provide comparative data for system analysis and troubleshooting.

4. Give definite information to allow resizing of the equipment, if necessary, to optimize well production and equipment efficiency.

Obviously, the effectiveness of the use of the data will be directly proportional to the accuracy of the data. This point should be stressed with those gathering and recording the data. When, and the conditions under which the data is taken may be as important as the data obtained. Was the well just put on production, is it tending to "head", was the casing found shut in, may be factors that will make the data vary from normal and this should be known.

TROUBLESHOOTING

Ammeter Chart Analysis

The ammeter chart is very useful in analyzing and diagnosing changing well conditions or equipment problems. Properly used it can allow corrective action to be taken that will possibly prevent downtime or equipment damage.

API Recommended Practice RP 11S provides examples of ammeter charts that may be encountered in operating Electric Submersible Pump equipment, and explains the probable cause and possible corrective actions. This is a good reference to use when analyzing ammeter charts.

Problem Troubleshooting

In addition to ammeter chart analysis, a basic problem troubleshooting approach is recommended as shown in API RP 11S. The troubleshooting chart begins with the system condition (pump running or pump not operating), lists apparent problems, then possible causes with the appropriate action.

This troubleshooting format provides a good logical approach to diagnosing and correcting many Electric Submersible Pump System problems.

Maintenance

Preventative maintenance on an Electric Submersible Pump System falls into two categories. Maintenance which is done only with the well down and the primary power disconnected, and maintenance checks made with the system operating.

Maintenance With Well Down

This maintenance may be scheduled or may be done while the well is down for other reasons. Care must be taken to be certain that the primary power is disconnected when performing these checks.

1. Test power cable and motor resistance to ground and phase-to-phase. Phase-to-phase readings must be balanced.

2. Check control panel:

a. Clean to remove moisture and dirt.

b. Door seal should be replaced if not in good condition.

c. See that electrical contacts and lights are clean and that all connections are secure.

3. Check transformer:

a. For oil leaks, corrosion, broken insulation, loose connections, and case condition.

b. Oil by an industry accepted standard. If oil is below minimum industry standards, it should be filtered or replaced.

4. Electrical connections and ground wires:

All electrical connections should be checked to insure that they are clean and secure. This includes ground wires between all components and enclosures, which should be checked for continuity and tight connections.

Maintenance With Well Operating

The following checks are made with the well in operation.

1. Wellhead cable pack-off should be inspected to insure seal is holding (no leakage).
2. Power factor determination should be made and corrective action taken if required. This will provide longer equipment life and reduced operating costs.

3. Ammeter calibration should be checked and corrected if required.

EQUIPMENT SIZING AND SELECTION

The third Recommended Practice the API Task Group is currently working on covers the Sizing and Selection of Electric Submersible Pumps and related system components. It will provide:

1. General descriptions and specifications for all Electric Submersible Pump System components.

2. Definition of Terms and Data required.

3. Reference charts, graphs, and specifications required in sizing and selecting Electric Submersible Pump equipment.

4. Three example problems covering the sizing and selection of Electric Submersible Pump equipment for:

a. Oil and water production with no gas.

b. Oil and water production with gas.

c. A viscous oil production application.

FURTHER WORK REQUIRED

The three Recommended Practices (RP) discussed cover the major portion of information that is required to have a working understanding of an Electric Submersible Pump system and the practices associated with selecting, handling, installing, operating and troubleshooting. These should provide the understanding required of the basic system but Electric Submersible Pump systems are also seeing some new innovations which make them even more applicable to oil well production. These include the use of soft start control panels to reduce the electrical and mechanical stresses on the system during start-up or shut down, and the variable frequency (speed) motor controller which allows the pump speed to be changed (above or below 3600 RPM) to optimize pump operation against well production. These two new controls offer significant operating flexibility to the Electric Submersible Pump system. Their application and operation may be another area that will require Task Group attention.

CONCLUSION

Attention to each and every phase and detail of Electric Submersible Pump selection, installation and operation is very important to insuring a good installation. An understanding and appreciation for the equipment and the procedures required to make a successful system installation can be obtained by making use of concise information recently completed in API Recommended Practices. Their use, together with Electric Submersible Pump manufacturer's specifications and service personnel assistance will provide the data and supervision necessary.

An Electric Submersible Pump system properly sized and installed will provide an effective and efficient lift system that is very competitive with any other means of artificial lift.

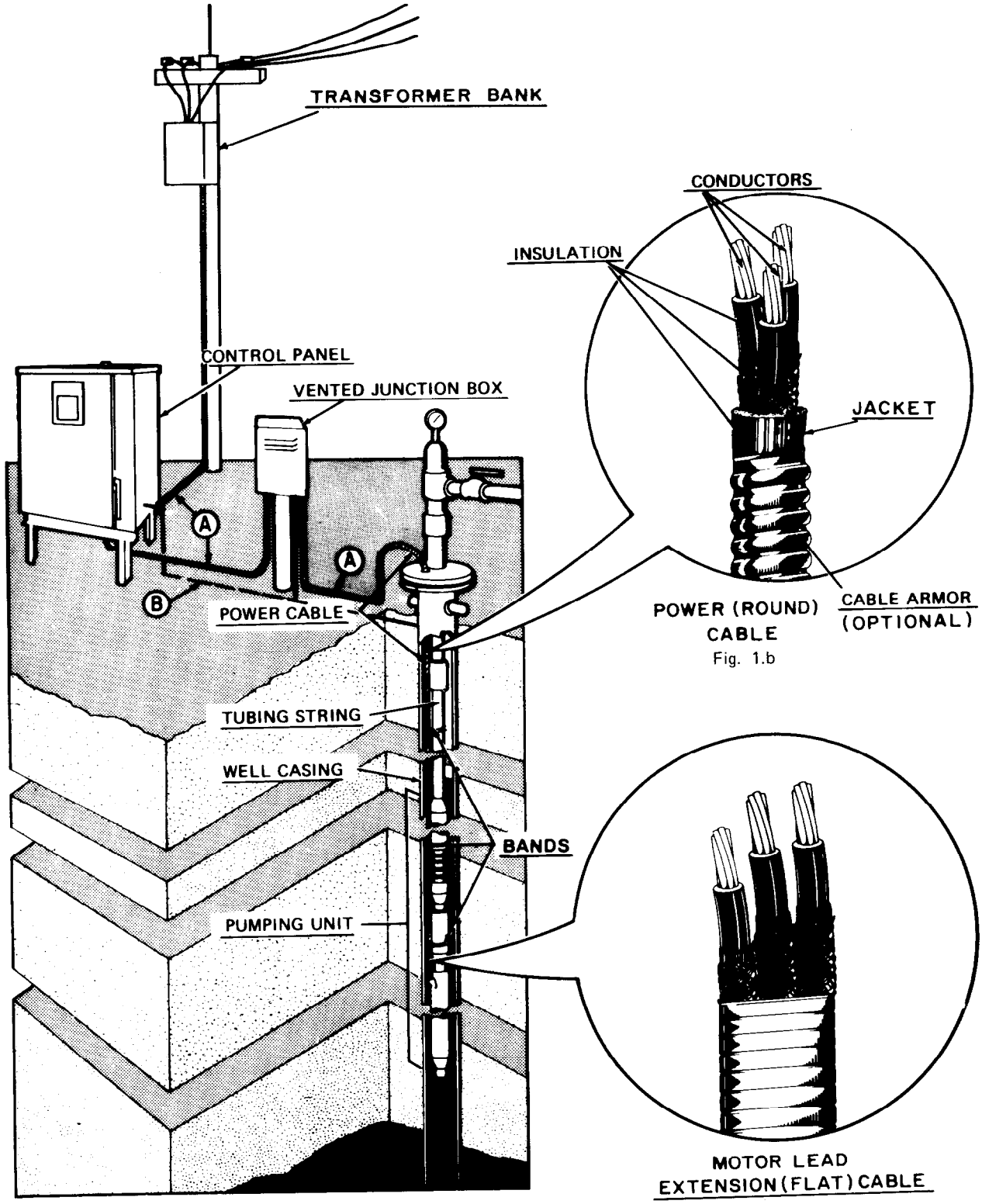
TRANSFORMER BANK
CONTROL PANEL
VENTED JUNCTION BOX
A
A
B
POWER CABLE
TUBING STRING
WELL CASING
BANDS
PUMPING UNIT
CONDUCTORS
INSULATION
JACKET
CABLE ARMOR (OPTIONAL)
POWER (ROUND) CABLE
Fig. 1.b
MOTOR LEAD EXTENSION (FLAT) CABLE
Fig. 1.c
(A) SURFACE POWER CABLE TO BE RUN IN CONDUIT AND BURIED (Ref. Par. 3.2.e)
(B) GROUNDING WIRE (BURIED)
Fig. 1.a

FIGURE 1

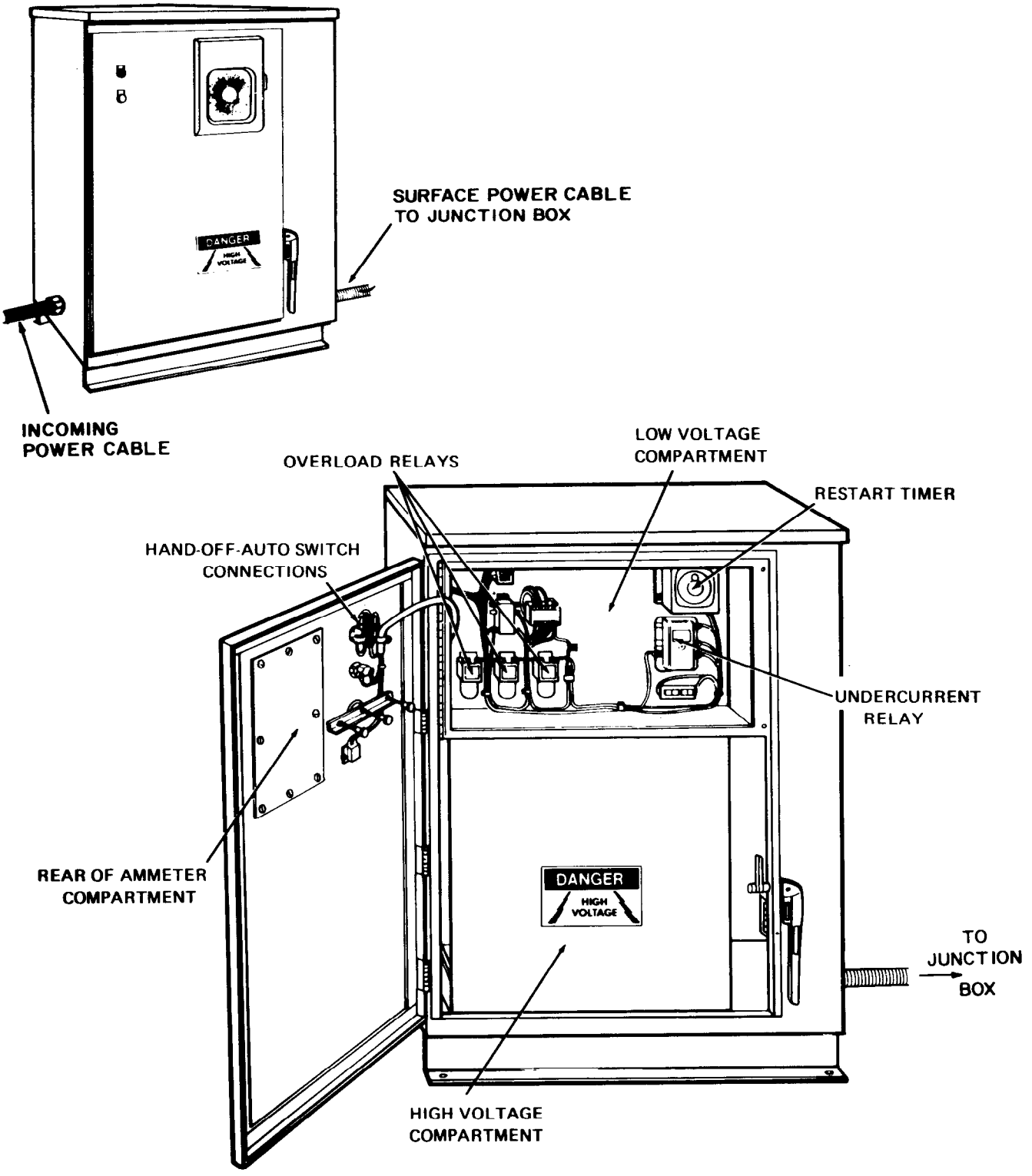
SURFACE POWER CABLE
TO JUNCTION BOX
DANGER
HIGH VOLTAGE
INCOMING
POWER CABLE
OVERLOAD RELAYS
LOW VOLTAGE
COMPARTMENT
RESTART TIMER
HAND-OFF-AUTO SWITCH
CONNECTIONS
UNDERCURRENT
RELAY
REAR OF AMMETER
COMPARTMENT
DANGER
HIGH
VOLTAGE
TO
JUNCTION
BOX
HIGH VOLTAGE
COMPARTMENT

FIGURE 3

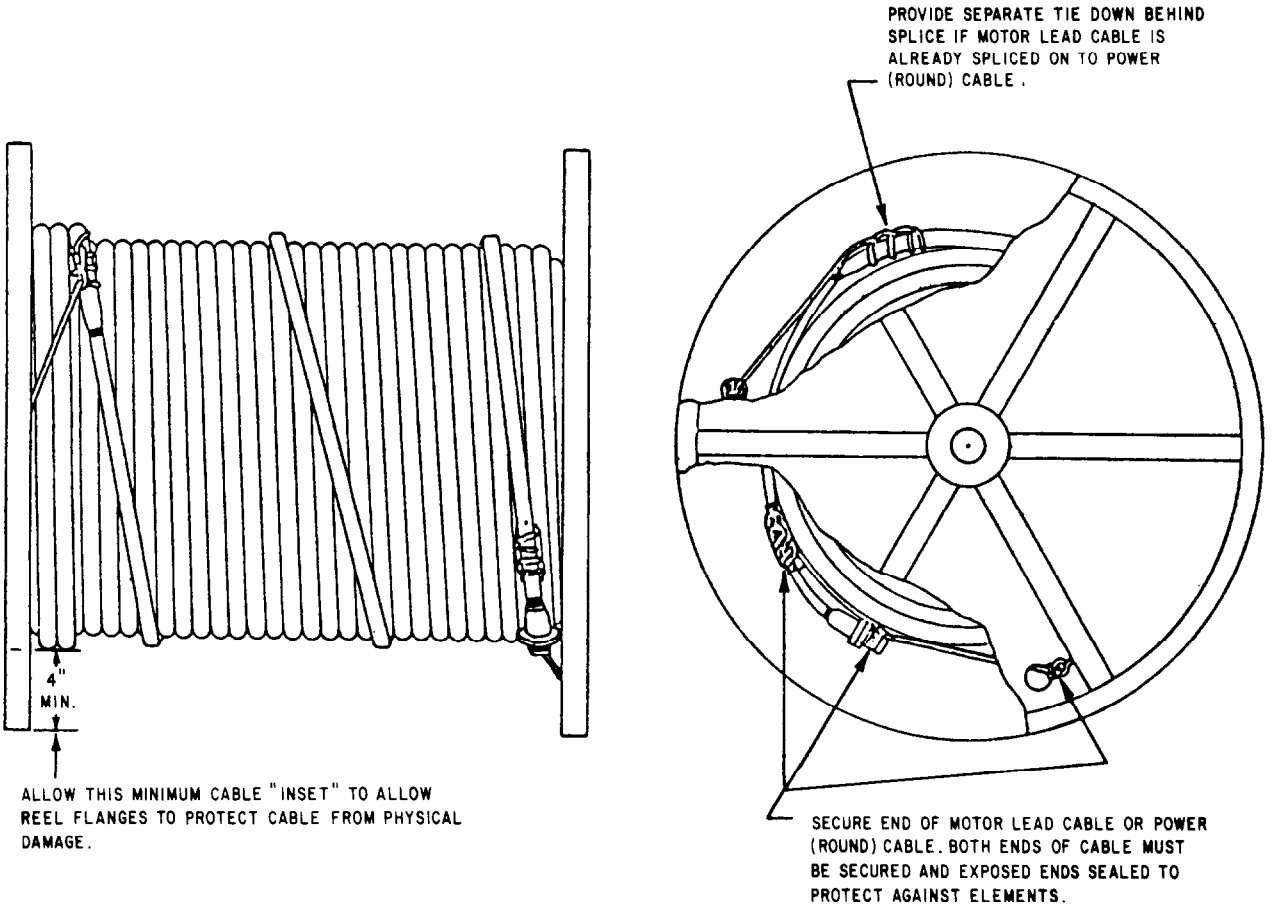

FIGURE 2

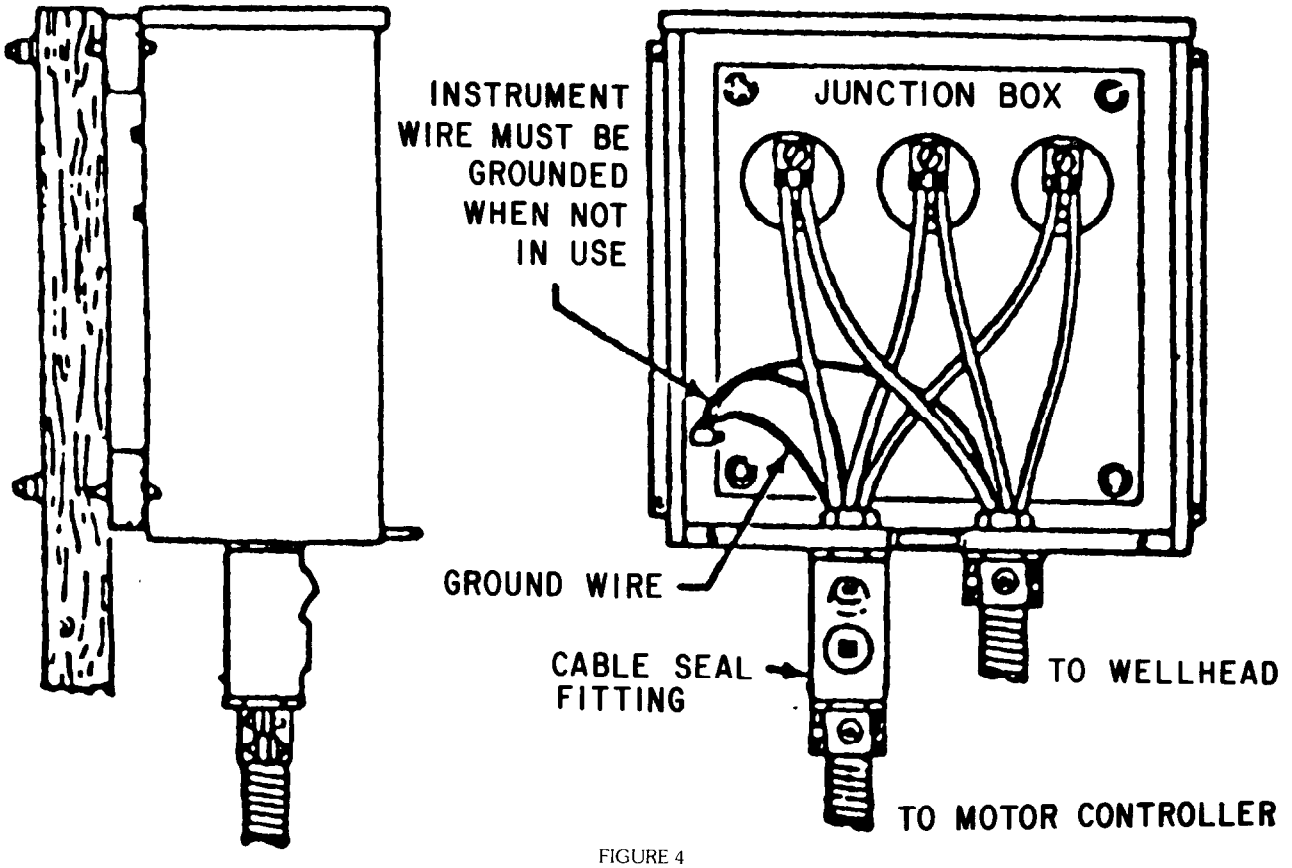

FIGURE 4