Types of Electric Motors for Oil-Well Pumping

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INTRODUCTION

By 1960 a good majority of all producing wells on artifical lift in the United States will be on electric pump. Electrification of oil leases is increasing at a rapid rate for several reasons: the increased value of gas as a commodity rather than as a source of fuel at the well head and the trend toward automation, which can be accomplished only by electric drive and control as new methods are devised to speed up production while decreasing the labor content in crude oil production. However, the big factor favoring lease electrification is just plain economics. In other words, all factors considered, it generally costs the operator less money to produce a barrel of oil by using electric power and equipment than it does by using gas engines. For example, actual records indicate that:

(1) Electric motors together with their controllers cost about half as much as gas engines cost.

(2) Motors and their associated control have about 1/4 the maintenance cost of comparable engines, including material and labor.

(3) Using electric motors, the average pumper can handle about twice as many wells on electric pump as he can those on gas engines, and he can still devote more time to gauging and work at the tank battery, saving up to 50 percent in operating labor.

(4) There will be less than 1/4 the total downtime and consequent loss of production if motors are used instead of gas engines. The amount of lost production recoverable, particularly under repressuring or secondary recovery operations such as water flooding, is a debatable issue. At the best, increased downtime will prolong the life and costs of the pumping operation, adding unnecessary expenses and time to the project.

(5) The salvage value of motors is much higher than that of gas engines. Electric motors have a good life expectancy of twenty-five to thirty years, whereas engines (particularly multi-cylinder ones) will probably last no longer than eight to ten years without requiring extensive overhaul and repair.

TYPES OF MOTORS

Many types of motors for oil-well-pumping service are in use today in the oil field. These vary all the way from the wound-rotor motor design, which was possibly the first a-c induction motor applied to beam-pumping installations, to single-phase a-c motors, used primarily on shallow stripper wells or where 3-phase a-c power is not available. And, although the vast majority of motor-powered beam-pumping installations today are driven by high-starting torque normal-slip a-c induction motors, many different types of motors are applied for oil-well-pumping duty. We shall examine these various types in more detail.

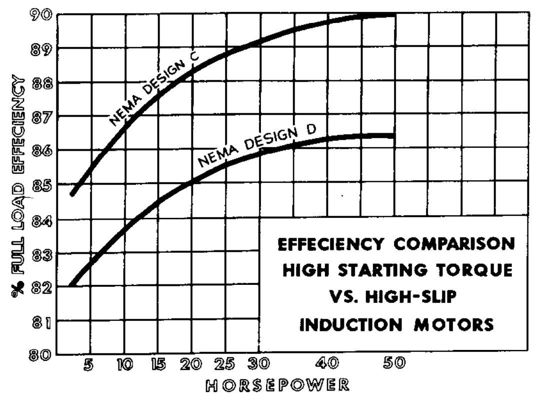
There are three popular types of polyphase low-starting current a-c induction motors as defined by the National Electrical Manufacturers Association (NEMA):

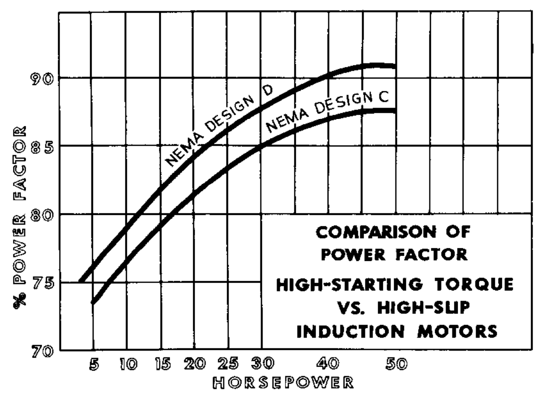
NEMA Design B - Normal starting torque, normal-slip, low starting current.

NEMA Design C - High starting torque, normal-slip, low starting current, and

NEMA Design D - High starting torque, high slip.

Figure 1 shows typical speed-torque characteristics for these three types of induction motors in sizes commonly used for oil-well-pumping applications.





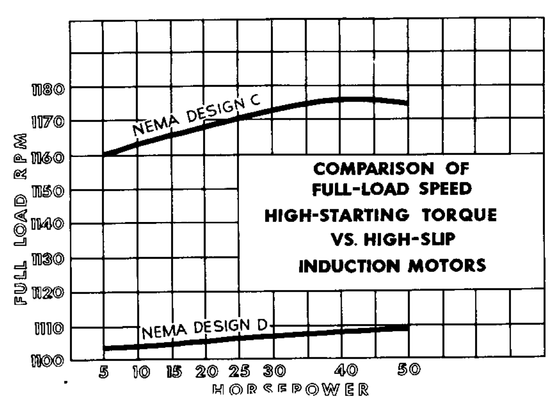


Figure 1. Comparison Curves of NEMA Design C and NEMA Design D Motors
A. Comparison of Power Factor
B. Comparison of Efficiency
C. Comparison of Full-load Speed

While NEMA Design B is the most popular general-purpose type of motor, its use is rather limited in the oil fields primarily because of its comparatively low starting torque. However, it does find application with centrifugal surface pumps, such as booster pumps and back-wash pumps used in water-flooding or where low-head or starting torque requirements are found.

NEMA Design C versus NEMA Design D

A motor used for oil-well-pumping duty must be selected on the basis of both the running load requirements and the starting load requirements. A safe rule to follow is that the motor selected must be able to break away and to accelerate the load under the worst possible conditions of counterweighting and fluid viscosity in the hole. Normally, this stipulation requires that a high-starting torque (either NEMA Design C or NEMA Design D) motor be selected. In fact, the vast majority of the oil-well-pumping motors installed, particularly in the Southwestern area, are of the high starting torque NEMA Design C type, 1200 rpm synchronous speed rating, 440 volts, 3-phase, 60 cycles. The 1200-rpm synchronous speed rating lends itself particularly well to double-reduction gear units driven from a V-belt drive to give output speeds in the range of 15 to 30 strokes per minute, which is the usual beam-pumping-unit speed range. Faster pumping speeds through single-reduction gearing generally require a 900-rpm synchronous speed motor.

To a lesser extent, NEMA Design D high- or medium-slip motors have been successfully employed for oil-well pumping. NEMA defines two types of high-slip, NEMA Design D motors: the so-called medium-slip (5-8%) and the high-slip (8-13%). Practically all NEMA Design D motors used for oil-well-pumping applications are of the medium slip (5-8%) variety, as they are more economical than the higher slip (8-13%) design and have operating characteristics that lend themselves to cyclic pumping loads such as for beam-pumping units.

The peculiar characteristic of the NEMA Design D motor is that it has the ability to slip or slow down under loads suddenly applied, thus giving up speed as this load is applied and causing electric heat losses to be generated in the motor rotor. This action is very much the same as the slip or slowdown in the output shaft (load shaft) of a fluid coupling as compared to the input shaft (driven shaft) when excessive loads are suddenly applied, causing losses in the form of heat to be generated in the fluid coupling. Figure 2 shows that at normal full load (100% torque), the NEMA Design B and Design C motors both have a full load slip of about 3% (or 1164 rpm for a synchronous speed rating of 1200 rpm), whereas the NEMA Design D motor operates at a full-load slip of about 8% slip (or 1104 rpm for a synchronous speed rating of 1200 rpm). At 100 per cent overload (200% full load

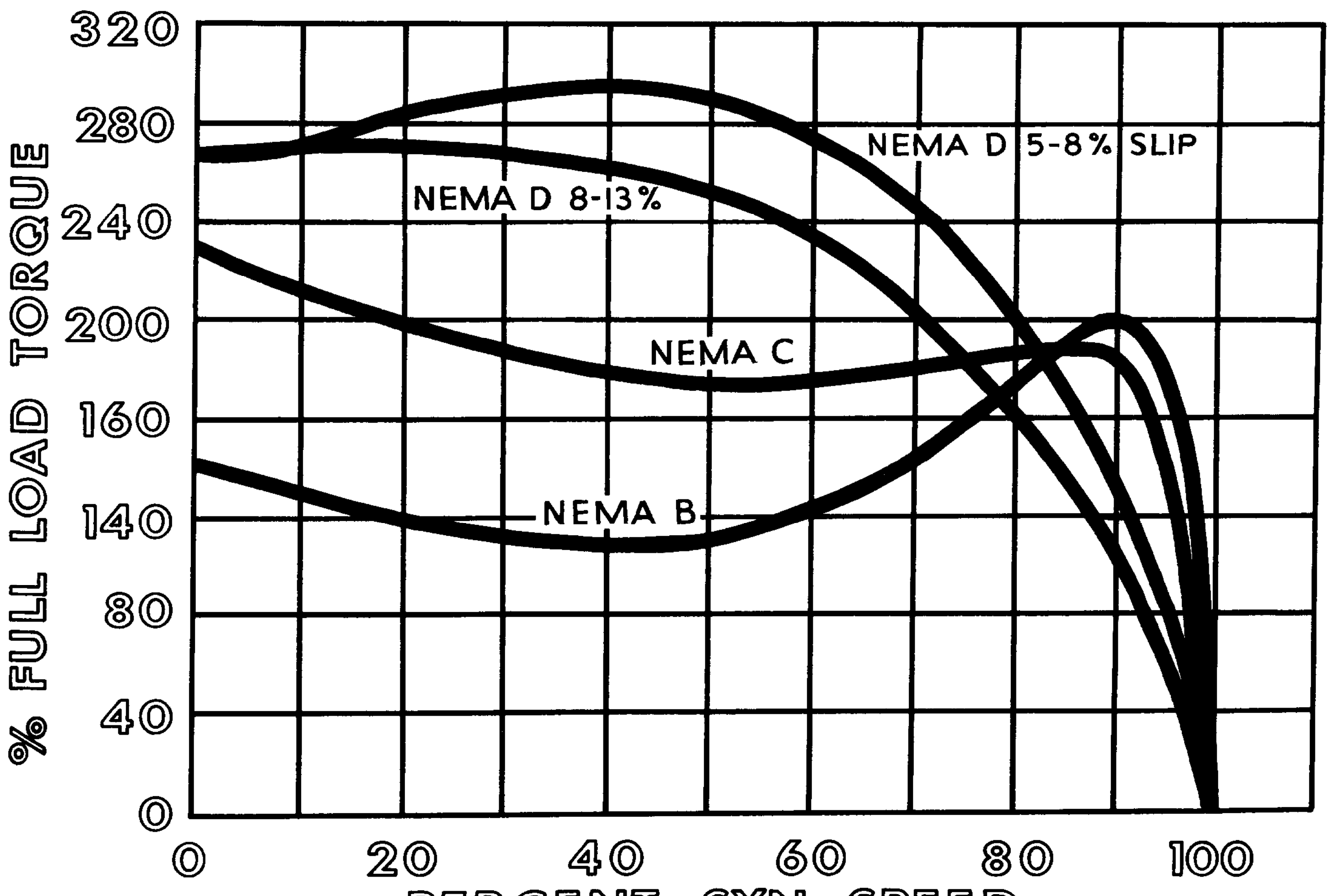


Figure 2. Typical Speed-torque Characteristic Curves for NEMA Design B, NEMA Design C, and NEMA Design D Induction Motors

torque), the NEMA Design C motor backs up along its speed-torque line to about 12% slip or 1056 rpm, but the NEMA Design D motor falls off to about 68% of synchronous slip, or 32% slip (which would be 796 rpm for a 1200-rpm synchronous speed rating). Thus the NEMA Design D motor will slow down or slip when overloads are suddenly applied, resulting in fewer strokes per minute on the pumping unit during this overload portion of the pumping cycle.

A favorable result, however, in the case of the NEMA Design D motor is that the current peaks introduced by the shock loads are considerably reduced, resulting in a reduction in the electric power input (kilowatts) to the motor. The NEMA C motor, on the other hand, has a "stiff" speed characteristic, resulting in high peak current when high overloads are applied suddenly. Thus, the kilowatt-hours per barrel of fluid pumped is reduced in most cases by using a NEMA Design D motor, but it must be remembered that production is also lost because of the slowdown in strokes per minute. If the sheave size of the NEMA D motor is changed to increase the speed to give the same strokes per minute as those for a NEMA C pumping motor, the reduced current peaks are not nearly so pronounced, and actually a higher input in terms of kilowatt-hours per barrel usually results. This is due primarily to the high heating or rotor losses induced in the high-slip motor as it gives up speed under overloads, and this is true even though the actual peak currents drawn from the line may be less than those for a NEMA C motor under the same load.

There are, however, certain times when a NEMA Design D motor should be used, and these can be summarized as follows:

(1) When power is supplied from an isolated lease generating plant having a small ratio of installed kilowatt capacity to load horsepower, making it extremely important to keep the current peak demands on the system to a minimum.

(2) Where a high pumping rate in strokes per minute is required, such as when a high water-to-oil ratio exists in the fluid, making it desirable to keep the power peaks down, particularly if an integrated demand charge is involved in the power contract.

(3) Whenever it is desirable to reduce the current peaks drawn on the line, such as when low-voltage conditions exist at the end of a long feeder run or when there is poor-voltage regulation on an overloaded system or on a transformer bank.

(4) Where, under poor-voltage-regulation conditions, there exist excessive line voltage drops during starting, or where a high torque-per-ampere characteristic is required to start under low-voltage conditions.

In summary, the characteristics of the NEMA Design C, 1200-rpm motor, its lower first cost, and its ready availability have made it entirely suitable for economic production of crude oil, and it is the type of motor most frequently selected. However, the smaller current peaks drawn by the NEMA Design D motor coupled with its higher torque-per-ampere starting characteristics give it a place for strong consideration, particularly under conditions as discussed above. Only additional field operating comparison tests on a comparable load and a power input basis (kilowatt-hours per barrel per day) can determine which type is best suited for cyclic oil-well pumping loads and which gives the operator the most for his money.

Refer to Figure 1 for additional comparative operating data on NEMA C and NEMA D types of motors.

TYPES OF ENCLOSURE AND INSULATION

In addition to being defined by starting torque and slip, a-c motors may also be classified by NEMA Standards according to enclosure, temperature rise, and types of insulation as follows:

(1a) Drip-proof, 40 C rise, Class A insulation, 1.15 service factor.

(1b) Drip-proof, 55 C* rise, Class B insulation, 1.15 service factor.

(2a) Splash-proof, 50 C rise, Class A insulation, 1.0 service factor.

(2b) Splash-proof, 70 C rise, Class B insulation, 1.0 service factor.

(3a) Totally enclosed, 55 C rise, Class A insulation, 1.0 service factor.

(3b) Totally enclosed, 75 C rise, Class B insulation, 1.0 service factor.

*There is no temperature rise specified in NEMA or ASA Standards for Class B insulation for open or drip-proof motors. However, a minimum of 20 C increase between Class A insulation and Class B insulation is allowed on all enclosures specified.

From the above it is noted that NEMA drip-proof motors carry a standard 15-per cent service factor, which specifies that the motor can be subjected to a 15-per cent continuous overload beyond its nameplate rating without suffering injurious heating. Neither splash-proof motors nor totally enclosed motors carry this 15-per cent service factor, and this would be a reason favoring the use of drip-proof motors wherever their use is feasible and where the motors are preferred over other types of enclosures. In passing, it might be noted that the above designated NEMA service factors do not apply to the NEMA Type D high-slip motor, which does not carry a guaranteed service factor even on the open or drip-proof, 40 C rise rating. This is due to the increased rotor heating and possible "hot spot" failures during overloads, as explained above.

A great deal of improvement in motor design has been made since motors were first adapted to oil-well pumping some twenty or twenty-five years ago. The modern NEMA-rated drip-proof motor has incorporated many improvements in insulation, material distribution, cooling effects, and types of bearings and greases that make it entirely suitable for outdoor use in most locales. In fact, the use of splash-proof-design motors is generally to be discouraged in most industrial applications today, and this is true for outdoor oil-well pumping. Modern drip-proof motors have a lower first cost, they are more readily available from stock, and they have proved superior in service over splash-proof motors, because they have a guaranteed service factor (overload capacity), whereas the splash-proof motor does not. The drip-proof motor with its closed-front end shield actually exceeds the NEMA requirements for splash-proof design on its air intake openings. This effectively prevents the direct entry of horizontal rain, snow, or blowing sand and rocks into the motor. Furthermore, with an unobstructed full flow of cooling air through the motor, there is less chance of burnout due to a pile-up of snow, sand, or other debris around the motor air intake and discharge openings, which possibility is actually aided rather than retarded by baffles or other restricted air openings necessary in the splash-proof design. Today, most manufacturers of electric motors will propose and recommend their closed-end drip-proof-design motor for outdoor use with the same service warranty as that for the splash-proof design.

In the matter of applying motors for use outdoors, some judgment and common sense must be used. Obviously, a totally enclosed motor should be considered for very adverse atmospheres, such as corrosive conditions in some strong sour gas fields, salt-water-laden air adjacent to the Gulf, and so on. Certainly, a totally enclosed explosion-proof motor should be used around tank batteries or other inflammable or explosive atmospheres. Again the point to remember is that both drip-proof and splash-proof motors have the outside air coming in contact with the motor windings, so that if the cooling air pulled through the motor contains abnormal amounts of salt, acids, chemicals, or fungus, these substances will be deposited on the motor windings whether a splash-proof motor or a drip-proof motor is employed. For such cases, the additional protection offered by a totally enclosed motor is justified cost-wise, and this type should be specified.

In addition to having improved mechanical design, modern drip-proof motors have improvements in materials and manufacturing processes. Blowholes and inconsistencies have been eliminated in the rotor using pressurized castings. This elimination has resulted in the reduction of "hot spots" in the motor and in better balance. Insulating materials and methods have been greatly improved by the use of many new inorganic or "Class B" synthetic or plastic materials such as Mylar* phase and slot-insulation and Alkanex ** enamel-wire insulation. These, along with better bearings and greases developed by bearing manufacturers and petroleum companies and lowered resistivity in copper, aluminum, and other conducting materials, have resulted in better motor design, better torques, higher full-load speeds, improved dielectric strength, and higher thermal capacity or overload ability. In addition, oil-well-pumping motors are generally equipped with standard industry accessories, including rodent screens, lifting eye-bolt, moisture-resisting impregnation on windings, and ball-bearings.

Today's modern drip-proof electric motor is tough, and if properly applied in accordance with its nameplate rating and design and if given proper protection against lightning surges, ground faults, prolonged overloads, and so on, it will give many years of trouble-free service with only a minimum of required maintenance and inspection service. Truly, electric motors are one of the most reliable and long-lived engineering developments of man.

TRIPLE-RATED MOTORS AND USE OF CAPACITORS

Triple-rated or multi-horsepower motors are delta-wound motors having 12 terminal leads brought out to the motor conduit box for reconnecting the winding from delta to wye-delta (or zig-zag) or to wye to give high-intermediate-low horsepower ratings, usually in the ratio of 10/7/4. Because of the large number of leads that must be brought out to the motor conduit box, triple-rated motors are more expensive than standard dual-voltage rated motors of the same high horsepower rating. Furthermore, they may not readily be available from stock, as are standard dual-voltage single-rated motors.

Triple-horsepower rated motors have been used in the past where the motor load at the well was expected to increase materially over a period of time as flow conditions of the well changed, for example, where water encroachment increased. This type of motor allows a low horsepower connection to be made initially in order to gain maximum power factor and efficiency in the sizing of the motor to the load. It also had an advantage when it was common practice for the power companies to make their demand charges for total horsepower load based on actual nameplate ratings connected.

Modern day practice, however, is to select a motor for the ultimate or final load conditions expected at the well and to install a capacitor of the proper size with the motor so selected. Not only is the first cost generally less expensive, but it also has the distinct advantage of no further costs for field reconnections, overload relay heater changes, or changes in fuse sizes that often have to be made at the motor or the controller once the installation has been made.

Since the capacitor sized for a particular motor will, in effect, supply the motor magnetizing and excitation current requirements (motor reactive current), the power factor of the motor is automatically corrected for all conditions of load on the motor from no-load to full-load. This results in a considerable reduction in line current, with resultant reduction in I^2R losses, and, therefore, in lowered power consumption and power costs (Refer to Figure 3). In addition, the capacitor will maintain higher voltage levels at the motor, thus giving better torques and improved operating

* Registered trademark of DuPont Company

** Registered trademark of General Electric Company

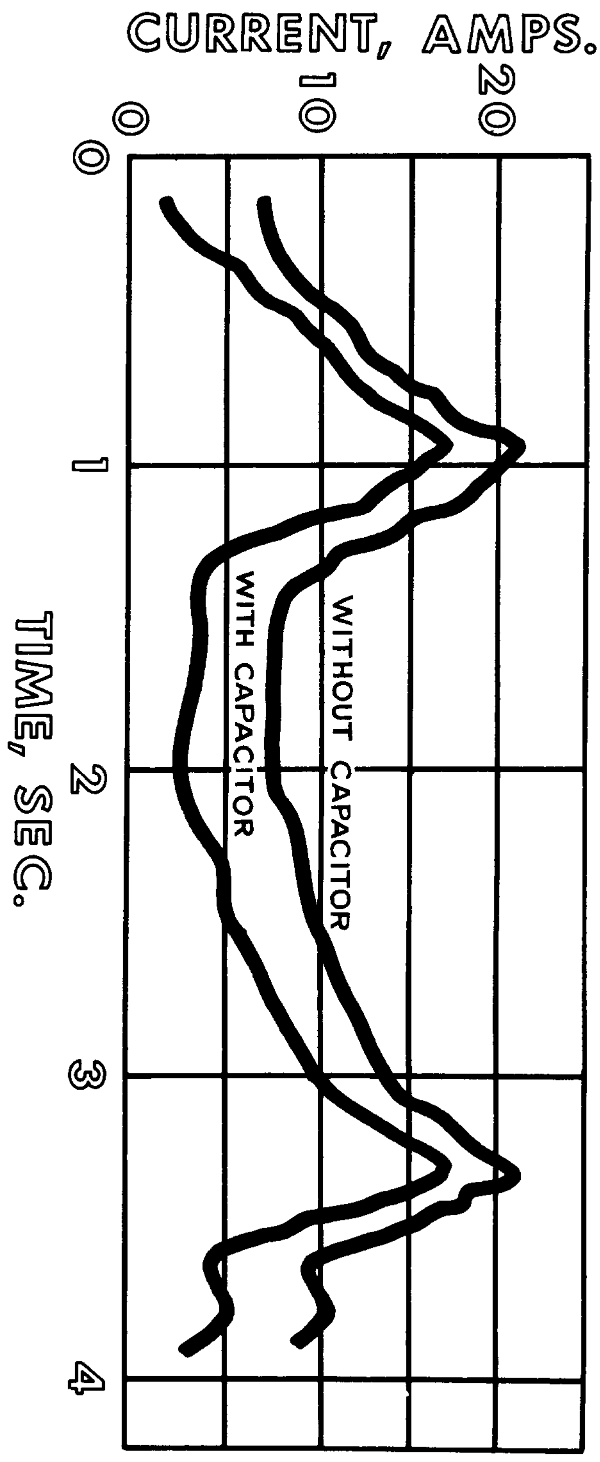


Figure 3. Actual Oscillograph of 10-horsepower Pumping-motor Installation, Showing the Line Current Drawn with and without Capacitor

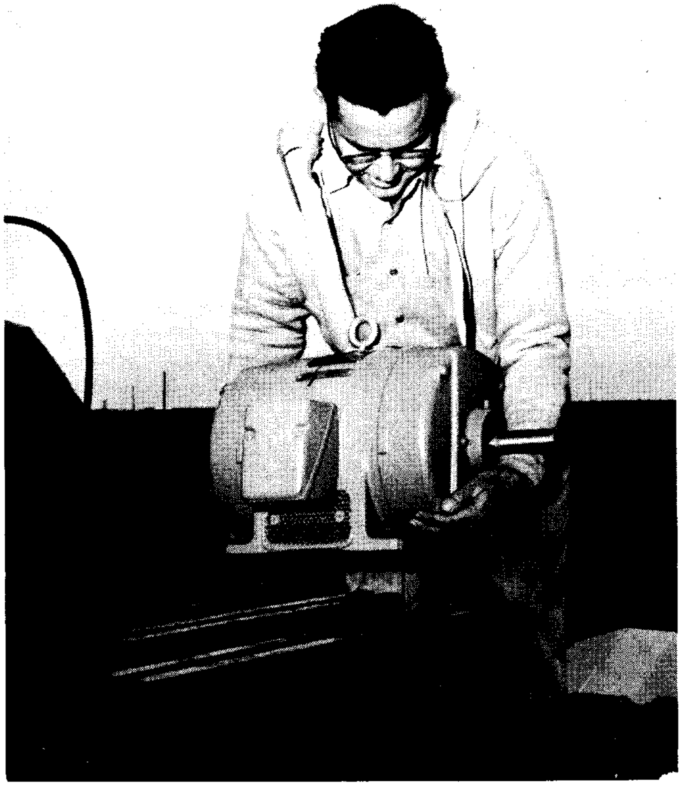
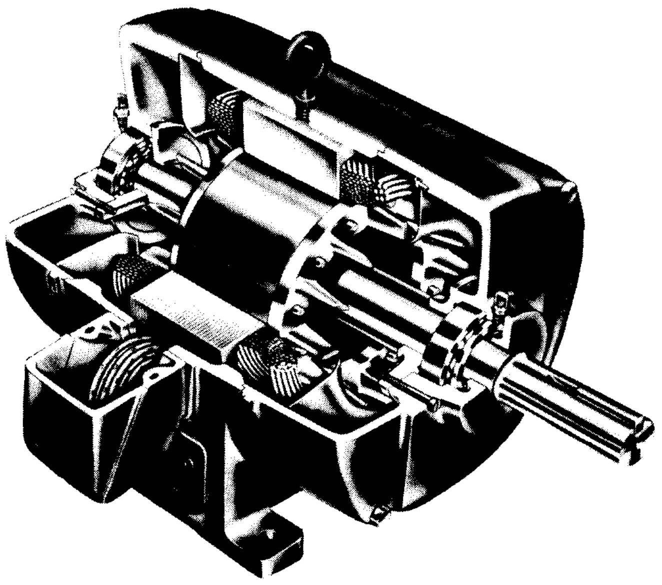
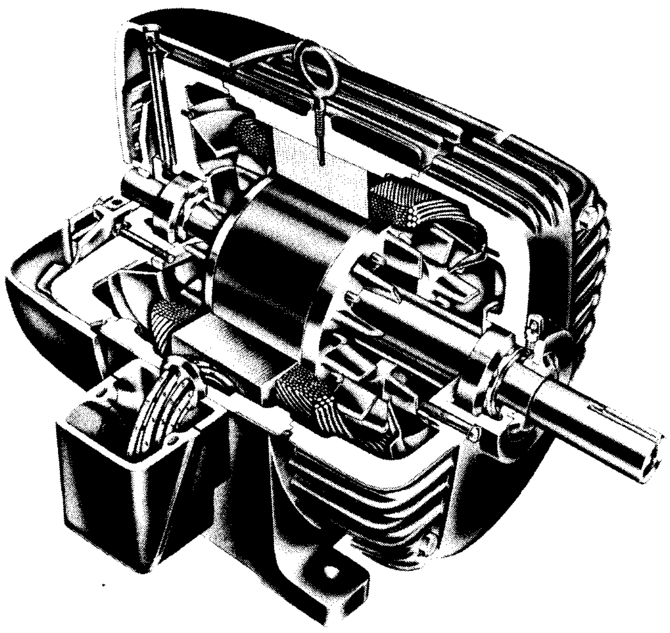


Figure 4. Modern Induction Oil-well-pumping Motor Incorporating Design Improvements and Accessories for Outdoor Use



A. Drip-proof



B. Totally Enclosed

Figure 5. Types of Motor Enclosures

characteristics for the motor. Therefore, it is recommended that, in general, capacitors be installed with oil-well-pumping motors, particularly if the motor is oversized with respect to the present load, if low voltage conditions exist at the motor terminals (on a long secondary feeder run, for example), or if a power factor clause is involved and enforced in the power contract. As a rule, capacitors are a worthwhile investment whether or not a power factor clause is involved, as savings in system losses alone usually will pay for the capacitor within two to four years. With an enforced power factor clause, the payout time for capacitors is usually six months to one year on typical oil leases. Capacitors generally are installed at the well location on the stub pole with the motor controller to be switched with the motor, as shown in Figure 6.

Figure 6. Usual Method of Installing a Capacitor on the Stub Pole with the Controller at the Well Location

To help prevent possible insulation failure or mechanical damage due to high transient excitation voltages, capacitors should not be applied in excess of the ratings shown in the application table, TABLE I. Also, it is recommended that

TABLE I. TABLE FOR SIZING CAPACITORS TO NEMA DESIGN C, 1200-RPM, 440-VOLT MOTORS

MOTOR HP	CAPACITOR KVAR
3	2
5	2 1/2
7 1/2	3 1/2
10	4
15	5 1/2
20	6 1/2
25	8
30	9
40	12
50	16

personnel not open or work on a controller for a motor equipped with a capacitor for several seconds after the motor has been switched off and that the capacitor and controller be properly grounded in accordance with recommended practice (See Grounding Practice below).

When the capacitor is switched with the motor, the proper amount of corrective load current will be applied automatically. This is preferable, generally speaking, to mounting the capacitors in the line where they would over-correct if substantial motor load were off the line, and also where they would require a separate disconnect switch.

Figure 7 shows that it is preferable to connect the capacitor in ahead of the overload relay in the controller. This connection allows the same sized overload relay heater elements to be used, whereas if the capacitor were connected at the motor terminals, the overload relay heaters would be too large and would give improper protection.

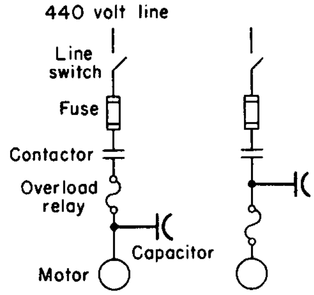


Figure 7. Methods of Installing Capacitors To Be Switched with the Motor for Automatic Power-factor Correction
A. At the Motor Terminals
B. Ahead of the Overload Relays (Preferred)

ELEVATED VOLTAGE MOTORS

Standard utilization or secondary voltages in the oil field are 220 or 440 volts a-c, with the vast preponderance being 440 volts, 3-wire, 3 phase, 60-cycle power. Some usage has been made of so-called "elevated voltages" between the highest low-voltage standard rating of 550 volts and the lowest high-voltage standard rating of 2300 volts. The intermediate voltages that have been used are 762 volts, 880 volts, and 1200 volts, all 3-phase, 60 cycles, the most popular being 762 volts wye, 4-wire, with solidly grounded neutral.

Basically, elevated voltages -- between 550 and 2300 volts -- are used in an attempt to gain maximum economic layout and operation. As is commonly known, the current required for a given horsepower load varies inversly with the voltage. Therefore, if we double the voltage -- say from 440 to 880 volts -- we theoretically halve the current. This not only allows us to use smaller sized current-carrying apparatus, conductor, control devices, switches, and so on, but also considerably reduces the system heating losses - I^2R losses. While the basic idea and objectives of elevated voltage systems for lease electrification are sound, there are some drawbacks, however, which should be considered.

First, recognized electrical standards such as National Electrical Manufacturers Association (NEMA), American Standards Association (ASA), and the Underwriters Laboratories (UL) of the National Board of Fire Underwriters all set the maximum rating of so-called "low-voltage equipment" at 600 volts a-c. When this rating is exceeded for utilization equipment, the recognized and designed insulation level rating of the equipment is exceeded, and, while the equipment in question may not fail if this is done, there is some risk in exceeding the guarantees and design capabilities of the equipment. In the case of a claim for failure or damage, this may conceivably be a source of trouble in conflicting with local electrical codes, insurance regulations, and other requirements.

Another point to be considered is the first cost of the equipment. While it is true that certain system components such as conductor may be reduced in size and therefore may be less costly, other items such as motors and controllers are increased in price because of the extra insulation required, the wide-pole spacing, and other factors. Thus, the economics of an elevated voltage system must be studied carefully to ascertain what overall system savings, if any, can be realized and whether such savings, even if evaluated out, are worth the deviation from the standard in terms of usual longer shipment, ready availability of parts, need for extra personnel training in "hot-line" techniques, and so on. Although 762-volt distribution is probably the economic choice for long, irregularly shaped leases- - particularly where wide well spacing and large sized pumping motors are involved -- it should be emphasized that in most cases an economical standard 480-volt, 3-wire distribution system can be designed, minimizing system losses, by the proper selection and sizing of transformers to the load (usually 3-phase, self-protected-type transformers in 15-, 30-, and 45-kva sizes) and a judicious use of capacitors to improve the system power factor and to keep the system losses to a minimum. (See capacitor discussion above).

As stated above, 762-volt motors and control are generally more expensive than standard 440-volt equipment. Normally the 762-voltage level is derived from the wye of 440 volts, and it is therefore very necessary to ground the mid-point of the wye solidly, so that phase-to-ground voltages cannot exceed 440 volts. In this manner, nominal 600-volt insulation motors can be utilized, although a higher price may still be justified for the special winding connections that must be brought out to the motor conduit box.

Since 880-volt levels cannot be derived from standard 440-volt equipment, special high-voltage insulation is normally required at a corresponding high-voltage price increase. Standard practice is not to use 600-volt insulated apparatus of any kind at voltages above 762 wye.

SINGLE-PHASE MOTORS

In some areas a 3-phase power supply is not available, and the producer must operate from a single-phase a-c power source. Compared to standard 3-phase motors, single-phase motors cost more initially, are limited in horsepower sizes available, have somewhat lower efficiencies, and require oversized and more expensive control. Therefore, if possible, three-phase motors should be used in preference to single-phase motors.

Single-phase motors are available up through about 7 1/2 hp at 1800 rpm synchronous speed, either 115 or 230 volts. Larger single-phase-motor installations have been made using phase-converters, either static or rotary type, whereby single-phase power is converted into 3-phase power. This is accomplished either by splitting one line of the single-phase power through a capacitor circuit to give a phase displacement or an offset voltage, or by generating a 3-phase output from a single-phase input to a rotary converter. In either case, an unbalanced voltage condition results on the 3-phase converted power, resulting in possible high currents and excessive heating of the 3-phase motor applied or connected to this source. Also, the cost is high and the efficiency is poor for phase-converting equipment, and this would further discourage the use of this type of equipment. Often, 3-phase motors of the same horsepower rating as that of the phase-converting equipment are applied, resulting in motor burnouts or failures from overload and unbalanced voltage. Normally a 3-phase motor of only about 60 per cent of the phase-converter rating can successfully be applied to this type of equipment.

There are several types of single-phase motors, such as repulsion start-induction run, capacitor start-induction run, and capacitor start-capacitor run. For high accelerating torque such as is required for oil-well pumping, a high-starting torque motor is required. This generally means a capacitor start-induction run type of motor. Typical speed-torques curves of single-phase motors are shown in Figure 8.

Like 3-phase motors, single-phase motors can be obtained in either drip-proof, splash-proof, or totally enclosed construction, and again splash-proof is seldom, if ever, required. Single-phase motors are NEMA-rated in regard to frame sizes, service factor (drip-proof only), and torque and current characteristics. Unlike 3-phase motors, standard operating voltages are either 115 or 230 volts, single-phase, 60 cycles.

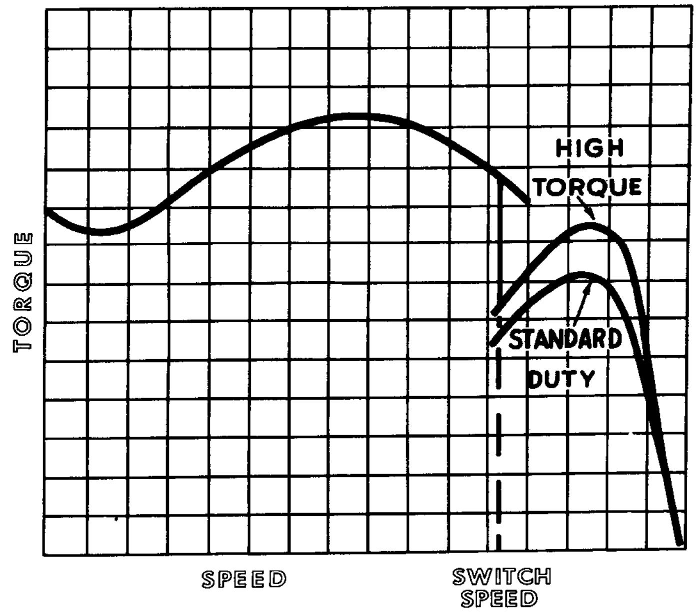


Figure 8. Typical Speed-torque Curves for Single-phase Motors
A. Standard Duty
B. High-torque

PROPER GROUNDING AND LIGHTNING PROTECTION

This discussion would not be complete without some comment on the matter of motor grounding and lightning protection, since probably more motors fail in the oil field from improper grounding than from any other one cause. A lightning arrester will not give reliable surge protection without a good ground. As shown in Figure 9, the frame of the motor also should be grounded, connected in to a common ground wire to the secondary of the lightning arrester mounted in the controller, to the case of the controller, and to the ground lead of the capacitor, if used. As shown in the figure, this common ground should be grounded to the controller by means of a ground rod driven a minimum of 12 inches below grade and also to the well casing, preferably by being solidly welded on. In dry areas, the West Texas-New Mexico area in particular, grounding to ground rods, to butt wraps on poles, or to surface pipe lines cannot be depended upon to provide a safe and reliable ground. Action field data indicate that many operators have experienced a drastic reduction -- as much as 65 per cent -- in motor failures after common grounding to the well casing had been adopted. For proper grounding, no wire smaller than No. 6 bare copper wire and no rods smaller than 8 ft by 5/8 in. approved non-ferrous ground rods should be used, except in close proximity to the well casing, perhaps within 25 feet. Here it may be advisable to use galvanized steel ground rods to minimize the possibility of electrolytic corrosion.

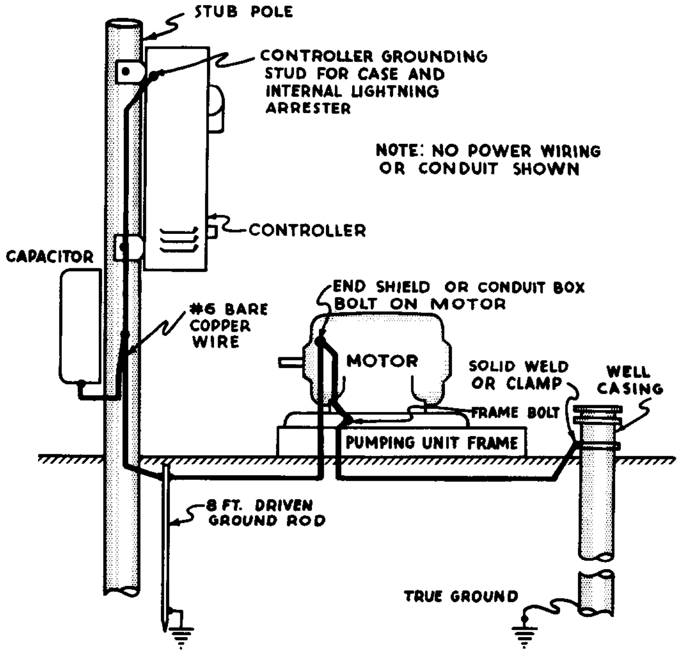


Figure 9. Recommended Method of Grounding, Showing Common Ground

CALCULATION OF MOTOR HORSEPOWER

Various formulae are used in the calculation of motor horsepower rating required to pump a certain well. They are all essentially based on a calculation of theoretical horsepower consisting of hydraulic horsepower (production and lift) and friction horsepower (weight of rod string and pumping speed). This theoretical horsepower must be factored to account for mechanical efficiency of the rotating parts of the rig and for motor heating losses. A typical formula for the calculation of well horsepower requirements is

$$\text{Nameplate Horsepower} = \left(\frac{BDG}{556} + \frac{WSL}{1{,}6000{,}000}\right) K,$$

where

B = Barrels per hour
D = Depth of well in feet
G = Specific gravity of fluid
W = Weight of rod string in pounds
S = Strokes per minute
L = Length of stroke in inches
K = Efficiency and motor heating factor (Usually in the range of 1.25 to 1.56)

The subject of the motor heating factor or the cyclic load factor is interesting and also one on which considerable difference of opinion exists. It is generally agreed that an induction motor subjected to a cyclic load or duty cycle will have greater induced heat losses than a motor operating with a steady state load of the same average kilowatt input or rms current. Therefore, in the safe sizing of a motor to a cyclic load such as oil-well pumping, a motor de-rating or "cyclic load" factor should be used to select the proper size of motor. This motor cyclic load factor is normally combined with the motor mechanical efficiency (usually assumed to be about 90%) to give a multiplying factor for selecting the motor, as in the formula above.

Since open or drip-proof motors have a rated service factor of 1.15 (except for the NEMA Design D type), a smaller cyclic load factor can be used for drip-proof motors than can be used for the splash-proof or the totally enclosed designs. A conservative value of K factor, including mechanical efficiency and motor heating, appears to be 1.34 for drip-proof motors and 1.54 for totally enclosed motors, although other factors are also used by other motors.

It should be noted in passing that Class B insulated motors inherently have a higher thermal capacity than Class A insulated motors have (see NEMA Heating Rating Chart). This would certainly imply that a larger service factor and a smaller de-rating factor could be used for Class B motors. However, it must be kept in mind that both "service factor" and common usage of "cyclic load factor" infer a higher or a smaller horsepower rating, respectively, and that horsepower rating depends upon both torques and load or thermal capacity. Since as stated previously, motors for beam-pumping duty are selected on starting torque requirements as well as on running characteristics, specifying a smaller horsepower-rating motor based on higher thermal capacity alone could conceivably result in a motor with too small a starting torque characteristic. Therefore, some care and experienced judgment must be exercised in the selection of motor rating based on increased thermal capacity (overload ability) alone, although certainly Class B insulated motors rated 55 C rise with a permissible 70 C rise certainly do have considerable thermal design margin available for extra heating - either load or ambient or both.

The load on an oil-well-pumping motor can be accurately measured by means of an indicating (or hook-on) volt-ammeter, a watthour meter, and a thermal ammeter. The hook-on volt-ammeter is used to ascertain line-to-line voltage on all three phases. These should be closely in balance on all three phases (within 2 or 3 percent) and should not be outside the range of plus or minus 10% of nameplate rated voltage. If they are above or below this voltage range, poor motor performance will result. High voltage can usually be corrected for by the taps on the transformer serving the load. Low voltage can usually be corrected for by installing capacitors at the motor (see discussion above), by changing transformer taps, or by adding additional transformer or conductor capacity to serve the load.

The instantaneous ammeter reading (hook-on type) can be used to balance the well being tested. There are two current peaks drawn from the line: one when the rod string is lifted and the other when the counterweight is lifted. The two peaks should be equal for most favorable duty on the motor and this equality can usually be accomplished by shifting the counterweights as required. (Note: It is recognized that there is no assurance that a well properly balanced will not become unbalanced as well flow conditions and other factors change. Therefore, the hook-on volt-ammeter should be used periodically by the pumper to check the well balance and to make the necessary corrections in counterweighting.)

As stated above, the true "heating" or rms-current input to a motor on cyclic duty such as oil-well pumping results from both the load current and the duty cycle heating. This current cannot be measured by an indicating ammeter, which would show only instanteous peaks and not true heating or rms-current input to the motor. True thermal ampere input must be measured with a special thermal ammeter, which is available for this purpose. It is important to allow a "warm-up" and equalizing time of at least 45 minutes before actual readings are made with a thermal ammeter. The watthour meter measures killowatt hours input to the motor. However, for short test runs, the disc of the watthour meter can be clocked for actual revolutions per minute, and this value can be multiplied by the meter constant K, found stamped on the meter nameplate to obtain kilowatt input from the formula:

$$\text{KW input} = \frac{\text{K X rpm X 60 min.}}{1000}$$

Then, by knowing the KW input, the actual load horsepower can be calculated from

$$\text{HP} = \frac{\text{KW input}}{.746}$$

and the power factor from

$$\text{P.F.} = \frac{\text{KW input}}{1.73 \text{ X thermal amps X line volts}}$$

Obviously, the horsepower calculated from the above should agree with the nameplate horsepower of the motor, within the service factor range at least, and the thermal ampere input observed should agree with the motor full-load current rating.

Of course, a tachometer can be used to check actual full-load speed on the motor, although this will vary with the slip.

As stated previously, comparative test data on different types of motors should be made on a kilowatt-hour-per-barrel-per hour (or day) basis and not just on a kilowatt-hour-per-barrel basis, in order to draw valid conclusions on true costs and production.

INSPECTION AND MAINTENANCE

The modern grease-lubricated ball-bearing motor requires very little attention and maintenance. Basically, the motor has only one moving part, the rotor and connected shaft, and therefore it has no appreciable wear or parts to be replaced. Two types of bearings are used in oil-well pumping motors, the pre-lubricated sealed bearing and re-greasable-type bearing. The sealed bearing cannot be re-greased unless the end bell of the motor is pulled necessitating the removal of the motor from service for some length of time; whereas the re-greasable bearing can have fresh grease added without disassembly or prolonged shutdown being required.

With the modern synthesized ball-bearing greases now used, motor bearings should not have to be re-greased for periods of three to five years, if a motor is properly aligned and is not subjected to excessive shaft stresses, such as those from an improper V-belt drive. (See Belting Table, TABLE II.) With the larger grease reservoir and the longer closely-machined shaft seals, the re-greasable-type bearing should last a great deal longer in service without requiring re-greasing than the so-called sealed-type bearings will. In order to discourage excessive re-greasing, motors with re-greasable bearings are normally shipped with pipe plugs installed in the bearing openings, necessitating the installation of a grease fitting before new grease is added to the bearing.

The proper procedure for adding new grease is as follows: First, shut down the motor as a safety precaution to prevent possible injury to a man working around the shaft or the coupling. Second, replace the pipe plug with a grease fitting in the top of the bearing and remove the purge plug from the bottom of the bearing. Third, add new ball-bearing grease as recommended by the motor manufacturer until new grease is expelled from the purge opening in the bottom of the bearing. Fourth, allow the motor to run for about five minutes. Sixth, shut down the motor and replace the purge plug and the grease fitting with a pipe plug in the bearing housing.

It is recommended that oil-well-pumping motors be checked at least once every six months by a competent pumper or electrician to see that the motor is operating properly, without excessive noise, vibration, or heat, that the coupling and V-belt drive is in good running condition, and that the rodent screens, the ground wire connection, and the ventilating passages of the motor are all satisfactory. An ounce of prevention in good periodic maintenance is certainly worth a pound of cure in preventing costly downtime due to motor burnouts or failures.

CONCLUSION

Electric motors have proved themselves admirably suited to oil-well-pumping duty. Their many advantages, both economical and operational, support the further extension of their use as the modern prime mover for oil-producing machinery.

Hp	Speed, Rpm Synchronous	Bearings	Suitable for—
40	2400	§Sleeve or ball	V-belt
50	1800, 1500	§Sleeve or ball	V-belt
60	1800, 1500	§Sleeve or ball	V-belt
75	1800, 1500	Ball	V-belt
100	1800, 1500	Ball	V-belt
	1200, 1000	§Sleeve or ball	V-belt
125	1200, 1000	Ball	V-belt
150	1200, 1000	Ball	V-belt
	900	§Sleeve or ball	‡V-belt
	800	§Sleeve or ball	V-belt
200	900, 800, 750	§Sleeve or ball	V-belt
250	720, 600	§Sleeve or ball	V-belt
	514, 500, 480	§Sleeve or ball	‡V-belt
300	720, 600, 514, 500	§Sleeve or ball	V-belt

‡ Also suitable for flat-belt drive with special pulleys, sleeve- or ball-bearing.
§ Sleeve bearing applies to open motors only.

TABLE II. RECOMMENDED BELTING TABLE FOR A-C INDUCTION MOTORS

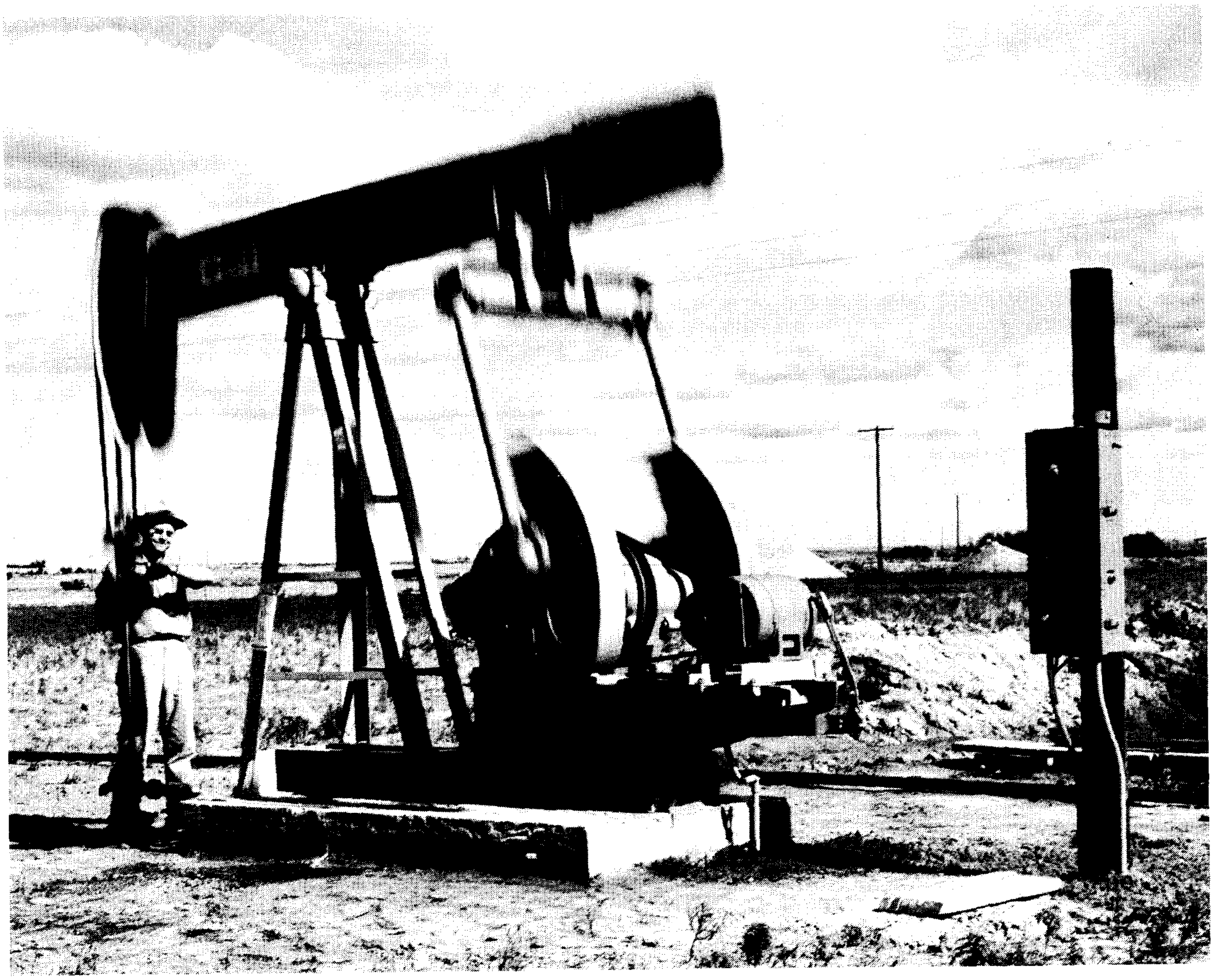


Figure 10. Typical Electrified Beam-pumping Installation Showing Neat, Compact Arrangement of Motor, Controller, and Capacitor at the Pumping Unit