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# TABLE OF CONTENTS

## Drilling Motor Introduction

Drilling Motor Design ................................................................. 2
- Top Sub ..................................................................................... 2
- Safety Catch ............................................................................. 2
- Power Section .......................................................................... 3
  - Power Section Cross Sections ........................................... 3
  - Power Section Elastomers .................................................. 3
- Coupling Section ...................................................................... 4
- Bearing Section ....................................................................... 4
  - Near Bit Stabilizers ............................................................ 4
- Bit Box ..................................................................................... 5

## Drilling Motor Applications

- Performance Drilling (straight-hole) Applications ............... 6
- Directional Drilling (steerable) Applications ....................... 7
  - Offset Stabilization ............................................................. 7
  - Adjustable Bend Housing .................................................. 7
- Air/Foam Drilling Applications ............................................. 8
  - Air Volume Calculations .................................................... 8
  - Air-Foam Volume Calculations ......................................... 8
  - Lubricant Recommendations ............................................ 8
  - Dump Valves ....................................................................... 9
  - Flapper Valve ..................................................................... 9
  - Operational Recommendations ........................................ 9
- Coring Applications ............................................................... 9
- Casing Drill Applications ........................................................ 9
- Sacrificial BHA Applications ................................................ 10
- High-Temperature Applications .......................................... 10
  - Guidelines for High Temperature Applications ............... 10
- Workover / Remedial Applications ...................................... 11
- Coil Tubing Applications ....................................................... 11
  - Pressure Drop Through The Coil Tubing ......................... 11
  - Torsional Yield of the Coil Tubing .................................... 11
  - Buckling of the Coil Tubing .............................................. 11
  - Coil Tubing Depth Control ................................................. 11
- Short Radius Applications ..................................................... 12
- High Flow Rate Applications .............................................. 12
- Other Applications .................................................................. 12
The drilling motor (see Figure 1) is a hydraulically actuated device that converts hydraulic energy into mechanical energy. The purpose of the motor is to generate the rotational speed (RPM) and torque needed to operate the drill bit. The drilling motor takes its energy from a succession of isolated working fluid volumes that force their way, under pressure, through the motor by displacing or deforming the spaces in which they are confined.

The downhole drilling motor has undergone substantial changes and improvements over the past 50 years making it a proven and reliable tool even in the most rigorous of drilling environments. Today, most all drilling applications have become a planned routine operation. The technological advances in downhole drilling tools have helped to lower the cost of drilling a well. With the development of durable and reliable downhole tools, the odds of bringing in a successful well have been improved significantly from years past. The Toro Downhole Tools (Toro) line of drilling motors is well suited for the drilling applications of today.

The primary focus of this handbook is to assist in explaining drilling applications, motor selection, and operations. This handbook includes information on the following topics:

- Drilling Motor Design
- Drilling Motor Applications
- Drilling Motor Operation
- Troubleshooting Charts
- Drilling Motor Specifications

By providing comprehensive motor performance curves and operational data, this handbook should help to provide effective solutions to your drilling challenges. Please read this handbook in its entirety. As always, the Toro technical staff is readily available to provide the information you may need regarding the operation of the drilling motor.
**DRILLING MOTOR DESIGN**

The Toro motor is a positive-displacement motor (PDM). As drilling fluid is pumped down the drill-string, the fluid flows through the cavities in the power section. The fluid pressure reacts against the lobes of the rotor and the walls of the stator causing the rotor to rotate. Torque is then transmitted through the coupling section, bearing section and down to the drill bit.

The Toro drilling motor is comprised of 6 basic components:

- Top Sub
- Safety catch
- Power-section
- Coupling section
- Bearing section
- Bit Box

Figure 2 is a cutaway view of the entire motor with these basic components identified.

**Top Sub**

A top sub, or crossover sub as it is sometimes called, is used to attach the motor to the drill-string. The crossover sub typically has a standard API box connection that connects to the drill-string and a proprietary pin connection that connects to the motor. Top subs may also be designed with a float bore for those applications that may require float valve.

Optionally, a dump valve sub can be used in place of the top sub. The dump valve sub has the same function as a top sub, but instead contains an internal bypass valve that enables the fluid in the drill-string to drain out when the string is pulled out of the hole.

**Safety Catch**

The safety catch provides the ability to remove the motor from the well in the unlikely case of a motor connection failure. The safety catch is an essential part of the motor, especially when tool joints are exposed to excessive loads from extreme drilling applications. This component helps to prevent a fishing operation on a broken motor in the well. The safety catch is available either as a one-piece or a two-piece design.
The power section is the part of the motor that converts hydraulic energy into mechanical energy, resulting in drill-bit rotation. The power section consists of two parts, the rotor and the stator (see Figure 3). When assembled, these two components form a continuous seal along their contact points.

The rotor is a high carbon alloy steel bar with a machined helical (multi-lobed) pattern. It is then chromed plated to reduce wear and corrosion. The rotor can also be bored to allow fluid to bypass the power section in order to extend the flow rate capability of the motor.

The stator is a length of tubular steel called a ‘can’ that is lined with a rubber compound called the ‘elastomer’. The elastomer is formed with a helical (multi-lobed) pattern similar to that of the rotor. The difference between the stator and the rotor is that the stator will have one more ‘lobe’ than the rotor. Since the stator always has one more lobe than the rotor, the ratio of rotor lobes (X) to the stator lobes (X+1) is usually designated as (X):(X+1). For example: 1:2, 3:4, 5:6, 9:10, etc.

Power Section Cross-Sections

Referencing the image to your right, the power section cross-section (or profile) shows different “lobed” rotors inside their corresponding stator. The power section profiles are designed with these different ratios to allow for specific motor speeds and torques. Motor speed can be easily changed just by changing the rotor/stator lobe ratio. Generally, the higher the number of rotor/stator lobes yields a power section with a slower speed and higher torque. Fewer rotor/stator lobes yields a power section with a higher speed and lower torque.

Power Section Elastomers

Toro offers two types of stator elastomers: A High Performance (HP) compound and a High Temperature (HT) compound. Toro’s HP elastomer is a high durometer (hard rubber) formulation. It has excellent mechanical properties and good resistance to aromatics for maximum performance. The HP elastomer is formulated for use in high temperature applications.
**Coupling Section**

The coupling section comprises of two components: the internal coupling and the external coupling housing.

The coupling (see Figure 4) attaches the lower end of the rotor to the upper end of the drive shaft. The coupling transmits the rotational speed and torque from the rotor to the drive shaft. In addition, the coupling converts the eccentric (side-to-side) motion of the rotor to the concentric (in-line) motion of the drive shaft. The coupling is precision machined for smooth articulation and minimal wear while providing optimum torque to the drill bit.

The coupling housing encases the coupling within the motor. The coupling housing provides an optimum location for the placement of a bend in the motor. Adding a bend to the coupling housing makes the motor a steerable tool. Coupling housings can have either a single fixed bend angle or a series of adjustable bend angles. Housings with adjustable bend angles typically have a range from either 0 — 3° or 0 — 4° and are easily adjustable at the rig site.

**Bearing Section**

The bearing section makes up the lower half of the motor. It is comprised of a drive shaft that is supported by a series of radial and thrust bearings. The bearing section is what controls the mechanical energy supplied by the power section to the drive shaft. The drive shaft transfers this energy to the drill bit through the bit box. Drilling parameters, such as weight on bit (WOB), circulation rate, and bit differential pressure directly affect the bearing section.
The Toro bearing section is an open bearing design (i.e. the bearings are lubricated by the drilling fluid). Toro uses a stacked multiple ball-and-race design for the thrust bearings (see Figure 5). An open bearing system offers the advantage of allowing higher differential pressures across the drill bit over a traditional sealed bearing arrangement.

The thrust bearings support the downward force resulting from the weight on the drill bit (WOB) and the loads from the combined hydrostatic thrust and weight from the internal motor components.

Radial bearings support the side loads on the drive shaft and help regulate the flow of drilling fluid through the bearing assembly. Some of the drilling fluid is diverted to cool and lubricate the bearings. Toro uses radial bearings with tungsten carbide tile inserts which are imbedded in a tungsten carbide matrix for maximum wear resistance from side loads.

Near Bit Stabilizers:

Toro motors are also available with the ability to add a near bit stabilizer onto the outer bearing housing. Threads are machined on the bearing housing outer diameter to allow a screw-on stabilizer to be installed just above the bit. This thread arrangement allows for easy stabilizer changes in the field. Figure 7 shows a steerable motor with a near bit stabilizer.

Bit Box

The drill bit attaches to the motor at the bit box. For added strength and durability, the bit box is integrated to the drive shaft. Toro motors incorporate a safety device that connects the lower radial bearing onto the upper half of the bit box. This helps to provide additional security against leaving the bit in the hole in the unlikely event the drive shaft were to break internally. The bit box typically is machined with an API Regular box (internal) thread.
Operators, drilling contractors, service, and tool supply companies have worked diligently over the years to improve drilling technology. Their common goal has been to reach their drilling targets, quickly, efficiently, and at a reasonable cost. Over the years, these drilling targets have become more complex and difficult to reach. Delivering horsepower directly to the bit has become increasingly important. To date, the best way to achieve RPM and torque to the bit, independent of rotating the drill-string, is with a downhole drilling motor.

The need for motors in different applications has led to the design of several types of downhole motors. These motors are specifically configured to the drilling application for which they are needed. Typical drilling applications and their corresponding motors are presented in this section.

**Performance Drilling (straight-hole) Applications**

A Toro drilling motor can be used for performance drilling applications. By turning the drill bit several times faster than the drill-string, a motor can effectively provide an increased rate of penetration (ROP). Since the motor is providing the rotation to the drill bit, rotational speed (RPM) of the drill-string can be significantly reduced from standard rotary drilling speeds.

A drilling motor can also provide angle control during adverse conditions commonly found in many vertical applications. Typically, a motor with an adjustable bend housing (ABH) can be used in conjunction with single-shot-survey orientation instrumentation. This arrangement is effective for course corrections, angle control, kickoff, and sidetracking.

Compared to rotary drilling technology, downhole motors offer considerable benefits that must be taken into consideration in the economical analysis between drilling with and drilling without a motor. Benefits from drilling with a motor include:

- Faster rate of penetration (ROP)
- Reduced drilling times
- Reduced drill-string rotational speed (RPM)
- Less wear and fatigue of drill-string connections
- Less drill-string torque
- Reduced number of BHA trips in and out of the hole
- Straighter holes, providing faster and smoother casing setting
**Directional Drilling (steerable) Applications**

When run with a bent coupling housing, a downhole motor can be steered with single shot, wireline steering tools, or with downhole telemetry tools (MWD). The drilling motor provides continuous bit rotation, while selective rotation of the drill-string controls well bore trajectory. Applications that are technically and economically feasible with these systems include:

- Directional wells with single or multiple targets.
- Horizontal wells with narrow production zones.
- Vertical wells with crooked hole tendencies.

Toro currently offers two basic types of steerable motors: Offset Stabilization and Adjustable Bend Housing.

**Offset Stabilization**

Offset stabilization consist of a straight downhole motor fitted with an eccentric stabilizer. The eccentric stabilizer helps to laterally load the bit to affect the desired change in the direction. Some of its advantages include:

- Faster rates of penetration
- Smoother well curvatures
- Better control of the gauge of the hole

**Adjustable Bend Housing**

Motors with Adjustable Bend Housings (ABH) utilize a bend in the coupling housing. This is the most common type of steerable motor. The bend in the motor creates an offset in the axis of the bit relative to the axis of the hole. This bend is generally an angle between 0 and 3 degrees. Some of the advantages of using an ABH are:

- Real time directional control.
- Changing the ABH angle changes the well curvature
- Changing the bit angle changes drilling direction.
- Helps to keep the bit centered in the hole rather than rely on side-cutting action

A Toro steerable motor is an excellent choice for the demands imposed by directional drilling. Our steerable motors can be matched with various types of PDC, roller cone, or diamond bits. A typical steerable BHA with an adjustable bend housing is shown in Figure 7.
Air / Foam Drilling Applications

The Toro drilling motor can be used successfully for drilling purposes where air or foam is the circulating media. Because air/foam is a compressible media, the motor will operate and behave differently than normal. In addition, the pressure required with air or foam drilling is approximately twice the pressure required when standard drilling fluids are used. When operated on air, the drilling motor will have the following attributes:

♦ Will require higher pressure to operate (2X over drilling with a liquid)
♦ Will require higher flow rates (3X to 4X the flow rate of a liquid)
♦ Will run at higher RPMs
♦ Be more weight sensitive
♦ Stall at a lower pressure (less operating torque)
♦ Require less WOB to drill

Air Volume Calculation

All Toro motor specifications are based using a liquid volume flow rate (gallons per minute or GPM). To run the motor on air, the liquid volume flow rate must be converted to an air volume flow rate (cubic feet per minute or CFM). Use the following calculation to convert the motor flow rate from GPM to CFM:

\[ 1 \text{ GPM of fluid equals approximately } 4.25 \text{ CFM of air} \]

For example: \[ 400 \text{ GPM } \times 4.25 = 1,700 \text{ CFM (estimated)} \]

Air-Foam Volume Calculation

When using air with foam as a the circulating media, it is recommended that 3 ½ to 4 ½ CFM of air plus 10 to 100 GPM of injected foam be used.

Lubricant Recommendations

Running the motor in air without adequate lubrication will result in severe damage to the internal components. It is extremely important that a minimal amount of lubricant (consistent with formation capability, available equipment, etc.) be used. Below are a list of lubricants that can be used successfully in a motor running on air.

♦ Liquid soap — 0.5 to 1 gal/bbl of water
♦ Graphite — 4 to 6 lb/bbl of water
♦ Gel — 0.5 to 1 lb/bbl of water
♦ Oil — 0.1 to 0.6 gal/hr

Lubricants should always be injected downstream of the air compressors to prevent contamination.
**Dump Valve**

A motor dump valve should not be used when running on air/foam. If the motor is equipped with a dump valve, replace it with a crossover sub.

**Flapper Valve**

A flapper valve should be used to control bleed-off and when running wireline tools. Float valves should be placed immediately above the motor and on the surface to avoid back flow. It is also recommended that drill-string float valves can be installed every 1,000 ft for additional control.

**Operational Recommendations**

Before turning on the air compressor, set the motor on bottom. Apply a light weight on the bit while pumping in the air. Do not allow the tool to run off-bottom. If the motor is allowed to run freely off-bottom, the rotational speed of the bit will rapidly increase as the compressed air expands through the motor. Excessive RPMs can damage the motor. Such damage may include:

- Stator damage due to friction/heat
- Thrust bearing damage due to friction/heat
- Thrust bearing damage if weight is applied suddenly to the bit

Turn off the air compressor before picking up off-bottom. Allow the air pressure to bleed off first until the standpipe pressure is equal to the annulus pressure.

**Coring Applications**

A downhole motor is an ideal tool to use for coring applications. Slow-speed motors are especially suited for coring because of their high torque capability. Properly configured motors can drive core barrels up to 90 ft in length.

To use a motor in a coring application, a special drop-ball sub is needed between the motor and the core barrel. An increase in flow rate causes a steel ball to drop from this special sub, thereby redirecting fluid flow to the annulus between the inner tube and outer tube of the core barrel for the coring operation.

**Casing Drill Applications**

Simultaneous drilling and running large-diameter surface casing has saved many hours of rig time in both land and offshore operations. This operation is performed with a casing drill, which is an assembly consisting of: a drill bit, a Toro motor, a jet sub, drill collars, and crossover subs. All of these items are suspended by a running tool that is latched into a preassembled conductor pipe. When the desired depth is reached, the drilling assembly is unlatched and tripped, leaving the conductor pipe in place. The casing-drill tool and technique are typically used in unconsolidated alluvial formations.
**Sacrificial BHA Applications**

Another application similar to a casing drill operation includes the use of a drilling motor on a sacrificial BHA. The motor is run in the hole at the end of the last casing string. The purpose for the motor is to drill out any collapsed areas of the hole while running in the casing string. The motor is then cemented in the hole along with the casing. Toro offers an economically designed motor specific for sacrificial BHA operations.

**High Temperature Applications**

Most applications have bottom hole temperatures below 250°F (120°C). Toro motors (with standard stator elastomer) are designed for such applications. Applications with bottom hole temperatures above 250°F are considered high temperature applications. A Toro motor, with the available high performance elastomer, is capable in running in temperatures up to 350°F (175°C). Appropriately equipped, a Toro drilling motor can be made to operate at even higher temperatures, though only for a limited time. For most high temperature applications, a reduced motor life should be expected.

It is important to note that drilling motor power sections are designed with a certain interference fit between the rotor and stator. For the drilling motor to operate efficiently, the interference fit must remain within a specified range. A high bottom hole temperature can cause the elastomer in the stator to swell, increasing the interference fit. A high interference fit can result in damage to the stator and reduce motor operating life. It is therefore very important for a drilling motor to have an appropriate interference fit to use in a high temperature drilling operation.

**Guidelines for High Temperature Applications**

For a bottom hole circulating temperature (BHCT) exceeding 250°F (120°C), the following guidelines are recommended:

- Contact a Toro motor representative to prepare a motor with a suitable elastomer and interference fit for use in a high temperature application.
- Stage the motor in the hole:
  - Upon reaching a depth where temperature is estimated to be approximately 250°F (120°C) or higher, stop and circulate cool drilling fluid for a few minutes to lower the temperature of the BHA.
  - Continue this process in stages of 500 to 1,000 ft until reaching operating depth.
- Non-circulating periods (surveying, orienting, etc.) must be as short and as infrequent as possible.
**Workover / Remedial Applications**

Workover and remedial drilling problems can be solved easily with a Toro drilling motor. The motor can be used for:

- Drilling through sand bridges and cement plugs
- Removal of paraffin buildup
- Window milling
- Horizontal drilling

**Coiled Tubing Applications**

Toro motors can be used in many different coiled tubing applications. Remedial, production, and drilling jobs have all been successfully executed with a downhole drilling motor. The following are important items to consider when planning a motor run on coiled tubing:

**Pressure Drop through The Coil Tubing**

Unlike conventional drilling operations, the length of coil tubing, spooled or unspooled, is fixed at all times. Hydraulic calculations must be made to ensure that the recommended flow-rate range of the desired motor can be achieved within the maximum working pressure of the pumps and the coil tubing.

**Torsional Yield of the Coil Tubing**

The maximum stall torque of the motor should not exceed 80% of the nominal torsional yield of the tubing for vertical drilling, and 50% of the nominal yield for drilling directional wells. The lower figure for directional applications allows greater coil stiffness for a more stable tool face. All other applications should adhere to the 80% rule. Mechanical properties of popular sizes and types of coil tubing can be found in manufacturers’ handbooks.

**Buckling of the Coil Tubing**

Computer software is available to calculate maximum WOB for a given directional or horizontal-well profile. For vertical applications, it is recommended that drill collars be run with sufficient outside diameter and length to keep the coil tubing in tension while providing sufficient weight to the bit.

**Coil Tubing Depth Control**

Depth control is critical with coil tubing, especially in deeper wells (greater than 5,000 ft). It is recommended that at least two depth-tracking methods be used. Typically, both mechanical and electronic depth control devices are used simultaneously, and their outputs are compared for accuracy during the job. In the absence of a backup system, the coil tubing can be hand strapped during tripping.
**Short Radius Applications**

Toro drilling motors, typically 4-3/4” OD and smaller, can be used for short-radius applications. Short-radius drilling is a highly specialized application for drilling motors, and each well requires a thorough drill-string and BHA analysis. Before planning a short-radius drilling job, we recommend contacting a Toro representative.

**High Flow Rate Applications**

Certain applications require the use of high flow rates in order to keep the hole clean, reduce the bottom hole temperature, removal of cuttings, etc. To extend the flow-rate range of a motor, a bored rotor can be utilized in the motor’s power section. A bored rotor permits a certain amount of drilling fluid to bypass the power section thus allowing the motor to handle higher flow rates than normal. Typically, a bored rotor uses a selectable nozzle to control the amount of fluid that is by-passed through the center of the rotor. To avoid adverse affects on motor performance, care must be exercised in nozzle selection. Contact your Toro representative for recommendations on a motor with a bored rotor and nozzle.

**Other Applications**

Toro motors are also available for applications such as:

- Horizontal directional drilling (HDD)
- Mining
- Geothermal drilling
- Downhole milling
- Hole opening
- Under-reaming
- Piling
- Casing
- Template drilling

Contact your Toro nearest representative for more information on motors for these and other drilling applications.
Motor Selection

The drilling operation can be very complex and require detailed planning for any type of application. Several factors must be considered when selecting the motor for a drilling application. These include the following:

- Hole size
- Bit type
- Required bit speed
- Required bit torque
- Weight-on-bit (WOB)
- Pressure drop across the bit
- Flow rate / annular velocity required to clean the hole
- Mud type (composition)
- Bottom hole circulating temperature
- Drill-string specifications
- Stabilizer placement
- Well profile
- Site logistics

Motor Pre-Operational Procedures

Proper and efficient operation of a Toro motor depends on operating the tool within the parameters defined in tool specification and on following the recommended procedures for motor operation. Specifications are listed in this handbook for each tool size and the following are the recommended procedures for motor operations:

**Caution:** Safety glasses, steel-toed shoes, and a hard hat must be worn while performing any of the following procedures. All applicable rig floor safety procedures must be followed. Lifting and torque equipment should be checked for ratings and operational condition per appropriate specifications before using.

Making Up the Motor

1. Make up the drill bit to the motor using a bit breaker and by placing the tongs on the motor bit box.

**Caution:** If a bit crossover sub or thread adapter is used, the overall length of the sub should be only long enough to accept make-up tongs (recommended maximum is 10 inches or 254 mm.). Lengths greater than this may damage or reduce bearing life and/or cause the drive shaft to break resulting in the loss of the sub and bit in the hole.
2. If the motor has been unused for an extended period of time, it is recommended that the following steps be taken to break-in the motor before use:

   Place make-up tongs on the coupling housing and, with the bit in the bit breaker, slowly rotate the rotary table one to two revolutions in the counter-clockwise direction.

   — OR —

   Place make-up tongs on the coupling housing, lock the table and pull on the tongs to rotate the stator one to two revolutions in the clockwise direction.

   Note: Do not place tongs on the bearing assembly as this may pinch the internal components and could prevent the motor from turning.

3. Lower the tool into the slips and secure with a drill collar clamp before removing or making up additional equipment.

4. If required, a float sub can be installed immediately above the tool. A float sub will avoid problems with plugging of the bit and motor while tripping in the hole.

   ♦ Do not thread joints into the motor top sub by rotating the motor with the rotary table. The bit could hang up on the casing wall and result in unthreading the tool’s internal joints or cause the bit to unthread.

   ♦ To avoid unthreading internal joints, the bit box should only be turned counter-clockwise with respect to the motor housing above.

Setting the ABH (if equipped)

Setting the adjustable bend housing is a fairly simple operation. Below is the procedure for setting the Toro adjustable bend housing:

1. Tong in the areas as shown in Figure 8. Do not tong on the Orientation Sleeve.

2. Break apart the ABH connection.

3. Unthread the Lower ABH Housing two to four complete turns.
4. Referencing Figure 9, slide the Orientation Sleeve down to disengage the interlocking teeth.

5. To adjust the bend angle, rotate the Orientation Sleeve (no more than ½ turn either direction) until the desired bend angle mark is in-line with the identical bend angle mark on the Upper ABH Housing.

6. Referencing Figure 10, Slide the Orientation Sleeve upward so that the interlocking teeth are fully engaged.

7. Check to see if the desired bend angle marks on both the Upper ABH Housing and the Orientation Sleeve are in-line. If not, re-adjust the Orientation Sleeve until the desired bend angle marks are in-line.

8. Apply thread dope to the bottom face of the Orientation Sleeve. 
   Caution – Do not use thread locking compound on the ABH connections.

9. While keeping the Orientation Sleeve fully engaged in the Upper ABH Housing, thread on the Lower ABH Housing until it shoulders against the Orientation Sleeve.

10. Tong in the areas as shown in Figure 8 and apply the appropriate torque to the connection. See the Table on the next page for the recommended ABH torque values.

11. The bend angle marks on the Upper ABH Housing and the Orientation Sleeve that match and are in-line with each other tell the angle of the ABH. In addition, these matching and in-line bend angle marks indicate the high side of the tool.

Note: an ABH Angle Mark Identification Guide is located in the back of this manual.
Checking Thrust Bearing Wear

It is recommended that prior to re-running a motor in the hole, the thrust bearings be checked for wear. Thrust bearing wear can be determined easily by the amount of play the drive shaft has between the back face of the bit box and the end of the bearing housing. The following describes how to check the allowable play the bit box can have:

1. Lift the motor off the rig floor and let it hang freely above the ground. Referencing Figure 11, take a measurement (L1) between the bottom of the bearing housing and the top of the bit box.

2. Lower the motor until it sits flat on the rig floor. Take a measurement (L2) at the same location.

3. To determine thrust bearing wear, take the result of L1 minus L2.

4. Do not use the motor if the thrust bearing wear exceeds the amount listed in the table below.

### Allowable Bearing Wear

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<th>Tool Size (OD)</th>
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<tbody>
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<td>in</td>
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<tr>
<td>(L1) - (L2)</td>
</tr>
<tr>
<td>(L1) - (D2)</td>
</tr>
<tr>
<td>(L1) - (D2)</td>
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<td>mm</td>
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<tr>
<td>---------------</td>
</tr>
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</tr>
<tr>
<td>9-5/8 (963)</td>
<td>61,000 ft-lbs</td>
<td>83,000 N-m</td>
</tr>
</tbody>
</table>

### Figure 11

**Thrust Bearing Wear Check**

Bearing Assembly

Bit Box

L1

L2
Checking the Near Bit (changeable) Stabilizer (if equipped)

Before running the motor, it is recommended that the near bit (changeable) stabilizer be properly torqued to the bearing housing.

Testing the Dump Valve (if equipped)

Before running the motor, it is recommended that a dump valve test be performed on all motors supplied with a dump valve.

1. Using a long dowel rod, apply pressure to the tapered face of the piston located on the top of the motor. Piston travel should be about 2~3 inches with moderate pressure applied.

2. Fill the valve body with water and then release the piston. Fluid should flow freely from all ports.

Flow Testing the Motor

1. Make up the kelly to the Toro motor and lower the bit box below the rotary table. If the motor is equipped with a dump valve, then lower the motor until the dump valve ports are below the rotary table.

2. Start the rig pumps. Use minimum flow rate for the first few revolutions, then increase slowly as needed.

3. Raise the motor far enough to visually check that the bit sub is rotating and the tool is operational. Keep the test short to avoid damage to the bit, surface pipe, or blowout preventer (BOP) stack. If equipped with a dump valve and after visually checking for rotation, lower the motor until the dump valve ports are below the rotary table

4. Stop the pumps. If equipped with a dump valve, keep the dump valve ports positioned below the rotary table until the dump valve opens and external drainage stops.

<table>
<thead>
<tr>
<th>Motor OD</th>
<th>English</th>
<th>Metric</th>
<th>Motor OD</th>
<th>English</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-7/8 (287)</td>
<td>1,500 ft-lbs</td>
<td>2,000 N-m</td>
<td>6-1/2 (650)</td>
<td>9,500 ft-lbs</td>
<td>13,000 N-m</td>
</tr>
<tr>
<td>3-1/8 (313)</td>
<td>1,500 ft-lbs</td>
<td>2,000 N-m</td>
<td>6-3/4 (675)</td>
<td>11,000 ft-lbs</td>
<td>15,000 N-m</td>
</tr>
<tr>
<td>3-1/2 (350)</td>
<td>2,200 ft-lbs</td>
<td>3,000 N-m</td>
<td>8-0 (800)</td>
<td>22,000 ft-lbs</td>
<td>30,000 N-m</td>
</tr>
<tr>
<td>3-3/4 (375)</td>
<td>3,000 ft-lbs</td>
<td>4,000 N-m</td>
<td>8-1/2 (850)</td>
<td>26,000 ft-lbs</td>
<td>35,000 N-m</td>
</tr>
<tr>
<td>4-3/4 (475)</td>
<td>4,000 ft-lbs</td>
<td>5,500 N-m</td>
<td>9-5/8 (963)</td>
<td>37,000 ft-lbs</td>
<td>50,000 N-m</td>
</tr>
<tr>
<td>5-1/2 (550)</td>
<td>6,000 ft-lbs</td>
<td>8,000 N-m</td>
<td>11-1/4 (1125)</td>
<td>44,000 ft-lbs</td>
<td>60,000 N-m</td>
</tr>
</tbody>
</table>
Motor Tripping Recommendations

Tripping In the Hole

While the Toro drilling motor is a reliable tool, it can be susceptible to damage if care is not taken when tripping the drill pipe. The following are recommendations for tripping the motor in the hole:

♦ Trip in at a controlled rate to avoid damage from striking bridges, shelves, or casing shoes.

♦ Ream through any tight spots by starting the pumps and reaming slowly. Excessive reaming operation may shorten motor life.

Caution: To avoid sidetracking when tight spots are encountered in a directionally controlled wellbore, the pumps should not be started without a directional driller or other knowledgeable and responsible person on the rig floor.

♦ If tripping to extreme depths and/or high temperatures, periodic stops for circulation (staging in the hole) are required. Every 500 to 1000 feet, it is recommended that the drill-string be circulated for a few minutes with the lowest volume and pressure necessary to start the motor.

♦ If extended circulation is required while in the casing, reciprocate the kelly to avoid localized casing wear.

♦ If there is a float valve in the string or if fluid characteristics prevent easy flow, periodic stops are recommended to fill the drill pipe.

Caution: Reduce tripping speed when approaching the last 60 to 90 feet of hole as there may be fill in the bottom of the hole or the pipe tally may be incorrect.

Blockage

If there is no float valve in the string and “backflow” is observed while making up connections, it may be possible that sand or other debris may have entered the drill-string. This condition could result in a blockage of the motor and/or other BHA component. In this case, a trip may be necessary to change out the blocked BHA section.

Tripping Out of the Hole

The following are recommendations for tripping out of the hole:
If the motor is equipped with a dump valve, the dump valve will only open when the pumps are stopped (no pressure in the drill-string). If there is any internal pressure in the drill-string, the dump valve may shut preventing the drill fluid from draining and causing a wet trip.

- When tripping out, the rotary table should not be used to break out connections of steerable assemblies with a high build-rate angle.

- Always reduce tripping speed when nearing casing shoe points.

- Control tripping speed to avoid swabbing the hole.

- Avoid excessive back-reaming as it may shorten motor life.

**Maintenance Procedures After Tripping**

The following post-run maintenance steps are required after tripping out of the hole:

1. Remove remaining fluid from the motor by placing the bit in a bit breaker.

2. Secure the motor body above the rotating bit sub with rig tongs.

3. Rotate the rotary table and bit counter-clockwise, forcing or “pumping” the fluid out the top of the motor.

4. After the bit has been removed, spray water directly through the bit box. This will wash out the ports above the drive shaft and help clean the bearing section.

5. If the tool is equipped with a dump valve, pour clean fluid into the top of the dump valve. Work the piston using a long dowel rod (i.e. broom handle) until it travels freely between the down (closed) and up (open) positions.

6. If the tool is to be stored for an extended time before re-use, flush the motor with clean water. Rotate the outer bearing housing to remove traces of the drilling fluid from the bearing stack. Pour a small amount of mineral oil or equivalent into the motor to protect the internal components from rusting or seizing. *Do not use a diesel-based oil.*

7. Re-dope the bit box and dump valve box. Install closed-end thread protectors.
Drilling Considerations

The performance and life of the motor is determined by the environment in which it operates. To ensure optimum performance and longest life, avoid

- Abrasive solids in the circulating system
  (the use of drill pipe screens is highly recommended)
- Aromatics in the circulating systems.
- High temperatures.
- Pumping higher than recommended fluid volume.
- Exceeding recommended weight on bit (WOB) loads.
- Exceeding the recommended pressure drop across the bit and motor.
- Repeated stalling of the motor

Flow Rates

The recommended minimum/maximum flow rate for each motor should be observed to achieve optimum torque and tool life. Flow rates for each Toro drilling motor are given in this Motor Handbook. It is recommended that before the motor reaches the bottom of the hole, the flow rate should be started at the minimum rate and then slowly increased to the recommended operating range.

Caution: Exceeding the recommended flow rates could potentially damage the motor. For applications requiring a high flow rate, refer to the section: [Drilling Motor Applications: High Flow Rate Applications] in this handbook.

Drilling References

The Toro motor is a hydraulically operated tool. Therefore, the primary rig-floor reference is the standpipe pressure gauge. The weight indicator can also be used as a drilling reference, however it may give inaccurate information about actual WOB because of potential “wall hanging” during sliding operations. In this case, the only true indication of whether the bit is on bottom drilling, is the pressure gauge. Refer to Figure 12 for off-bottom, drill-off, and stall-out conditions that are discussed in the following sub-sections.

Off-Bottom Pressure

When the motor is off-bottom circulating, the standpipe pressure gauge shows the total amount of pressure required to pump a known volume of fluid through the drilling system. This is called “off-bottom” pressure.

Output torque is directly proportional to the pressure drop across the motor and is indicated as a change in total system pressure. Motor differential pressure is defined as the pressure above off-bottom pressure.
Note: When the bit is side loaded due to an offset stabilizer or adjustable bent housing, off-bottom pressure will include the motor pressure to provide torque to rotate the bit with the imposed side load. True motor differential pressure is obtained from standpipe pressure only when the bit is not side-loaded or when system pressure losses, without the motor, are known.

**Pressure While Drilling**

More WOB means a higher total system pressure at the surface. As the bit drills off, the total system pressure decreases. Therefore, the standpipe pressure gauge can be used as an indicator of bit weight as well as torque. Drill pipe friction will not cause a distortion of the readings. When the pressure gauge reads the optimum on-bottom pressure and the driller subsequently stops adding weight to the bit, a drill-off occurs. The pressure will steadily fall until the driller puts more weight on the bit. Performance curves and recommended differential pressures for the Toro motor are included in this handbook.

**Stall Pressure**

When enough WOB is added to exceed the maximum differential pressure of the motor, a stall will occur. The backpressure of the drilling fluid will cause the elastomer in the motor’s power section to deform. This results in the drilling fluid to flow straight through the motor without causing the bit to turn. The pressure gauge will rise abruptly, and then remain stationary, even if more weight is added to the bit. Stall pressure is typically about twice the recommended optimum differential pressure across the motor.

When a stall occurs, turn the mud pumps off and allow the standpipe pressure to bleed off. After bleed off, carefully raise the bit off bottom slightly to allow for any torsional wrapping of the drill string to slowly unwind. Normal drilling procedures may commence once the drill pipe has been completely unwound.

**Caution:** Operating in a stalled condition, even for a short period of time, can seriously damage the motor. Stalling can lead to tearing or “chunking” of the stator elastomer. Once a stator is chunked, motor performance will dramatically decrease or possibly the motor could cease to function.
Rotating the Motor

Steerable applications and many performance (straight-hole) applications require rotation of the drill-string. Rotation of the drill-string is necessary for issues such as directional control, lower drill-string torque or reduced drill-string drag, transport of cuttings, and differential sticking. Rotating the drill-string with a downhole motor is allowable, however it is recommended that the drill-string RPM be kept to a minimum to prolong motor life. A maximum drill-string speed of 60 RPM is recommended, although speeds up to 120 RPM may be permissible in some applications.

The two most common problems associated with drill-string rotation are component fatigue and connection back-off. Fatigue is a function of stress level and the number of load cycles at that level. Increasing RPM increases the number of load cycles within a given period of time, thereby potentially reducing component life.

In steerable applications, the angle of the adjustable bend housing can have a large impact on the stress level of a motor component. The following table shows what adjustable bend housing angles are allowed for drill-string rotation in order to prolong motor life:

<table>
<thead>
<tr>
<th>ABH angle</th>
<th>Rotation of Drill-String</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 — 0.93 degrees</td>
<td>Allowed (50 RPM or less)</td>
</tr>
<tr>
<td>1.22 — 1.76 degrees</td>
<td>Permissible for short periods (40 RPM or less)</td>
</tr>
<tr>
<td>2.00 or higher degrees</td>
<td>Not Recommended</td>
</tr>
</tbody>
</table>

Back-off of a connection can occur if the drill-string becomes stalled and then rotates suddenly when released from the stalled state. Back-off typically occurs when drilling through ledges, tight spots, or formation stringers. This condition, also known as stick-slip, causes severe lateral vibration resulting in potential connection back-off. When drilling through stringers or other formation conditions that are known to cause stick-slip, it is recommended that rotary speed be reduced as much as possible.

Caution: When a drill-string is completely stalled, do not pick up the drill-string until the torsion energy in the drill-string is released. Allow the drill-string to slowly drive the rotary table or top drive backwards until all of the torque is released. Then pick up the drill-string and resume drilling at reduced RPM until the stick-slip condition is overcome.

Build Rate Factors

In steerable applications, many factors affect the build rate of the motor.
Factors such as tool-size to hole-size ratio, drilling fluid type, flow rate, hole erosion, formation anisotropy, placement of stabilizers or pads, bottom hole assembly (BHA), motor bend angle and distance from bit to bend, and the type of bit used. Following these recommendations can minimize these factors affecting build rate:

♦ The lower the tool-size to hole-size ratio, the better the build rate.
♦ Changing the WOB can cause the build rate to change. Generally, an increase to the WOB causes the build rate to increase.
♦ The placement of pads and the use of a near bit stabilizer on the BHA has a significant impact on achieving a good build rate.
♦ Build rate can be better predicted if formation-class empirical data are available. Some formations prohibit good build rates, and these types of formations should be identified while planning the drilling program.
♦ Build rate is directly related to bend angle severity and the distance from the bend to the bit.

**Drilling Fluid Considerations**

While Toro motors are suitable for a wide range of drilling muds, the following factors should be considered before running the motor.

**Drilling Fluid Additives**

Drilling fluid additives should only be used in limited amounts. Drilling fluid properties for use with a motor should be maintained within the same constraints as standard rotary drilling. However, the following precautions should be observed:

♦ The drilling fluid should be free of plugging agents, as well as foreign objects.
♦ The use of a drill-pipe screen is highly recommended.
♦ The fluid should have the least possible sand content (1% or less is recommended).
♦ Certain amine-based additives, such as emulsifiers, corrosion inhibitors, and scavengers, can cause damage (even in very small quantities) to the motor. It is recommended that amine-based additives not be used.
♦ Where possible, hematite-weighting materials should not be used. These materials can reduce the operational life of a motor.

**Lost Circulation Material (LCM)**

Excessive amounts of LCM can have a significant impact on motor performance. LCM is acceptable for use with a Toro motor as long as the following considerations are observed:
The amount of LCM should be kept to a minimum.

- LCM should be added to the drilling fluid slowly. A poorly mixed “slug” or “pill” can plug up the motor and terminate operations.
- Fibrous LCM should be limited to 10 lbs/barrel.
- Synthetic polymer and other non-fibrous LCM should be limited to 25 lbs/barrel.
- Keep LCM abrasives to a minimum. They can cause premature wear to the internal motor components and reduce the motor life.

**Oil-Based Drilling Fluid**

It is highly recommended that the motor be equipped with a power section using an elastomer suitable for use in oil-based drilling fluids (drilling fluid with diesel as the base). Oil-based drilling fluid can easily damage the motor’s power section and significantly reduce the operational life of the motor.

The degree of motor damage depends on the specific chemistry of the oils used. One measure of an oil’s aggressiveness in damaging elastomers is the oil’s aniline point. The aniline point of a material may be defined as the lowest temperature at which equal volumes of freshly distilled aniline and the oil being tested are completely miscible. As an oil’s aniline point decreases, the oil becomes more damaging. While aniline point is a useful measure, some oil-based drilling fluids can still be aggressive despite a high aniline point.

It is important to note that drilling motor power sections are designed with a certain interference fit between the rotor and stator. For the drilling motor to operate efficiently, the interference fit must remain within a specified range. Oil-based drilling fluid can cause the elastomer in the stator to swell, increasing the interference fit. A high interference fit can result in damage to the stator and reduce motor operating life. It is therefore very important for the motor to have an interference fit appropriate for use in oil-based drilling fluid.

*Note: The stator should contain an elastomer compound suitable for use in oil-based drilling fluids. Because of the degradation of elastomers exposed to oil-based drilling fluids, Toro recommends that the elastomer compound selection be based on fluid compatibility testing. Please contact your Toro representative for more information regarding the use of oil-based drilling fluids with motors.*

**Brine or Fresh-Water Drilling Fluid**

Brine and fresh-water muds (with the exception of bentonite gels) provide little lubrication for the motor power section and internal components. Abrasive wear can be a concern. Further, brine drilling fluids can cause corrosion of motor internal components. It is recommended that a Toro representative be contacted if brine or fresh-water drilling fluids are to be used.
### TROUBLE-SHOOTING CHARTS

Toro downhole motors are designed and manufactured with strict adherence to high quality control standards. A Toro motor should provide trouble-free performance when proper operational procedures are followed. However, should a problem arise, the following Trouble-shooting Charts provide commonly encountered drilling problems with their corresponding solutions.

Note: These trouble-shooting charts offers assistance in solving common motor problems that may develop. They are not intended as a substitute for experienced supervision. Should you need further assistance, please contact your nearest Toro representative.

<table>
<thead>
<tr>
<th>CIRCULATING PRESSURE</th>
<th>POSSIBLE CAUSE</th>
<th>REMEDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in circulating pressure (lower than expected)</td>
<td>Lost circulation</td>
<td>Follow lost circulation procedures</td>
</tr>
<tr>
<td></td>
<td>Drill-string washout</td>
<td>Pull out of hole. Check string.</td>
</tr>
<tr>
<td></td>
<td>Open dump valve (if equipped)</td>
<td>Stop pumps. Restart using increased flow</td>
</tr>
<tr>
<td>Increase in circulating pressure (higher than expected)</td>
<td>Plugged motor or bit</td>
<td>Stop pumps. Restart pumps and vary flow rates. Reciprocate string.</td>
</tr>
<tr>
<td></td>
<td>Bit side-loading</td>
<td>Drill ahead carefully to relax tool assembly</td>
</tr>
<tr>
<td>ROP</td>
<td>SPP</td>
<td>WOB</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>Falls</td>
<td>Normal</td>
<td>Falls</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>Falls</td>
</tr>
<tr>
<td></td>
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<td>Normal</td>
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<td>Normal</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>Rises</td>
<td>Normal</td>
</tr>
</tbody>
</table>

ROP = Rate of Penetration  
SPP = Stand Pipe Pressure  
WOB = Weight on Bit
### DRILLING WITH MOTOR ONLY (NO ROTARY)

<table>
<thead>
<tr>
<th>FIRST INDICATOR</th>
<th>SECOND INDICATOR</th>
<th>POSSIBLE CAUSE</th>
<th>REMEDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ROP</td>
<td>SPP Higher than Maximum</td>
<td>Motor Stall</td>
<td>Pull off Bottom, Add WOB carefully to restart</td>
</tr>
<tr>
<td>SPP Rises Higher than Maximum</td>
<td>No ROP</td>
<td>Motor Stall</td>
<td>Pull off Bottom, Add WOB carefully to restart</td>
</tr>
<tr>
<td>SPP Rises, WOB Normal</td>
<td>SPP Falls, WOB Normal</td>
<td>Broken or worn bit cutters, Bit ringing</td>
<td>Calculate cost/foot and either continue drilling or pull bit</td>
</tr>
<tr>
<td>SPP Falls, WOB Normal</td>
<td>Hard formation or stabilizer hanging up</td>
<td></td>
<td>Continue with caution. If unsatisfactory, pull bit</td>
</tr>
<tr>
<td>SPP Rises, Fails to respond to increased WOB</td>
<td>Bit Balling</td>
<td></td>
<td>Lift off bottom, reciprocate. Wash away balling material</td>
</tr>
<tr>
<td>Slow Fall in SPP</td>
<td>Bit is Wearing</td>
<td></td>
<td>Calculate cost/foot and either continue drilling or pull bit</td>
</tr>
<tr>
<td>SPP Fluctuates</td>
<td>Assembly bouncing junk in the hole</td>
<td></td>
<td>Attempt to wash away junk. Fish if necessary</td>
</tr>
<tr>
<td>Sudden Increase in ROP</td>
<td>SPP Rises, WOB normal</td>
<td>Softer formation</td>
<td>Pull off Bottom, recalculate angular reactive torque. Contine drilling using recalculated parameters.</td>
</tr>
<tr>
<td>Toolface heading (TFH) turns to the Left</td>
<td>Softer formation</td>
<td></td>
<td>Pull off Bottom, recalculate angular reactive torque. Contine drilling using recalculated parameters.</td>
</tr>
</tbody>
</table>

ROP = Rate of Penetration  
SPP = Stand Pipe Pressure  
WOB = Weight on Bit
**DRILLING MOTOR SPECIFICATIONS**

Toro offers a wide range of drilling motors from a small 1-11/16” OD to a very large 11-1/4” OD. Typically, drilling motors are categorized by the size by outer diameter. For each size, there are several different configurations that are available to meet a wide range of drilling applications. Unfortunately, there are too many configurations to list in this Operational Handbook. The latest Motor Specifications Sheets are available as a free download from the Toro Downhole Tools web site: ToroTools.com. It is important to note that the motor performance specifications are derived from theoretical, calculated and/or controlled testing and that actual performance may vary for each application.

**Recommended Operational Load (ROL)**

For best performance and reliability, Toro recommends that the motor be operated within the Recommended Operational Load (ROL). The ROL is the differential pressure load at which the motor can achieve optimum performance and maximum life. Refer to the Motor Specification Sheets for the proper ROL for each tool configuration. Motor specification sheets are available for download from the Toro Downhole Tools web site: ToroTools.com.

**DRILEX Power Sections**

Toro Downhole Tools is proud to feature the DRILEX power section in its line of drilling motors. Known for its power and performance, the DRILEX power section utilizes a unique multi-lobe design that is optimized for maximum torque output and controlled speed for today's high tech drilling applications. For more information about Drilex power sections, visit DrilexPower.com.
**Build Rate Prediction**

Motor build rates are generated from a “three-point” geometry of the drilling assembly. Since any three points not in a line describe an arc, the top of the motor, the adjustable bend housing, and the drill bit form such an arc. Figure 12 shows the basic three-point geometry and formula used to generate the build rates. Build Rate Prediction Tables are available on the Motor Specification Sheets for each tool configuration. Motor specification sheets are available for download from the Toro Downhole Tools web site: ToroTools.com.

Below are some notes regarding the predictions for the build rates.

- The build rate prediction values can vary as the gauge and placement of near bit stabilizers are changed.
- When the motor is sliding or during the rotation of a bent motor, it is assumed that a standard gauge hole is being drilled.
- A short-gauge bit will produce better directional tendencies than an extended-gauge bit.
- The formation is assumed to be homogeneous. Variations of formation hardness and type are not considered.
- The tables assume all stabilizers are 1/8” (3.2 mm) under-gauge.
- The build rate prediction values should be regarded as estimates only. Formation characteristics, bit profile, BHA design, and drilling parameters can all affect the directional response.
- The units for build rate prediction are in degrees per 100 ft. The formation is assumed to be homogeneous. Variations of formation hardness and type are not considered.
- The tables assume all stabilizers are 1/8” (3.2 mm) under-gauge.
- The build rate prediction values should be regarded as estimates only. Formation characteristics, bit profile, BHA design, and drilling parameters can all affect the directional response.
- The units for build rate prediction are in degrees per 100 ft.

**Tool Operation and Performance Disclaimer**

Toro Downhole Tools has taken every precaution as to the accuracy of the content and data for each motor specification. Toro make no warranties, guarantees, or representations concerning the accuracy or individual interpretation of the data. Specifications are subject to change without notice. For the latest information regarding tool operation and performance, it is recommended that the nearest Toro representative be contacted.
ABH ANGLE MARK IDENTIFICATION GUIDE

Top of Motor

Upper ABH

Orientation Sleeve
Toro Downhole Tools is proud to feature the DRILEX power section in its line of drilling motors. Known for its power and performance, the DRILEX power section utilizes a unique multi-lobe design that is optimized for maximum torque output and controlled speed for today's high tech drilling applications. DRILEX power sections are manufactured in the U.S.A. and use a process that eliminates the need for sanding or polishing. This process reduces profile distortion thus yielding a higher performing power section with superior torque output. For more information about Drilex power sections, visit www.drilexpower.com