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Deep Sea Research and Electric Motors

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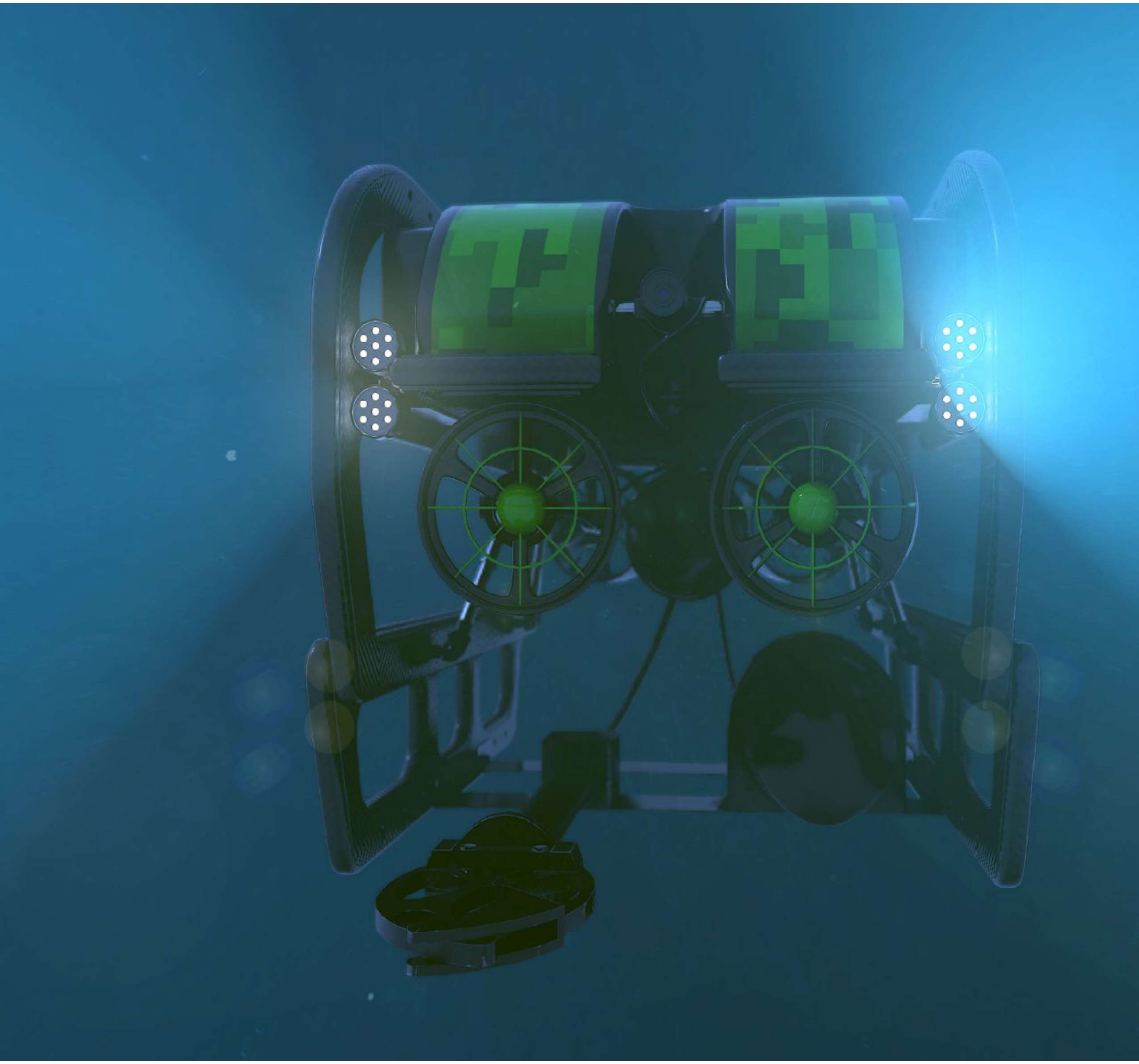
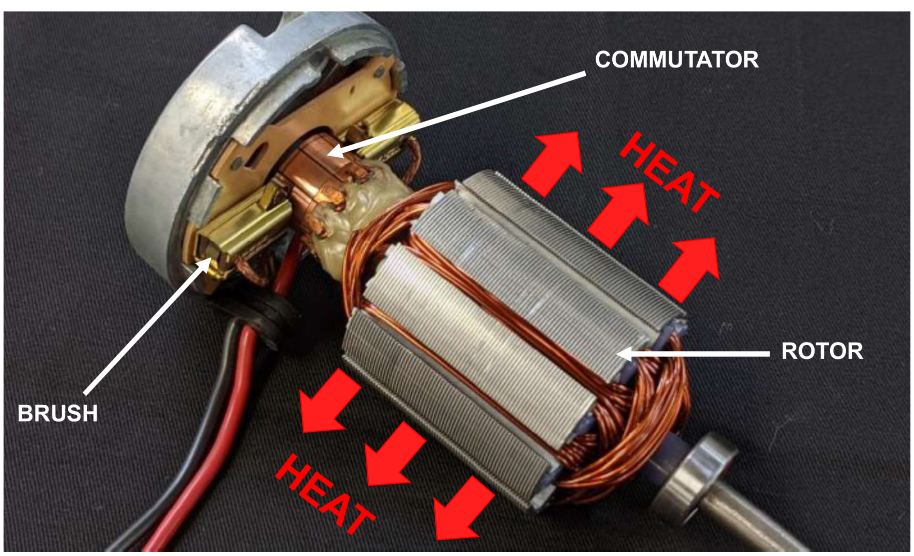


Even as a technology dating back to the 1800's, electric motors still finds its way into modern applications such as subsea vehicles and research instruments. Part of the fascination of electric motors is that they are simple machines and do not need air to run. This means they can operate in hermetic conditions, vacuum, submerged or under pressure. In terms of energy storage, electricity is safely stored in batteries which are reliable and continue to increase in storage capacity. Deepsea research aims for systems that operate reliably submerged, but increasingly, the demand is for long duration operation resident on the ocean floor or operating continuously in the water column, without the benefit of regular maintenance. As such, today electric motors are used for propulsion systems, driving pumps, running winches, opening & closing valves, driving deployment mechanisms, pointing sonars, cameras, lights or other measuring devices, driving traction wheels and more.

Exposing man-made structures to the hostile ocean environment is always a challenge. When these include moving components such as motors and mechanisms, this brings its own set of design considerations. Considerations include type of motor, control electronics needed, battery type, system voltage, torque and speed, weight & size envelope available, materials, corrosion, life, efficiency, capacity, duration and more. There is rarely a perfect solution. In my experience, the engineering comes down to an assessment of tradeoffs. I have spent thirty years designing specialty electric motors for the Space Station, Mars missions, Hubble telescope and, in the past 20 years for subsea operation.



Brushed DC Motor showing Commutation Brushes and heat generated in Rotor (Courtesy: Hydrospace Group)

The same techniques for high reliability motors in space exploration are applicable to deploying instruments to the sea floor for long duration. This article starts with a very basic overview to give an arms-around feel for important concepts when considering electromechanical motion.

Electric Motor

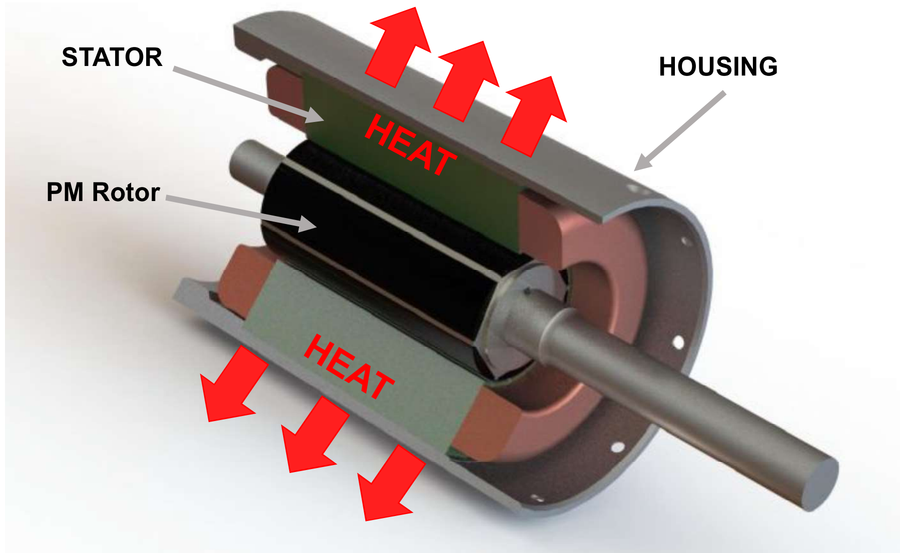
Most people picture an electric motor with two or more wires, producing rotary motion when electricity is applied. When discussing electric motors, there are three basic types that are used in subsea systems, and each have their advantages:

1. Brushed DC motors
2. Brushless DC motors
3. Induction Motors or AC motor

All of these are in use in one of two ways: 1) as a direct-drive application, where the load is directly connected to the motor shaft such as a propeller for a propulsion system, or 2) integrated with a gearbox or speed reducer such as a deployment mechanism, a robotic actuator or a traction drive. Since the subject gets technical rather quickly, it is useful to start with a review of the primary element, the electric motor itself; the differences, advantages and tradeoffs between three types of motors.

Brushed DC Motors

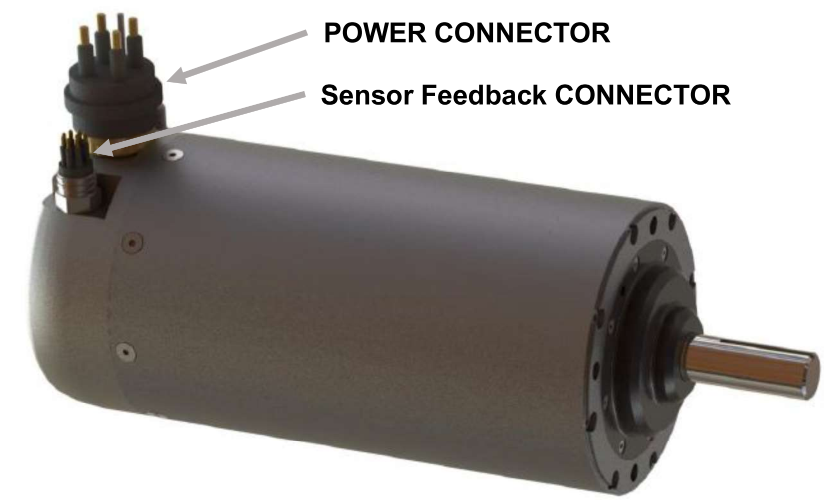
Brushed DC motors are among the most common motors due to their simplicity and low cost. We probably know them first as small electric motors in toys, found in physics experiments in high school and the starters of our cars. They are everywhere and have been used for 50 years in subsea devices. All electric motors are based on the electromagnetic physics of two magnetic fields that interact with each other, repelling or attracting each other to create motion. One magnetic field is created by a fixed electro-magnet and is called the Stator. The other magnetic field rotates and is referred to as the Rotor. In a brushed DC motor, both magnetic fields are produced by electro-magnets, ie. winding a wire around a magnetic material core. Commutation of the magnetic fields, which means switching the current direction in the coils at the right time to produce rotation, is achieved mechanically. A set of conductive bushes transfers the current to the rotor via an "armature". No special electronics are needed. Material costs are low, and these motors typically appear in the ½ to 5 HP and 6-60V voltage range. The advantage of this low-cost solution, however, is tempered by the wear characteristics of the brushes and need for periodic maintenance. The brushes also present limitations at high voltages when the physical contact with the armature is subject to arcing. Brushed DC motors work best for low duty cycle, low power applications where simplicity of controls is a primary concern and life cycle is not critical.



Permanent Magnet Brushless DC Motor showing efficient heat dissipation (Courtesy:Hydrospace Group)

Brushless DC Motors

Thirty years ago, new formulations of permanent magnet materials (mainly Neodymium) made it possible to produce very high magnetic fields. This gave rise to the popularity of Brushless DC motors and their use in aerospace for their high efficiency, compact size, reliability and low weight. In these motors, the permanent magnets (PMs) are mounted on the rotor. This offers two immediate advantages: First, there is no current carried on the rotor and consequently no heat generated. Since the rotor is supported by only two bearings, any heat generated in the rotor is very difficult to remove. This is a primary concern for both Brushed and Induction motors. Second, the stator winding which carries all the electric current is in direct contact with the motor housing and provides excellent thermal conduction. In subsea applications, where the motors are immersed in the water, the cooling is exceptional and helps further increase the motor efficiency. These thermal management advantages account for a large part of the efficiency of BDC motors.



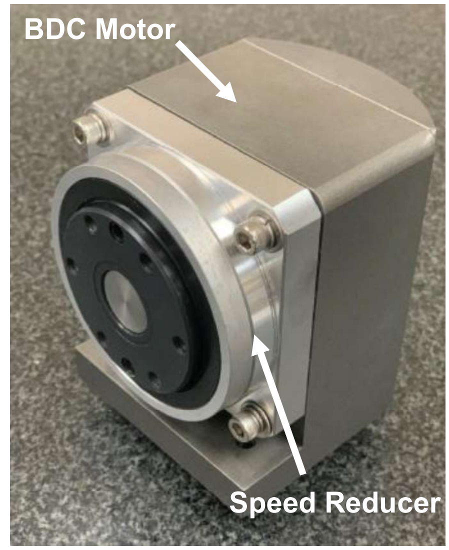
Direct Drive PM Brushless DC Torque Motor (10HP @ 500VDC) (Courtesy: Hydrospace Group)

The tradeoff of these motors is that they require feedback devices such as encoders, resolvers or hall sensors to commutate the fields. Some clever algorithms allow BDC motors to be controlled without feedback devices. These are called sensorless servo drives - a subject all its own. These feedback devices instruct the power electronics to "switch" the current in the motor phases to produce the right torque and rotation. This is why it is common to see BDC motors with two connectors, one for the power to the motor phases and the second for the commutation feedback to the electronics. BDC motors have many advantages: linear speed control, high torque output over a wide range of speeds, high efficiencies, high reliability, and low maintenance. The tradeoff is the increased cost of fabrication and the cost of the control electronics. The power levels range from 1 to 50HP and operate from 12V to 800VDC and have efficiencies of 90-95 percent.

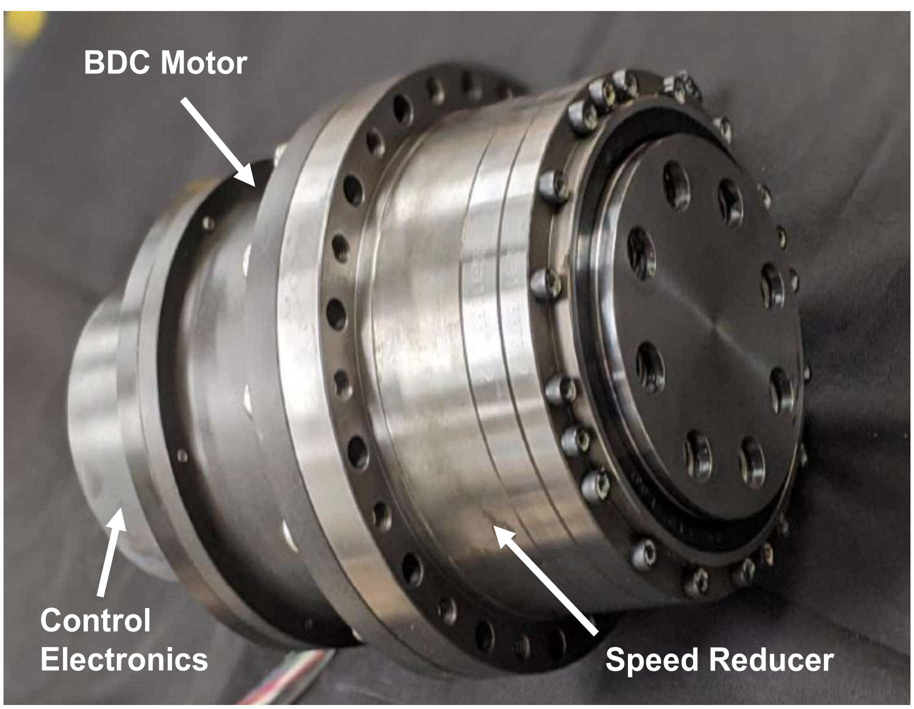
Induction or AC Motors

Most industrial motors found in factories, electric cars and dishwashers are induction motors. Their main advantages are simplicity, low maintenance, the ability to produce very high-power levels at a low cost per HP. Just like BDC motors, the main field is generated in the stator, which is similarly in contact with the motor housing for efficient thermal conduction to the outside. The difference is in the rotor. Induction motors do not need a permanent magnet or even an electromagnet winding to generate the rotor field. This is due to the magic of magnetic induction, first discovered by Mr. Faraday. The short version is that if you excite the stator winding with an alternating current (AC current), this will induce a current and a corresponding magnetic field in the rotor which will automatically oppose the magnetic field of the stator. You can picture this as pushing one magnet forward with another magnet of opposing polarity. Consequently, the rotor for an AC induction motor is simply a lump of magnetic steel. There are no brushes, no maintenance, no commutation, no expensive switching electronics, no sensors. All quite marvelous and made in sizes, from 1/2HP to 3000HP, with only two bearings as the moving parts. One technical challenge induction motors have in common with Brushed DC motors is that the induction generates a lot of heat in the rotor. AC motors, therefore, integrate airflow mechanisms through the motor or in subsea applications, the motors are filled with oil and require engineered internal designs to circulate the oil for heat extraction.

Bottom line, AC induction motors offer robust solutions with simple design features, high life, high power and relatively low cost per HP. The natural question is: Why not use AC induction motors in all subsea systems? One tradeoff is that you need an alternating current source (AC source) and batteries only store direct current (DC) power. Another tradeoff is that the induction fields in the rotor are a function of the AC source frequency (typically 60HZ) and the functioning motor speed must be an integer of 60Hz. Consequently, most AC motors are specified for 1800 or 3600 RPM operation. For applications that require high torque and constant speed, this is perfect. When lower speeds are required, it is easier to add a gear box. For linear speed control, from zero to full speed, this requires extra electronics. Motors speed can be varied by generating source power at different frequencies, but this requires larger switching electronics. These are called frequency drives or "Inverter" and in applications where variable torque or speed control is important, it is often easier and more compact to produce with brushless DC motors. Where induction motors excel is in the high-power spectrum, 100-2000HP range, for applications such as propulsion systems for large ships. Induction motors have efficiencies on the order of 85-90 percent. These are also common on large ROVs with surface supplied power and can operate at high voltages (100-4000V).



Small Compact Brushless DC geared motor (100:1 ratio & 24 VDC) (Courtesy: Hydrospace Group)



Heavy Duty Geared PM Brushless DC Rotary Actuator (Output 500 lbs ft torque @ 150VDC) (Courtesy: Hydrospace Group)

Conclusion

There is no one-size fits all solution to subsea motor solutions. While there are a lot of intricate details that determine the performance of a motor, it is possible to run basic back-of-the envelope calculations to get an order of magnitude idea of the correct motor size and specifications. But, this will have to be a subject for another time.