PREFERRED RELIABILITY PRACTICES

SELECTION OF ELECTRIC MOTORS FOR AEROSPACE APPLICATIONS

Practice:

Careful attention is given to the specific application of electric motors for aerospace applications when selecting motor type. The following factors are considered in electric motor design: application, environment, thermal, efficiency, weight, volume, life, complexity, torque, speed, torque ripple, power source, envelope, duty cycle, and controllability. Brushless direct current motors have been proven to be best all-around type of motors for aerospace applications because of their long life, high torque, high efficiency, and low heat dissipation.

Benefit:

Selection of the optimum electric motor for space flight operations results in a safe, reliable, effective, efficient and economical electric motor power source for space flight. Brushless direct current motors provide the lightest weight alternative for most applications.

Programs That Certified Usage:

Tethered Satellite System (TSS), Solar Max Mission (SMM), Infra Red Telescope (IRT), Saturn 1B (S1B), Saturn V (SV), Skylab, High Energy Astronomy Observatory (HEAO), Lunar Roving Vehicle (LRV), Hubble Space Telescope (HST), Advanced X-Ray Astrophysics Facility (AXAF), and other MSFC projects.

Center to Contact for More Information:

Marshall Space Flight Center (MSFC)

Implementation:

Four principal types of electric motors are suitable for in-space applications, AC Induction Motors, Brush Direct Current (BDC) Motors, Brushless Direct Current (BLDC) Motors, and Stepper Motors. Table 1 shows the most predominant applications for each type of motor.

Generally AC Induction Motors are used for constant speed applications where a fixed frequency power source such as 60 Hz or 400 Hz is available in the spacecraft. Typical applications are fans and pumps. Motor construction consists of windings on the stationary part of the motor and copper shorting bars on the iron laminations of the armature. The AC voltage applied to the windings induces a current in the armature of the rotor, creating a magnetic field. This field reacts with the field in the stationary part of the motor to create torque. These motors are rugged, with no wear out mechanisms other than the bearings.

Table 1. Uses of the Four Principal Types of Electric Motors for Space Applications

A.C. Induction Motor	Brush D.C. Motor	Brushless D.C. Motor	Stepper Motor
1. Thrust Vector Control (TVC) Actuators	1. Limited-life applications	1. TVC actuators	1. Optic drives
2. High torque and high RPM applications	2. Low RPM applications	2. Fuel valve control actuators	2. Solar array deployment
	3. High torque applications	3. Solar array deployment	3. Gimbal positioning
		4. Control moment gyroscopes	4. Low torque applications
		5. High RPM applications	5. Open loop micropositioning
		6. Light weight applications	6. Timer switching
		7. Low thermal emission applications	

The BDC motors use commutators and carbon brushes to apply current through the windings as the motor rotates. The BDC motor utilizes wound elements in the rotor and permanent magnets attached to a stationary stator ring. In a BDC motor, electrically separated motor windings are connected to the commutator ring. Current is carried by spring loaded brushes, through the commutator into the windings of the rotor. The current in the windings creates magnetic fields, which react with the stator’s permanent magnetic field. The magnetic repulsion causes the rotor to rotate. This rotation causes the brushes to make and break connections through the commutator with different winding pairs. The moving magnetic field provides the torque necessary to rotate the motor’s armature.

The BLDC motor uses electronic commutation to control the current through the windings. The BLDC motors use permanent magnets on the rotor. The BLDC motor contains rotor position sensor electronics so that the power input wave form to the windings is in sequence with the proper rotor position. Motor efficiency is enhanced because there is no power loss in the brushes. In the BLDC motor, the stator is wound with electromagnetic coils that are connected in a multiphase configuration, which provides the rotating field, and thearmature consists of a soft iron core with permanent magnet poles. Sensing devices define the rotor position. The commutation logic and switching electronics convert the rotor position information to the correct excitation for the stator phases. Sensing devices include hall-effect transducers, absolute encoders, optical encoders, and resolvers. The electronic controller can be separate or packaged with the motor.

BLDC motors are preferred over BDC motors for most space environments. If BDC motors are used, the qualification of brush motors for the space environment is both expensive and time consuming. The advantages and disadvantages of the two types of D.C. motors are listed in Tables 2 and 3.

Table 2. Advantages and Disadvantages of BDC Motors

Advantages	Disadvantages
1. Low cost	1. Brush dust
2. Simplicity	2. Brush to commutator arcing and wear
3. Availability	3. Electromagnetic interference
	4. Mechanical noise
	5. Short motor life
	6. Low efficiency
	7. Limited speed
	8. Poor thermal characteristics in vacuum

Table 3. Advantages and Disadvantages of BLDC Motors

Advantages	Disadvantages
1. High speed (up to 100,000 RPM) 2. High torque at high speed 3. Approximately double the output torque over BDC motor of the same size 4. Windings on the stator instead of the rotor improves heat dissipation 5. No brushes, so motor lasts as long as the bearings hold up 6. Higher efficiency 7. Vacuum compatible	1. Higher electronic cost 2. Greater motor drive complexity

Application gives the designer the intended use and could perhaps optimize an existing design. The no-load speed, stall torque, and the load point are used to establish the motor torque loadline. Knowing the no load speed and available voltage, the designer can establish an initial back EMF constant and the motor torque constant. The stall torque combined with the loadpoint torque helps establish motor size. The duty cycle, temperature, and expected heat sinking are used with the motor size to determine the temperature rise of the motor. The design is optimized to meet the customer’s requirements.

Since the BLDC and stepper motors are the most predominant motors used for aerospace applications, an expanded listing of applications and requirements is shown in Table 4.

Stepper motors are a special case of BLDC Motors. Construction is identical except that they contain no position sensors. Excitation is sequentially applied to the windings, creating the rotating field to produce torque. The advantages are simplicity and compatibility with digital control schemes. Disadvantages are high continuous power dissipation and high ripple torque.

Table 4. Application of BLDC Motors

Applications	Requirements	Remarks
Centrifuges	Direct control of acceleration, deceleration and speed. Unidirectional rotation. High speed (5000 to 100,000 RPM). Designed to withstand extreme centrifugal forces.	Used in industry, science, medicine, and space experiments as a cost-effective way to separate, by density, components in liquids.
Fans and blowers Constant mass blowers in: aircraft, spacecraft cleanrooms, electronic equipment cooling, and environmental control systems	Precise speed control, variable speed, constant load, inertia, long life, and quiet operation.	Used in space applications such as air conditioning and life support systems.
Pumps	Precise speed control, low maintenance, high starting torque, current limiting circuits, and variable speed.	Used in space applications such as environmental control systems, fluid systems, and thrust vector control systems.
Servo robotic positioning actuators	Accuracy, stability, four quadrant drive, low torque ripple, bidirectional rotation, and camping and settling time. Operates in a harsh environment.	Used in space robotic arms, manipulators, and actuators.
Constant speed Controlled Capstone drive Timing applications Laser scanners Precision optics	Speed > 1000 RPM. 4-pole motor is adequate. Low torque ripple. Toothless stator. Accurate speed control.	The designer should discuss the nature of the load with the motor vendor and drive vendor when considering anything but the basic rotor inertia in precise, accurate speed applications.
Traction and torquing Screw drivers Nut runners	High peak torque. Short acceleration times. Large stall torque circuits. Dynamic braking.	Choice of motor and drive for torquing applications involves special consideration of current, heat rise, control type, and feedback methods. Used for astronaut tools for extra-vehicular activity.
Tape transports VCR head drives	High starting torque. Smooth motion.	To obtain low speeds (<100 RPM), usually requires 12 or more poles and flat construction. Can be used for recording results of space experiments.

The system designer typically requires the motor information listed in Table 5.

Table 5. Typical Motor Design Factors

Application
Commutation method
No-load speed
Stall torque
Load (operating) point
Power source
Envelope (volume)
Environment
Duty cycle
Weight
Lifetime
Torque ripple
Controllability
Heat dissipation

Technical Rationale:

Selection of the appropriate motor for a given application permits more reliable operation, while minimizing weight, power consumption, and thermal dissipation requirements.

Impact of Nonpractice:

Failure to adhere to proven electric motor selection practices could cause shortened mission life, premature cessation of component or experiment operation, mission failure, and in extreme cases loss of mission or life.

References:

1. Sokira, Thomas J. and Wolfgang Jaffe: “Brushless DC Motors Electronic Commutation and Controls,” Tab Books, Inc., Blue Ridge Summit, PA, 1990.

2. Dang, Ngon T: “Overcoming Brushless DC Motor Limitations,” Electronic Products, pp. 63-67, July 1993.

3. “Brushless DC Motor Handbook,” Inland Motor, Kollmorgen Corporation, Radford, VA, 1989.