Motor Design for Aerospace Applications

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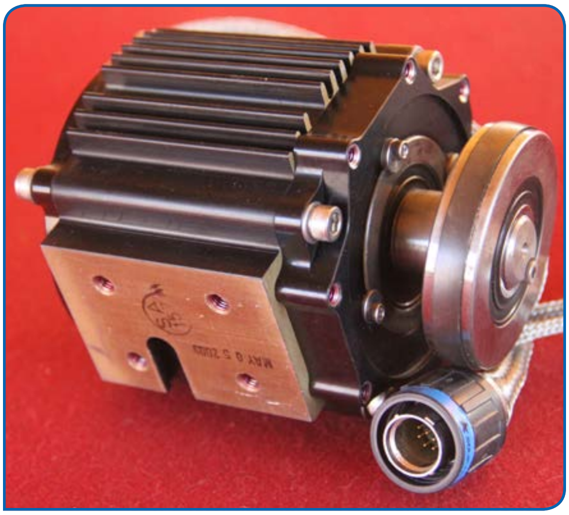
Modern aircraft, missiles and space vehicles employ a large number of electric motors and actuators. While the basic design of these motors is in many respects very similar to that of their automotive and industrial counterparts, motors for aerospace applications differ significantly in some areas.

Similar to automotive motors, the specifications for aerospace motors call for a wide operating and storage temperature range. For our discussion we will focus on electronic temperature specifications, as most electric motors would fall under those specifications. MIL-STD-810 is the primary environmental standard for U.S. military equipment. Military equipment can encounter ambient temperatures as low as –61°C; the high temperature limit is often determined by the mounting location of such equipment and it may require ambient operating temperatures well above 100°C. Aircraft can ascend or descend from sea level to 40,000 ft — or even higher in just a few minutes where they can encounter temperature changes of Δ80°C or more. Space vehicles may encounter low temperatures near the absolute zero of minus 273°C and very high temperatures when they are exposed to direct sun exposure and, again, the operating temperatures can change very rapidly. In some extreme cases, electronics and actuators may even have to be heated or cooled to allow them to operate in these harsh environments.



Cooling fan for navigation system.

Not only must aerospace motors withstand these temperatures and these repeated rapid temperature cycles; they must also endure them very reliably over a very long period of time. Typical military storage requirements are 20 years of shelf/storage life, while the actual operating life may be shorter. Space vehicles, on the other hand, may

be designed for lifespans well beyond those — a formidable technical challenge. The very long shelf and operating life requirements place limitations on material selections, bearing grease, magnet materials etc., that we do not normally encounter in industrial — or even automotive — applications.

The closest to the aerospace markets are automotive actuators and motors which are designed to very high standards and generally tight specifications; but even those do not compare to the shock and vibration requirements that are typically required for aerospace motors designed to continuously handle extreme shock and vibration environments.

The main difference between these motors is rooted in the application itself. Most aerospace systems provide for redundancy, where each system has at least one backup system, which is very occasionally, but rarely, encountered in automotive or industrial systems.

It is in fact this design feature that differentiates the two applications the most. In order for a backup system to function, it is important that, if a failure were to occur, such a failure must not interfere with the operation of the backup system. Thus, a potential failure that can lock up the whole actuator mechanism is unacceptable.

Therefore, much of the design effort for aerospace motors focuses on "safe failure modes" that will allow the backup system to take over without interference, if required.

Therefore the magnetics of a motor must be designed such that a winding short will not "lock" the rotor; rather, the rotor must be able to spin — even when such a major failure occurs. Therefore, aerospace motors are often induction motors or reluctance motors where the rotor will spin freely in case of a winding failure or, if permanent magnets must be used, these will often be embedded so that the magnetic circuit limits the short circuit currents and forces.

Along these lines, critical aerospace motors are often designed as 4- or even five-phase count motors, which can allow for continued operation — even if a single phase becomes inoperative.

Weight and efficiency are other important considerations for all aerospace motors. The designer will try to minimize weight by removing any unnecessary magnetic material. A significant design effort can be spent on analyzing the magnetic requirements (flux), as well as the mechanical strength and optimizing the design for minimal material content, including the very challenging operating environment. It is not uncommon to spend many months fine-tuning an aerospace motor design for mechanical strength and endurance at minimal weight and volume, as opposed to an automotive design that is mostly cost-driven.

To achieve highest strength and efficiency, aerospace motors will employ different material choices compared to automotive motors. For the lamination steel, designers will often use

Hiperco steel, which has much higher mechanical strength and better magnetic properties (higher flux density, lower losses) than comparable industrial/automotive lamination steel. But it will cost orders of magnitude more than common laminations. Also, the use of titanium (high strength and very light weight) is common in aerospace motors. Titanium has one added advantage: it is truly non-magnetic compared to "non-magnetic" steel which does have magnetic properties which can result in losses in the motor — especially at higher RPM.

Another important difference between aerospace motors and industrial/automotive motors is that military applications and, in some cases, commercial aircraft components restrict the country of origin. Much of the underlying technology base is classified or ITAR-restricted at best, and cannot be shared with many low-cost-producing countries. It therefore should be no surprise that aerospace motor are significantly more expensive than their industrial counterparts.

Pump motor for an airborne compressor.

One of the current challenges in the aerospace supply chain is the emergence of counterfeit parts that are lower cost, but also often fail to meet the stringent requirements of the original OEM components. This presents a great safety hazard, and to date there is no reliable way to ensure the origin of these parts in the supply chain. Unfortunately, this is not just a loss of revenue but also literally a matter of life and death. The U.S. Department of Defense and industry are working hard to find solutions. **PTE**

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With over 70 publications and 9 U.S. patents on sensorless and efficient motor controls and low-cost power circuits to his credit, **George Holling** (PI) is an in-demand consultant to many major U.S. and International corporations for motors and drives. At present he holds significant influence in two companies — as technical director of Electric Drivetrain Technologies (2011– present) Moab, UT and as CTO of Rocky Mountain Technologies (2001– present), Basin, MT. Holling is a graduate of the University of Aachen, earning his B.S. (1974), M.S. (1978) and Ph.D. degrees there, while picking up his MBA at the University of Wisconsin.