FAULHABER Whitepaper

Implementation of Redundancy in a Miniature Stepper Motor

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Some of the recent research activities in the area of electric motor drives for critical applications (such as aerospace and nuclear power plants) are focused on looking at various fault tolerant motor and drive topologies.

After discussing different solutions, this paper focuses on a miniature PM stepper motor design which falls in this fault tolerant category by providing an increased redundancy.

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Safety critical systems are taking on increasing importance in the industrial world. Some examples of such systems are aerospace, transportation, medical and military applications, and nuclear power plants. These all accommodate a number of electric motor drives installed to a point where the plants rely heavily upon them. Any failure in these drives may cause catastrophic failures in the plants, which may be very costly in term of human resources and capital cost, and clearly undesirable. Techniques behind most of the electric drives on the market today are not adequate for safety-critical applications. Therefore, there is a need to improve the survivability of critical systems given the increasing dependence on them, and the serious consequences of their failure. One of the common tools used in the design of safety critical systems is redundancy. Ideally, many fault-tolerant systems should mirror all operations; that is, every operation should be performed on two or more duplicate systems, so if one fails the other can take over. Therefore, redundancy within the system is an essential aspect.

What is a fault-tolerant motor?

The specifications of a fault tolerant motor include:

- Higher redundancy, by using identical motor segments on the same shaft.
- Electrically isolated phases to prevent phase to phase short-circuit.
- Magnetically uncoupled windings to avoid reduction of performance in the case of a failure of the other phases.
- Physically isolated phases to prevent propagation of the fault into the neighboring phases and to increase the thermal insulation.

What solutions are offered?

Coupling two motors on the same shaft (Figure 1) is what comes normally to one's mind first. Although its implementation is straightforward, this solution presents several drawbacks which are often underestimated:

- This solution costs roughly twice as much as the nonfault- tolerant system.
- The driving motor has to overcome the friction torque and cogging of the idle motor while it induces in addition iron losses in the later, reducing the overall efficiency of the system.
- It brings in unpredictable resonance frequencies which may severely impact the proper running of the system.
- It does not fulfill at all the requirements of small size and light weight requested by the aero-space industry

Duplicating the windings of a traditional two-phase PM stepper motor is also conceivable. The windings could be either made of individual component placed side by side (Figure 2) in order to create two 2-Phase motors or, with the same intent, made of two windings wound together (Figure 3). Both however do not secure an optimal thermal insulation and the fault of one phase may be propagated to the one next to it. Overall, these designs requires significant modifications of the motor construction and do not meet exactly the specification of a fault tolerant motor as described above.

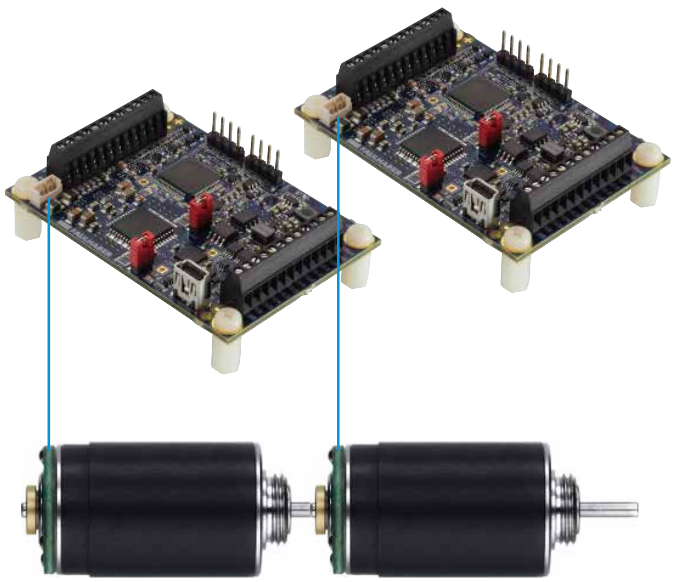


Figure 1: Two motors coupled on the same shaft

Figure 2: Two independent windings placed side by side

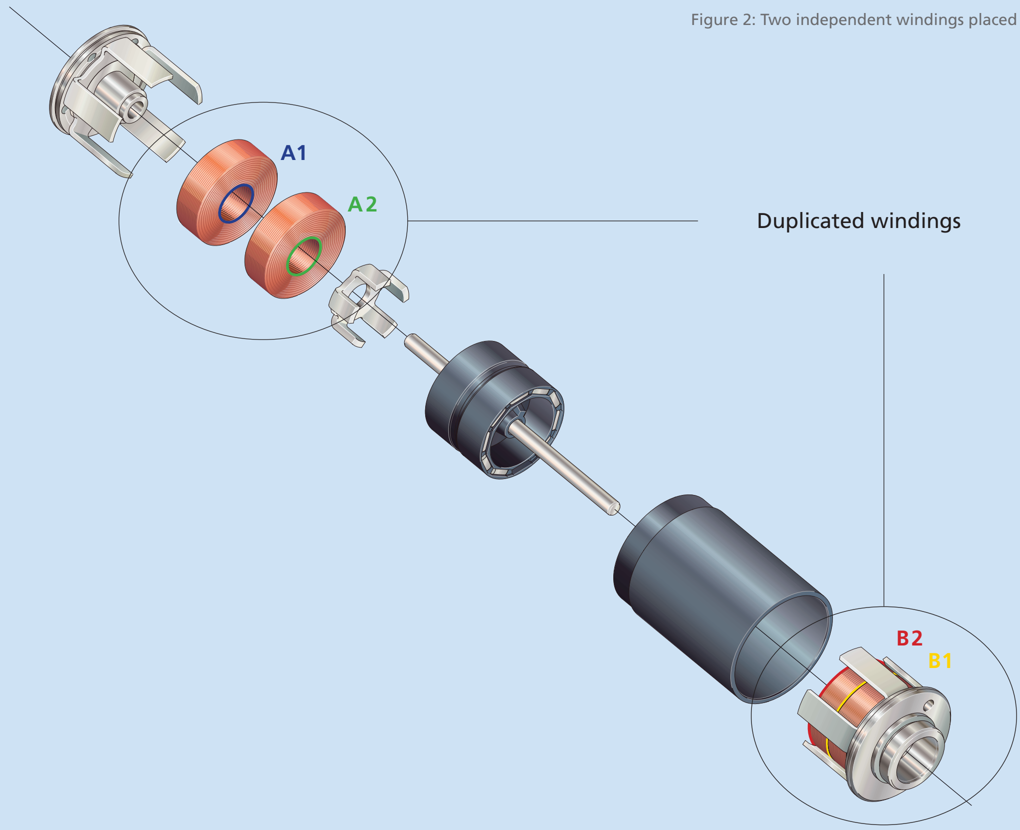


Figure 3: Windings wound together

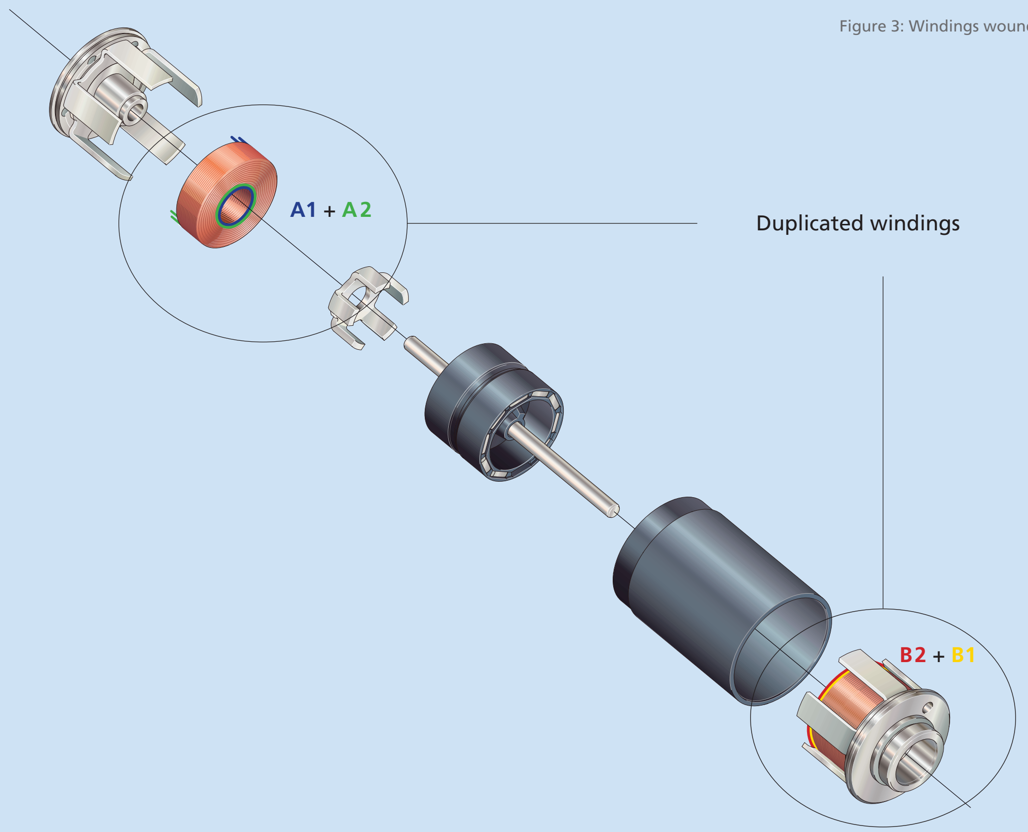
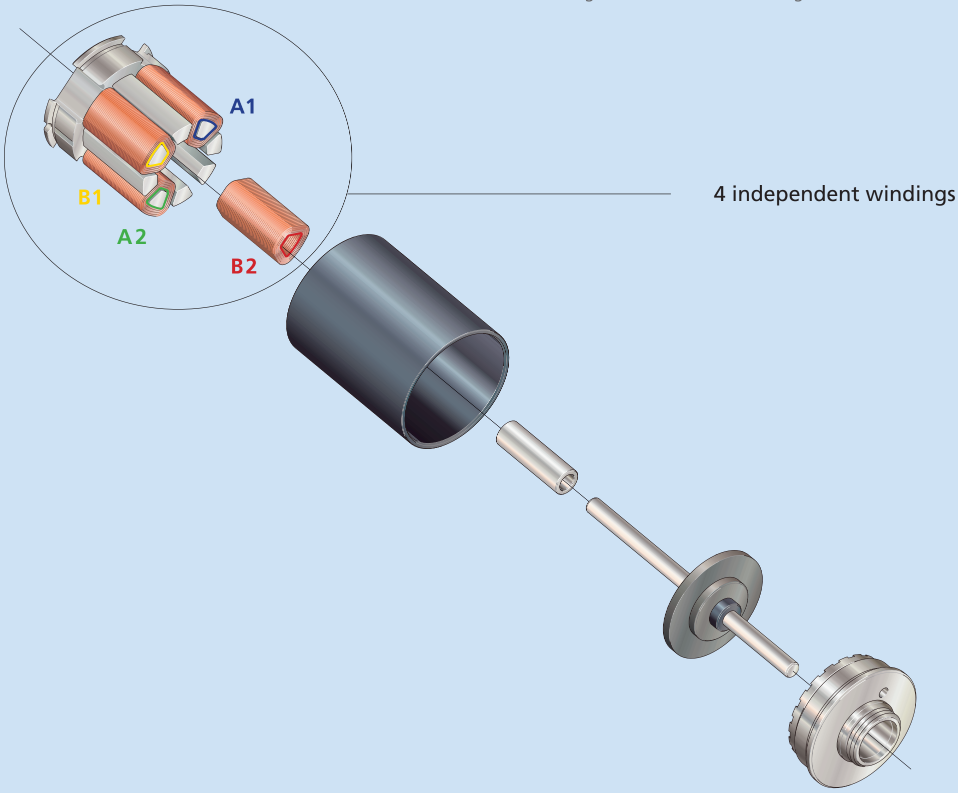


Figure 4: FAULHABER Disc Magnet motor with redundant windings



The existence of FAULHABER Disc Magnet motors simplifies the quest for redundancy capability. By default, this patented motor design features 4 windings which are normally connected by pair to form a Two-Phase stepper motor. A customised solution letting the 4 windings independent from each other creates two Two-Phase PM stepper motors with physically and electrically isolated phases which are the key to achieve a failure free system (Figure 4). The windings are only partially magnetically coupled and the redundant configuration leads to only a torque reduction of 30% when compared to the standard motor configuration at equivalent dissipated power. With proper heat sink and phase current increase, the same output torque can be reached.

Conculsion

The specific and patented design of some existing small miniature motor (down to Ø6mm) meets, with very little adaptation, the specifications for a fault-tolerant, robust, reliable motor with the degree of redundancy which is crucial in safety-critical applications that rely on the failurefree operation of electric motor drives.

Reference: Fault Tolerant Motor Drive System with Redundancy for Critical Applications N. Ertugrul, W. Soong, G. Dostal and D. Saxon. The University of Adelaide