CARPENTER ELECTRIFICATION®

WHITE PAPER

BATTLEFIELD ADVANTAGE

Mission critical, faster, more agile drones
with high-torque, power-dense motors

SUMMARY

The use of unmanned aerial vehicles (UAVs), also known as drones, is rapidly increasing across a range of defense applications. From battlefield information, surveillance, and reconnaissance, to targeting, package delivery, and attack, drones provide the functional advantage of remote operation with minimum supervision and provide access to hard-to-reach locations or those that create vulnerable positioning for human forces. For example, a drone can be effectively deployed to maneuver through urban landscapes and buildings to monitor enemy movements in real-time surveillance operations without any troop insertion.

With the expanding possibilities drones provide for battlefield advantages, modern armed forces will require technologies to make UAVs faster, more agile, reliable, and robust. Yet drones are unique products that combine several functional challenges: a good vision platform to support the end-user functionality, a strong propulsion system to support the required flight times and distances, and efficient AI platforms to enable automated operation for maximized precision and productivity.

Carpenter Technology modeled drone motor performance to highlight the capabilities of Hiperco® 50A stator technology for commanders to translate into tactical, operational, and strategic battlefield advantages.

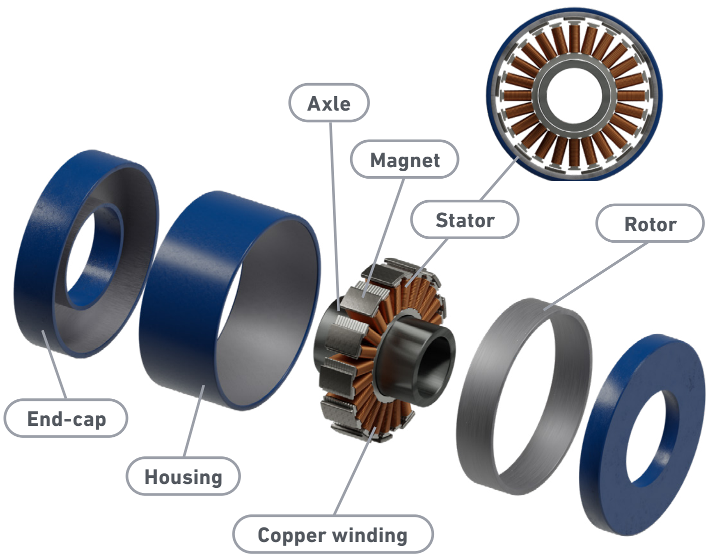
DRONE DESIGN

FIGURE 1—HARDWARE COMPONENTS OF A STANDARD UAV

Figure 1 highlights standard drone hardware components. Ever-improving camera technology and smart software platforms address the vision and automation challenges presented in drone design. A propulsion system with energy-dense battery technology can optimize performance for longer flight times and faster acceleration and provide the endurance to cover more distance. Of the motor, propeller blades, and power management systems within the propulsion system, motor technology provides the most viable opportunity
for improvement.

The outer-rotor permanent magnet synchronous machine design of the drone motor, as depicted in Figure 2, is useful for direct-drive applications such as UAVs. We modeled the motor for a desired UAV flight cycle to compare performance using a drop-in replacement in the stator core. Two materials were used in the stator core, and the performance of the drone motor was modeled using finite element analysis.

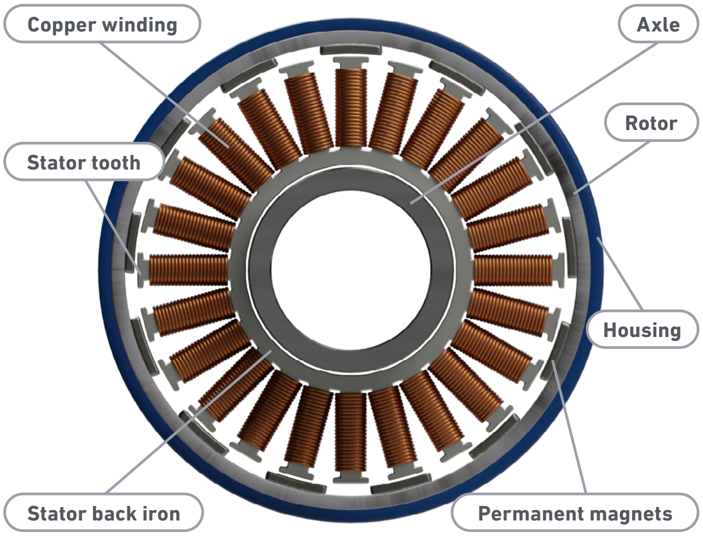
FIGURE 2—EXPLODED VIEW OF THE OUTER ROTOR PERMANENT MAGNET SYNCHRONOUS MOTOR



Hiperco vs. silicon steel

For the comparison, stator cores of both commonly used silicon steel and the advanced Hiperco 50A were utilized, each with a 0.25 mm lamination thickness. Both models' rotor cores consisted of silicon steel laminations and NdFeB magnets with 42 MGOe as the permanent magnets. The varying stator cores were interchanged and the motor was modeled between silicon steel and Hiperco 50A.

FIGURE 3 — CROSS-SECTIONAL VIEW OF THE OUTER ROTOR PERMANENT MAGNET SYNCHRONOUS MOTOR

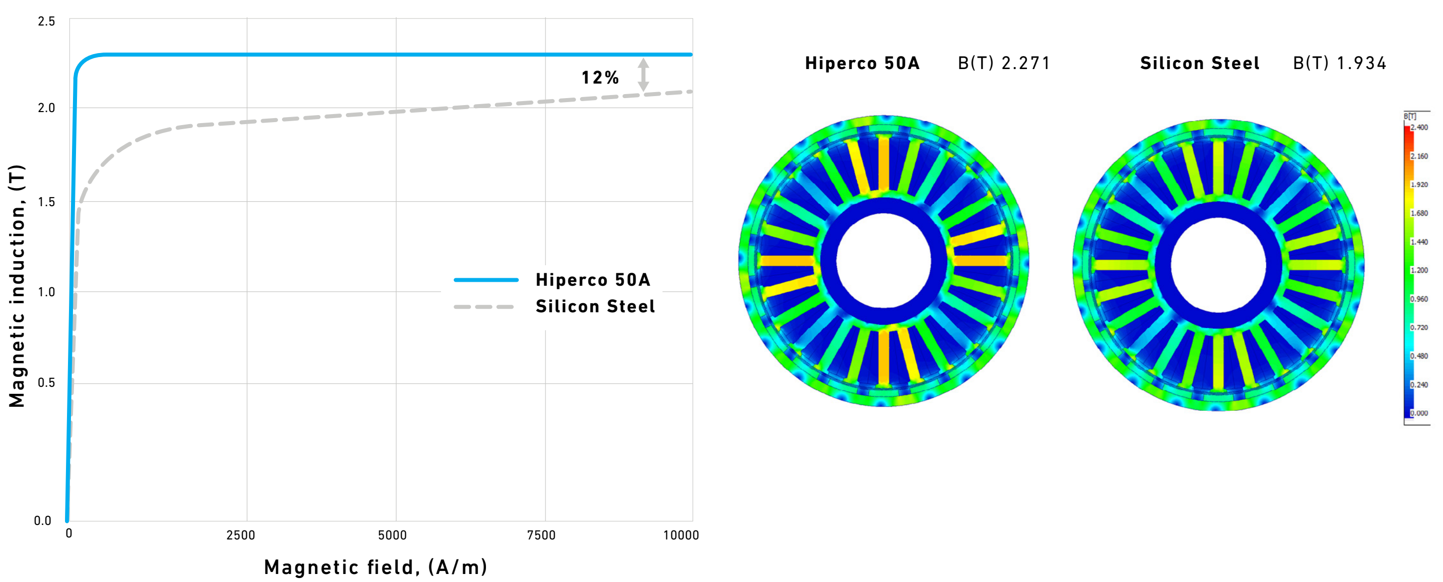


Magnetic flux density

Hiperco has a significantly higher magnetic flux density than silicon steel. The magnetization curve of both alloys shows a 12% improvement in saturation magnetic flux density with Hiperco 50A. The permeability of Hiperco alloys are also 2-4x higher than standard silicon steel alloys. The right image in figure 4 shows the flux distribution in the stator core. The maximum flux density in the silicon steel core is 1.9 T range, whereas the Hiperco 50A core reaches 2.25 T range.

The increase in magnetic flux density with Hiperco helps increase torque and reduce machine size.

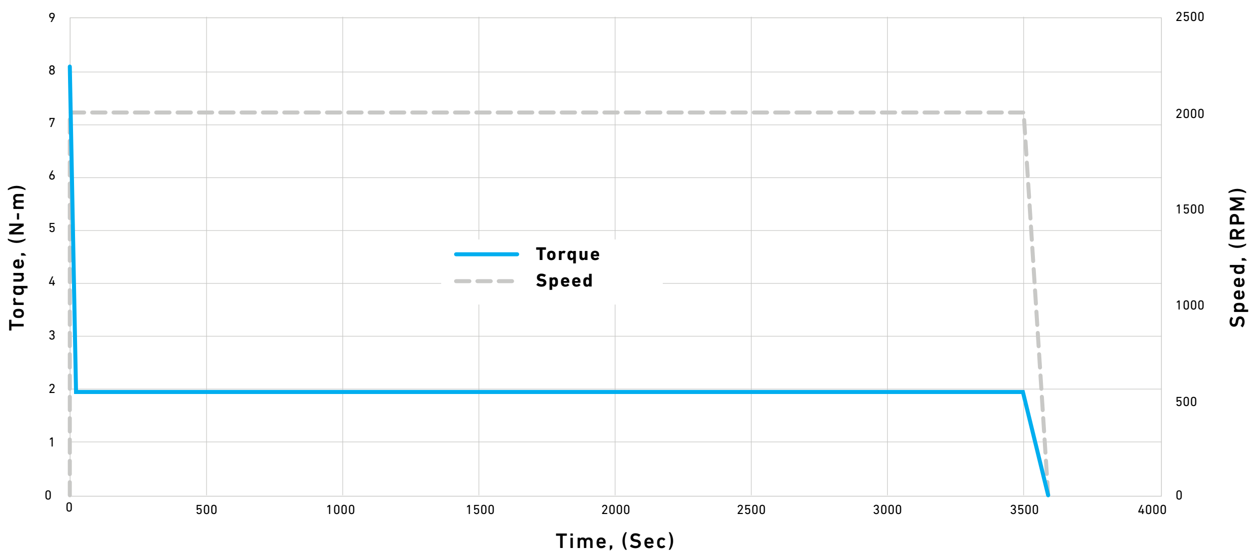
FIGURE 4 — THE MAGNETIC INDUCTION OF HIPERCO 50A AND SILICON STEEL SHOWN IN THE MAGNETIZATION CURVE (LEFT) AND THE STATOR CORE (RIGHT). THE FLUX DENSITY IN THE STATOR CORE SHOWS AN INCREASE WITH HIPERCO 50A.



Motor modeling

We completed the motor modeling with a flight profile to ensure the thermal boundary conditions of the operation. The motor ramped up from 0 to 2500 rpm in five seconds and was then run at a constant speed for 60 minutes as shown in figure 5. The 60-minute flight time provides a thermal envelope to the motor operation, making the model a realistic simulation of a drone flight.

FIGURE 5—THE FLIGHT CYCLE USED FOR MOTOR MODELING. THE DRONE MOTOR RAN FOR 60 MINUTES WITHIN A THERMAL ENVELOPE.

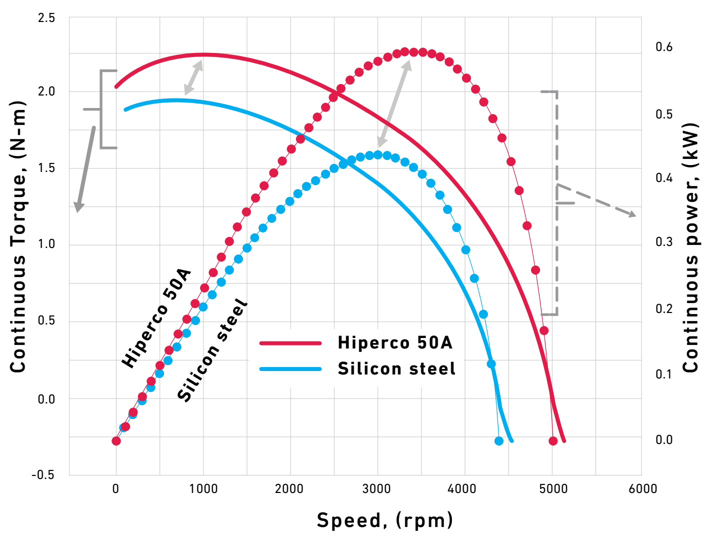


Continuous power and torque

The modeling showed a significant increase in the motor's performance using the Hiperco 50A stator core, with improvement in both continuous power and torque. The continuous power of the Hiperco 50A stator improved 36% compared to the silicon steel core. The continuous torque also increased by 25% at 2500 rpm speed.

These Hiperco-driven performance improvement metrics enable drones with lower core losses for higher system efficiency with increased agility.

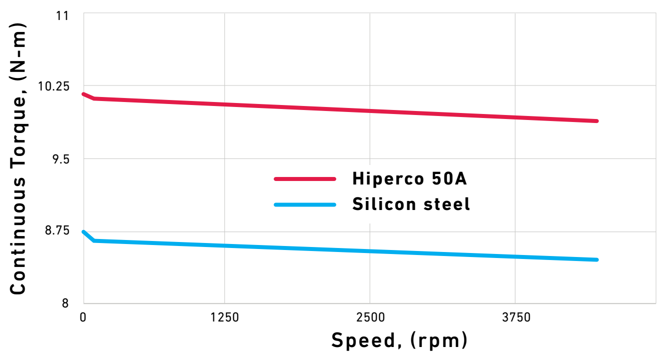
FIGURE 6—THE CONTINUOUS POWER AND TORQUE OF THE MOTOR IN THE DRONE OPERATION, WHICH INCREASED BY 36% AND 25%, RESPECTIVELY



Peak torque

The peak torque of the motor also increases significantly with the Hiperco 50A stator core. The higher magnetic flux density, or induction, from the Hiperco 50A magnetic core enables a higher peak torque, a 16% increase over the silicon steel stator core.

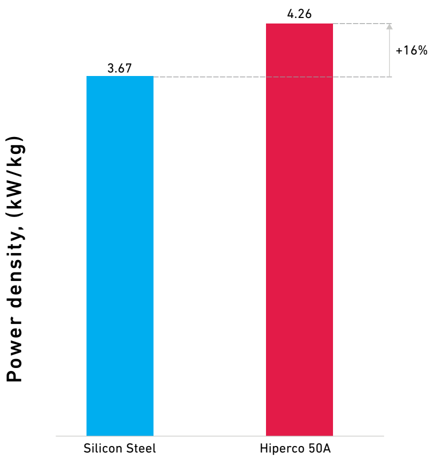
FIGURE 7—THE PEAK TORQUE OF THE MOTOR IN THE DRONE, WHICH INCREASED BY 16% WITH THE HIPERCO 50A STATOR CORE



Power density

The Hiperco 50A core-based motor's power density is 16% higher compared to the silicon steel core-based motor, a result of the increase in peak power because of the higher magnetic induction.

FIGURE 8 — POWER DENSITY OF THE MOTOR-OPERATED WITH BOTH A SILICON STEEL AND HIPERCO 50A STATOR CORE



Efficiency

The power-dense motor with the Hiperco 50A core is also more efficient than the silicon steel core motor. A 2% increase in overall power efficiency and a stator phase current 11% lower was measured utilizing Hiperco 50A cores compared to silicon steel. Motors operating at lower currents can benefit from proportional power saving to the battery while the drone is operational. Thus, the overall efficiency of the propulsion system can increase significantly, resulting in an increased range or payload capacity.

The Hiperco 50A core-based motor performed substantially better than the silicon steel core-based motor. The analysis found the following benefits from the Hiperco stator core:

- 16% increase in power density
- 16% improvement in peak torque
- 36% increase in continuous power
- Significant increase in flight time or payload capacity

Increased peak torque will enable drones to be more agile in operation. The acceleration and speed of drones will continue to increase because of increases in peak and continuous torque. Higher continuous power provides drones with more mobility and reliability, while power-dense motors make drones more functional, providing options to add more value through items such as more sensors or improved cameras to meet users' functionality requirements.

This full spectrum of performance improvement realized through the replacement of silicon steel with a Hiperco 50A stator translates perfectly to the warfighter's needs in drone applications. Hiperco 50A-equipped drones provide an advantage in speed, range, agility, endurance, and mission payload. In other words, Hiperco 50A stators deliver targeted benefits spelled out by the Army vertical lift doctrine. Combat commanders can translate these capabilities into advantages at the tactical, operational, and strategic levels that provide the margin for victory on the future battlefield.

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electrification@cartech.com | 610 208 2000

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