Aerospace Electrification Event, hosted by ATI and WMG

Challenge session: Machines and drives

During the breakout session, Marc Holme, Senior Director of Electronic Controls and Motor Systems at Collins Aerospace led the group, with the support of Tom Hillman, Lead Simulation Engineer at YASA in guiding the group around identifying the key challenges and solutions that will be needed for future machines R&T.

Outline

Future electric machines will be at the heart of electrifying aerospace, ultimately being responsible for delivering electrical energy to propulsors on the aircraft to generate the required thrust and lift power. Whether it is motors, inverters, generators or other drive components, these elements represent a significant challenge for aerospace organisations to qualify and certify for adoption.

A number of challenges were identified by the group, including:

- Standards for electrical safety, both in operation and testing for relevant voltage levels.
- Hybrid propulsion and barriers to its adoption.
- System requirements and how these cascade to machines and drives. For example, transferring requirements at subsystem level, such as size and weight targets for power electronics, machines and drives.

The group then prioritised the top three challenges and discussed ways to address them and next steps.

Challenge 1: Machine technology development and adoption

Developing the capability of machines was, unsurprisingly, an area of much discussion, looking into some of the technical barriers that would require R&T focus to enable the machines and drives of the future to be fit for purpose and performance optimised. The overriding drivers are the size of these components and sub-systems, the power densities of the machines, operating efficiencies, and ways to manage cooling requirements.

New, high performing, high temperature capable magnets is one of the prime areas of interest, with developments to produce lightweight and compact magnets, using novel and advanced materials such as cobalt steels and composite materials to achieve higher flux densities than traditional silicon steels. On the topic of material selection, there remains a concern regarding the challenge of sourcing sustainable and ethically obtainable base materials.

The arrangement of these magnets in the machine architecture is also an area of much interest for optimising field properties, with configurations such as Halbach arrays and other novel arrangements. Development of high temperature capable adhesives and other joining solutions also lends itself to reducing overall system weight through reduced need for mechanical joining.

Overall thermal performance of these machines is also an area of much interest. Minimising losses and self-heating mechanisms across the machines represent a big opportunity to increase efficiencies and would look to understand more fundamental loss mechanisms through advanced models and simulations to identify potential solutions. Other solutions for enhanced thermal management include the use of slot cooling, oil spray and heat pipes to effectively control the heat generated more sufficiently. Superconducting machines represents an area of significant technical benefit and challenge in reducing losses through cryogenic cooling. Technologies likely to provide a big impact on thermal management include the increased use of additive layer manufacturing techniques using novel lattice structures for machine elements, as well as thermal harvesting devices that will reutilise excess heat and recycle this back into the system.

Current trends for permanent magnet machines yield the highest specific power of available machine topologies, however there are considerations that overall system safety and other requirements may drive the development of alternative architectures that move away from Permanent Magnetic topologies. There is much discussion in the industry regarding the trade-offs between axial vs. radial flux machines, with suggestion that aerospace should look to recent developments in the automotive sector in assessing how each topology impacts electromagnetic performance, use of windings and cooling solutions.

Recognising the significant opportunities to learn from other sectors including automotive, rail, power generation and industrial applications using electrical machines and drives, a cross-sector symposium is the next logical step to maximise this learning. It is envisaged this will allow representatives from all sectors to share roadmaps, discuss similar requirements, identify pinch points and learn from experience.

Challenge 2: Attribute trade-off requirements

The second of the key challenge areas stem from a need to better understand how the differing levers of technical and economic capability for machines and drives impact one another and enable the most effective solutions. Utilising fast, multi-physics, multi-system simulations and optimisations will enable rapid and effective assessments to be undertaken to arrive at the most important optimisation parameters for machine design. Key characteristics including system power density and thermal performance are likely to be critical measures that will be influenced as part of integrated simulation environments and toolsets. Overall system efficiency will also play a key role in these trade studies and increased understanding of the attributes that should carry the most weighting in a model will require collaboration. Being able to build a fully representative bill of materials at a model level will impact the cost modelling capability for future machines and will need to consider the balance of off-the-shelf components vs. bespoke systems. Workflow management, in taking a holistic view of process and product flow will need to be optimised to deliver the required standard of end products.

In the development of future tools, there will need to be consideration for capability in simultaneous mapping of efficiency, noise and vibration, meta-model based modelling and optimisation, system component interaction understanding from an early design stage, functional mock-up interfaces (FMU/FMI) standards, and a general need for standardisation of tools and interfaces across the industry. There will also be collaboration opportunities in the generation of databases of attributes and characterisation for different machine operating cycles and conditions to aid in rapid development. It is expected that there is good opportunity for consortia R&T projects in tool development, with joint projects between tool suppliers driven by aerospace manufacturers expected, as well as knowledge transfer potential from other sectors and teams in areas such as machine and inverter models for sub-system design and whole system design.

Challenge 3: Manufacturing of future machines

The final challenge area focused on the enabling manufacturing capabilities and processes required to deliver these electrical machines of the future. Along with many traditional manufacturing processes in aerospace, the move towards more digital-based manufacturing solutions is key. With ever greater standards and tolerances for machine and drive manufacturing processes being employed, greater in-process monitoring, and control mechanisms are being sought after, particularly focusing on adopting novel AI and machine-learning principles to improve process control and material development. There is also interest in how useful data is gathered during the design, manufacturing, and assembly processes to give each machine a "unique fingerprint" to be used during its lifetime.

The design and application of novel windings is an area of prime focus, with the materials, architectures and processes used under consideration. Traditional machine windings constituted from linear single-element structures suffer from "skin effects", leading to power losses in high frequency applications. Litz wire (collection of single enamelled wires stranded together) increases the surface area of the conductor and reduces these effects so is well suited to winding applications. This presents a number of challenges including the need to provide more automated winding processes for higher volume production capability, increase durability and lifetime requirements of the wires and managing the losses of these architectures. Insulation systems will also play a part in optimising processes, with slot liners often getting damaged, encouraging other solutions to be derived.

There is also a significant interest in the adoption of additive layer manufacturing techniques, particularly in the design and optimisation of the machine structures. Additive manufacturing will also play a role in the thermal management capabilities of these machines, with increased capability for cooling flow optimisation.

Testability was the final key focus under the manufacturing theme, with current end user requirements pushing the need to perform expensive and detailed testing of machines in varying configurations. This also included sub-topics such as end of line testing, joining techniques and right first-time principles. Design for end of life and enhanced recyclability of these machine components needs to be considered in order to meet the ever-increasing challenge of material usage and cost reduction.