Transferring the Experience and Technology of Electric Mobility into Aircraft

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Abstract
The civil aviation market will continue to grow with 4-5% each year within the next 20 years. In addition, the public debate on the worldwide civil air traffic is dominated by environmental and climate issues, even though only 2% of the man-made carbon dioxide (CO$_2$) emissions are due to air transportation. Therefore, the aerospace industry will have to focus on a low-emission and quiet air traffic and on the conservation of natural resources and our environment by enabling electric-technologies - already being utilized in applications in the automotive and industrial sector - for aircraft systems.

Rolling bearings are one of the components which significantly determine the reliability and mechanical efficiency of aerospace applications such as aircraft and rotorcraft engines and transmission systems. They have to withstand very demanding operating conditions. Advanced solutions in aspects of design, analysis, materials and surface technologies are required in order to meet the environmental, reliability and economical requirements of advanced aerospace bearing systems.

Additionally, electromechanical or mechatronical systems already used in automotive applications are an increasing part of the development for aerospace applications. These systems should replace conventional hydraulic systems and add additional functionality, higher quality and better controllability using the experiences made within the automotive applications. The challenge is to transfer systems like a wheel-hub drive (e.g. for electric taxiing applications) or a rotation-symmetrical actuator like a roll stabilizer to the extreme constraints for aerospace applications, like space, power availability and weight. This is part of current examinations.

In this contribution, highly energy efficient rolling bearing systems as well as current e-mobility development trends for automotive and industrial applications are discussed. Furthermore the transfer of these developments into aerospace applications is presented with the examples of the wheel hub motor, the roll stabilizer and linear actuations such as the planetary roller spindle drive.

Aerospace Rolling Bearing Systems
Advanced bearing design solutions contribute to lower friction power losses and increased system efficiency. For example, highly integrated aircraft engine main shaft bearings (cf. Figs. 1, 2, and 3) present significant weight, functional, and maintenance benefits compared to standard design bearings. This is achieved by integration of functional features such as elastic spring beam fixations (Fig. 1) or cooling channels in the outer diameter (Fig. 2).

For these two examples weight savings of up to 30% and power loss reductions of up to 25% are accomplished [1].

The trend for further functional integration is shown in Fig. 3. Starting from catalog-type bearings in the 1960’s, aircraft engine main shaft bearings developed into highly integrated shaft/bearing modules in the late 1990’s. Besides significant reductions in system weight and power loss, the integrated bearing solutions represent increased system reliability, i.e. less maintenance and overhaul.
The progress in bearing materials and surface technology development is the basis for weight and friction energy reduction in aerospace bearing systems. The further development of VIM-VAR case hardened bearing steels with increased high-temperature hardness and compressive residual stresses contribute to high-performance-bearings and therefore to more compact and higher rotating aircraft engines. The recent introduction of Duplex Hardening - a method of applying a thin nitrided layer to raceways and rolling elements made of conventionally hardened aerospace bearing steels - enables even higher shaft rotational speeds and temperatures equivalent to higher aircraft engine efficiency [2]. The primary attributes of a duplex hardened surface are its increased hardness accompanied by increased strength and compressive residual stresses in the near-surface layer providing more resistance and robustness against superimposed tangential stresses from high speed or contamination effects [3]. Simultaneously plastic and ceramic materials were developed throughout the last decades for low weight and energy efficient aerospace bearings. PEEK for instance - a thermoplast material typically reinforced with glass or carbon fibers - is used widespread as aerospace bearing cage material in helicopter and gearbox applications offering weight reductions of more than 80% compared to standard steel cage material. Silicon nitride is used as rolling element (ball or roller) material (Fig. 4) in so called hybrid bearings achieving further weight reductions of more than 40% compared to conventional steel rolling elements.

Beyond that, hybrid bearings have been proven to generate less heat and therefore operate at lower bearing temperatures [4]. This results in both increased bearing system efficiency and reliability.

Fig. 5: Performance Characteristics of all-steel and hybrid bearings

The combined use of proven and reliable aerospace rolling bearing technology and newly developed e-mobility solutions will feature optimized systems for high efficient future aerospace applications.

E-Mobility Development Trends

In the context of development for e-mobility applications a variety of approaches is regarded which strongly focus mechatronic systems. On one hand there are applications which can be named as supporting systems, e.g. steering systems or leveling devices. On the other other hand there application directly used for the drive train, e.g. hybrid engines or wheel hub drives.

This trend for electrification can also be regarded in the area of aerospace applications. The expected benefits are lower weight of components, a better and more accurate controllability, faster reactions, and – last but not least – less power consumption. The latter one has regarded especially in comparison with hydraulic systems wherein the needed hydraulic pressure has to be provided permanently, and that means permanent power consumption which can not be neglected.

The question is, in which way ideas, experiences, and systems already settled in or developed for automotive applications can be transferred to aerospace applications. Two examples should be regarded in detail.

A strong trend within the development for electric drive concepts is the use of highly integrated wheel hub drives.
The figure above shows the Schaeffler E-Wheel Drive which represents the integration of all necessary components within the space of a rim. This includes beside the electric engine – the power electronics as well as the control unit.

Transferring this automotive application to the area of aerospace applications the so-called electric taxiing of grounded planes can be an adequate target. Using an electric taxiing system provides a lot of advantages such as less emission (noise and CO₂), independence of ground support, and less fuel consumption. All of these advantages result in reduced costs for the airline. The drawbacks of such a system are the additional weight and additional electrical power during ground operation. At the end, the use of such a system has to be valued in consideration of the concrete constraints of operation and a break-even point can be determined.

A special challenge of a transfer is to fulfill the technical requirements for the application “Electric Taxiing” e.g. like necessary torque, necessary power, weight, size in comparison to available space, and environmental resistance. All these issues are part of current research activities.

At the end a decision for the system will be taken by the customer if the investment and the expenses during operation are significant smaller than the benefit of using this system.

An example for a mechatronic system which is one of the above mentioned support applications is a roll stabilizer system.

The figure above shows an example for such a roll stabilizer system. Comparable to the wheel hub drive all necessary components are highly integrated within the space of a tube. The diameter of the tube is about 90mm and the length is about 400mm.

The benefit of this system is a rotation-symmetrical actuator with a usable torque range of +/- 900Nm, a high lifetime accuracy, and the possibility to measure the adjusted torque range without additional sensors. This system can be used for applications with a reduced installation space and requirements for high precision. In addition, conventional hydraulic systems may be replaced by such an actuator, saving power as well as reducing the necessity for hydraulic pipes. But fulfilling the extreme environmental constraints also remains a challenge for such kind of systems.

References