# Special Section on High Speed Electrical Machines and Drives

## Guest Editorial

The use of high speed electrical machines and drives is in continuous evolution for a number of engineering applications, including electrical spindles for milling cutters and grinding, turbochargers, electrical turbo-compounding systems, aero-engine spools, helicopter engines, racing engines and fuel pumps. These application have a typical operational speeds over 10,000 rpm and $RPM\sqrt{kW}$ specific indexes in excess of $10^5$. Applications with maximum speed up to 150,000 - 200,000 rpm are now under consideration with the first experimental realizations ready.

The academic and industrial interests in this topic are growning very fast pushing their researches towards improvements in the involved technologies with a significant impact in many application areas. One of the main advantages of high speed machines and drives is the reduction of system weight for a given power conversion. This is especially desirable in all transportation applications where a weight reduction results directly in reduced fuel consumption and emissions. The more electric transportation systems are one of main topics of a significant push for advancing high speed technologies. A second reason in adopting high speed machines in certain applications is the improvement in reliability due to the elimination of intermediate gearing, such as high speed direct drives.

The previous considerations have pushed the Guest Editors to propose to the Transactions on Industrial Electronics Editors this Special Sections on *High speed electrical machines and drives*. The Special Section was fully approved and it got a strong interest in Electrical Machine and Drives researchers community. The Special Section received 53 papers to be submitted at the peer review. Among these papers, only 19 ones have been accepted for publication.

All the accepted papers include strong experimental activities to validate the proposed solutions. The accepted papers now represent a milestone for the researchers interested on the Special Section topics.

The Special Section starts with a paper presented by high speed machines specialists from Cummins together with the Guest Editors concerning the State of Art of the High Speed Electrical Machines and Drives [1]. In this paper a reviews of the current technologies used in high speed electrical machines applications is discussed through an extensive survey of different topologies developed and built in industry as well as in academia. In addition, the developments in materials and components including electrical steels and copper alloys are reported too.

The other 18 accepted papers have been grouped in several parts taking into account their main topics.

The first part concerns the presentation of novel motor topologies. In fact, in order to cope with the load request, high speed electrical machine applications often require innovative electromagnetic structure and the three papers present very interesting novel and innovative machine structures. The first paper, by A. Tuysuz *and others* , presents a novel motor topology with a lateral stator useful for drilling applications where the space in the tool head is limited [2]. The stator of the motor grows in one lateral direction, allowing for a compact direct drive design. The second paper, by J. Ikaheimo *and others*, discusses of a new type of synchronous reluctance rotor with a mechanical robust structure [3]. The two pole rotor design incorporates soft magnetic flux guides inside a non-magnetic matrix material. The third paper, by B. Gaussens *and others*, deals with new topology of Hybrid Excited Flux-Switching Machine (HE FSM) with excitation coils located in stator slots or inner DC windings [4].

The high speed electrical machines and drives are enlarging the field of application where the direct drives are adopted instead of the classical lower speed drive connected to mechanical gears. As a consequence, in order to better understand the new application performance requirements, a presentation of the innovative application areas driving the development of high speed machines and drives has been included too. For this reason, the second part deals with four interesting applications of high speed electrical machines and drives. The first paper. by J. Sloupensky *and other*. presents an interesting high-speed drive and frictionless suspension system for textile applications [5]. The new rotor spinning unit is an innovative textile technology potentially leading to higher productivity, reduced power consumption and dust deposit. The second paper, by L. Solero *and others*, discusses a solutions for developing a direct coupled electric drive to be used in combination with a radial turbo-expander for exhausts energy recovery in automotive applications [6]. The high speed machines and drives play an important role in automotive applications and the third paper, by J. Abrahamsson *and others*, is on that topic again[ 7]. The paper is concerning the design and optimization of a 30,000 rpm kinetic energy storage system. The device is used as an energy buffer storing up to 870Wh, in urban vehicles. The fourth paper, by A. Tenconi *and others*, is concerning high speed machines used in Electrical spindles [8]. The paper summarizes and discusses the electrical and mechanical aspects involved in the high speed machine design, highlighting the main problems and the trade-offs that the designer must consider. Correlation between volume reduction and the speed increase, based on commercial high-frequency rotor-stator units, is discussed as well.

The design of high speed machines represents a challenge from the electromagnetic and mechanical point of view. The high supply frequencies lead to an increase both of the iron losses in the stator laminations and of the additional losses in the winding due to the skin effects.

For the previous reasons, the third part groups 6 papers concerning the electromagnetic design of high speed electrical machines. The first paper, by H. Qiu *and others*, discusses the use of rotor sleeve and their influence on the electromagnetic characteristics [9]. The analysis is carried out on a super high speed permanent magnet generator. The second paper, by D. Gonzales and D. Saban, studies copper losses in a 5.0 MW, high-speed permanent-magnet machine designed with form-wound winding [10]. In particular, the impact of the slot configuration on the proximity effect is analyzed considering open and semi-closed slots. The third paper, by M. Dems and K. Komeza, analyzes the use amorphous laminations small induction motor stator core with high frequency supply [11]. The fourth papers by, H. Qiu *and others*, presents a super high speed permanent magnet generator which has an alloy sleeve on the rotor outer surface [12]. The sleeve used to fix the permanent magnets and protect them from being destroyed by the large centrifugal force influence the rotor eddy current losses generated in the alloy rotor sleeve, increasing the machine temperature. The fifth paper, by M. Van der Geest *and others*, deals with a simple and flexible method to estimate stator parasitic effects, such as skin and proximity effects producing uneven distribution of the currents across the winding strands and additional circulating currents [13]. The last paper, of this part, by L. Papini *and others,* is about the design of a high speed permanent magnet motor to be used in fault tolerant operation [14]. A multidisciplinary approach to the optimal design of the machine is adopted minimizing the additional losses resulting from faulty operating conditions and accounting for the remedial control strategy.

From the mechanical point of view, the high rotational speeds bring into play problems concerning the mechanical stresses due the peripheral speed and the right selection of the bearings. As a consequence, the fourth part is constituted by two papers concerning the mechanical and bearing problems in high speed machines. The former. written by J. Boisson *an others*, presents an analytical approach for the determination of the mechanical eigenfrequencies of an electrical machine stator [15]. The model is based on the calculation and the minimization of Rayleigh’s quotient and the use of Timoshenko kinematic model. The latter, by A. Looser and J. Kolar, describes a hybrid bearing approach with an aerodynamic gas bearing for load support, a small-sized active magnetic damper concept [16]. The proposed bearing solution enables stable high speed operation of the gas bearing with a minimum of additional complexity and costs.

The high rotational speed and consequently the high frequency supply increase the problems due to a correct control of the machine. Sophisticated controls requires accurate measurement of the stator currents and of the rotor speed and position and these signal have to be elaborated by high speed hardware (DSP, FPGA, Micro-controllers etc) able to reach the requested high bandwidth. In order to show the possible solutions, the Special Section last part includes three papers on high speed drives and related control strategies. The first paper. by D. Marcetic *and others*, presents the performances of a high speeds shaft-sensorless drive performance with a very low sampling to fundamental frequency ratio [17]. The second paper, by A. Hasanzadeh *and others*, present a multi-platform hardware-in the-loop approach to observe the operation of a high speed permanent magnet synchronous generator coupled with a micro-turbine in an all-electric-ship power system [18]. The third paper is written by H. Mitterhofer *and other*, and it deals with the high speed capacity of bearingless discussing a high speed bearingless disk drive, designed to reach speeds of beyond 100,000 rpm [19]. In the paper, the mechanical properties and the control system requirements necessary for high speed operation are described too.

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