ERCIM "ALAIN BENSOUSSAN" FELLOWSHIP PROGRAMME

ERCIM
European Research Consortium for Informatics and Mathematics

Scientific Report

First name / Family name	Firdausa Ahmed
Nationality	Indian
Name of the *Host Organisation*	VTT Technical Research Centre of Finland Ltd.
First Name / family name of the *Scientific Coordinator*	Pippuri-Mäkeläinen Jenni
Period of the fellowship	01/09/2021 to 31/08/2022

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During the fellowship I have been actively involved in two research projects. The detailed scientific activities carried out during the fellowship are as follows:

(i) Research project 1: Multiscale Optimization of Additively Manufactured Magnetic Cores for Electrical Machines (ADDMAG).

- The ADDMAG consortium, formed by Tampere University (TAU) and VTT Technical Research Centre of Finland Ltd, ambitiously aims to take a leap in the utilization of additively manufactured (AM) soft magnetic cores in electrical machine applications. In particular, the plan is to benefit from the flexibility of AM techniques for achieving novel core structures for transverse-flux machines (TFMs), in which 3-D flux paths can be fully exploited and can be suitable for Electric Vehicle applications. Basic challenge for design of traction drive for EVs is the requirement of high torque density. Transverse flux motors (TFMs), unlike conventional radial motors have the advantage of higher number of poles without reduction in the armature winding space. This enables TFMs to have separate electrical loading and magnetic loading. In TFM, the flux enters segments of stator core in transverse manner i.e., perpendicular to the direction of rotor movement in the crosssection plane, therefore, it is called transverse flux machine. TFMs are classified into three categories namely as follows:

- TFM with active rotor where the exciting permanent magnets are placed on the rotor
- passive type, where permanent magnet is on stator
- reluctance type without permanent magnets.

The study is initially started with a detailed literature review of Transverse Flux machines. The literature review has been categorized as follows:

(a) Constructional topologies of Transverse Flux Motors with Permanent Magnets and Transverse Flux Reluctance Motor.
(b) Various structures of stator and rotor cores
(c) Types of winding
(d) Types of airgaps
(e) Application in electric vehicles particularly in e-bikes
(f) Control methods of Transverse flux reluctance motors.

- Modeling and design of Transverse Flux Permanent Magnet Motor:

A basic transverse flux permanent magnet motor (TFPM) is selected as an initial design to study the behavior of the machine. An outer rotor configuration with U shaped stator and I-core bridges are considered. The dimensions and sizing of the motor are calculated in MATLAB by using the mathematical equations of electric motor design based on standards. An e-bike application with speed limit as 25 km/hr is taken as reference. The maximum torque required for the selected e-bike is calculated as 36.78 Nm, the power rating of the motor is taken as 1kW and the number of phases as 3-phase. The calculated dimensions are then used to develop a finite element-based model in COMSOL©. Initially, a sector symmetry model for one phase is developed in COMSOL considering linear materials. A parametric analysis has been done for varying currents, varying pole pair numbers, air-gap length, pole pitch, and rotational angle and the results of torque and emf have been obtained. From the parametric analysis the pole pair numbers, airgap length, pole pitch and the maximum current of the motor has been fixed to obtain the required maximum torque. The model is further analyzed for non-linear materials and the results of torque and emf have been compared with the linear material model. The results obtained from the FEM analysis are of good significance and match. Further, a time dependent analysis has also been done to compare the results of emf obtained from the static analysis.

- Modeling and design of Transverse Flux Reluctance Motor:

The study is further carried out in designing a three-phase transverse flux reluctance motor (TFRM). Unlike the TFPM, the TFRM works on the principle of reluctance torque and does not contain magnets on the rotor side. A TFRM is selected having U-core shape stator tooth with a circumferential winding along it. It has a double salient topology and has the same number of poles on both stator-rotor parts and each phase can be modelled as an independent module. The dimensions of the motor are calculated using mathematical equations for reluctance-based motor in MATLAB. The calculated dimensions are further used to develop a finite element model in COMSOL©. In this case, a sector symmetry model of one phase TFRM is analyzed having 24 number of rotor and stator poles. The objective of this study is to drive the TFRM model as a switched reluctance motor drive. Hence, the TFRM must be supplied with switched currents at regular intervals, with respect to rotor position such that continuous positive torque is obtained. A parametric analysis has been done for varying currents, from one aligned rotor-stator position to the subsequent aligned position. The flux linkage characteristics and the torque profile has been obtained. In case of 24 poles TFRM, for one complete rotation of rotor, the rotational angle is 15 deg. It could be observed that the torque is positive for only 7.5 deg of rotational angle, hence the conduction angle of current is fixed based on the positive torque region.

To drive the TFRM as a direct drive system, a basic control methodology has been developed in MATLAB/Simulink software environment. The control methodology used is similar to a switched reluctance motor control. The TFRM must be supplied by a power electronic converter which gives unipolar pulses of phase currents, precisely synchronized with the rotor position. A current control with PWM generation is used as the controller for torque and a PI controller for speed control. A PWM signal is generated as control signal, with respect to rotor position and a reference current, which controls the turn-on and turn-off angle of the gates of the converter circuit. A three-phase asymmetric bridge converter is used for the switched power supply. The FEM data of flux linkage, current, rotor angles obtained from the FEM model are used as look up table in the TFRM model in Simulink. The results obtained from the controller are of good significance and the current reaches the maximum reference value of 25 Amps at 0.5 secs. The average torque is observed as 1.5 Nm and peak torque per phase as 2.8 Nm. The magnitude of torque obtained is low, however it has been observed that by switching the current at each phase sequentially a continuous torque can be obtained in TFRM. This study signifies that TFRM can be controlled like a switched reluctance motor drive system.

The models and methods developed in this project serve as a basis for further design and optimization tasks of transverse flux motors for additive manufacturing and prototyping of TFRM.

- Future work:
  (a) a topology optimization of the TFRM model in COMSOL.
  (b) an advanced control drive system for TFRM.
  (c) prototyping of the proposed motor.

- In addition to the design and modelling work of Transverse flux motors, I have also been a part of testing and experimental measurements of a switched reluctance motor prototype developed using additive manufacturing. The motor prototype has been successfully tested with a speed-current controller and demonstrated at high speed. The measurements include phase voltages, phase currents and power of the motor.

(ii) Research Project II: Magnetic Screw

- This project includes experimental testing and measurement of a prototype of Magnetic Screw. I have been actively involved in developing a real time measurement program using FPGA in NI Compaq Rio (cRIO) systems. The objective of the work focused on measuring the torque, rotational angle and the linear position of the magnetic screw which is run at a constant speed by a DC motor. The work also included few activities of fabricating circuits for generating isolated digital pulse signals from the rotary encoder output to be fed into the digital input module of cRIO system. I have also worked in developing a circuit for controlling remotely the output voltage of the DC power source using a program in cRIO.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

- None. To be submitted in near future.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

A conference paper accepted for presentation entitled '**Coupled FEM/Simulink Modeling of Transversal Flux Synchronous Machines with Core Losses by Lookup Tables and Proper Orthogonal Decomposition'** at the 20th International IGTE Symposium to be held from September 18-21, 2022 in Graz, Austria**.**
Authors: Alex Aaltonen, Joonas Vesa, Firdausa Ahmed, Jenni Pippuri-Mäkeläinen and PaavoRasilo

IV – RESEARCH EXCHANGE PROGRAMME (REP)

Attended a Research Exchange Programme (REP) to the Department of Electromobility, RISE, Research Institutes of Sweden, Gothenburg, Sweden from 15th -19th of August, 2022. During this research exchange programme, I have been actively involved in design and modelling of an asynchronous motor with higher number of poles for its application on an Indian tuk-tuk (three-wheeler) and its conversion to an electric vehicle for public transportation. The project is led by Professor Stefan Pettersson, Director of RISE Mobility and Systems-Electromobility. The host institute also introduced me with the team of SEEL, Swedish Electric Transport laboratory and made a visit to the laboratory. Professor Stefan also introduced me to the team of additive manufacturing and organized a visit to the laboratories. The meeting and discussions were very helpful in exchange of ideas and knowledge and helped in building relations between VTT, Finland, RISE, Sweden and India for future collaborative projects on e-mobility.