MODELING AND ANALYSIS OF HIGH-SPEED PMSG USED IN AIRCRAFT APPLICATIONS

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Astract—The permanent-magnet synchronous generator (PMSG) specification for high speed applications is analysed and a compatible specification is arrived at using analytical design relations. For this application, high-power density above 0.03kW/kg is required. To identify the best topology and to fulfil the given requirements, various design solutions for the PMSG are taken into account. This contains various six-phase winding configurations to minimize losses or weight. Moreover, a possible magnet and various sleeve materials are taken into account in order to ensure mechanical stability. A high-speed permanent-magnet synchronous generator (PMSG) with a continuous power of 5 kW as a turbo generator for the usage in aircrafts is designed for varied specifications to obtain less weight and smaller size. The machine is modeled using CATIA and analyzed using ANSYS software to check suitability of the selected specifications.

Keywords: PMSG, Turbo Gas Turbine, FEM.

I. INTRODUCTION

A Permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The term synchronous refers to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature.

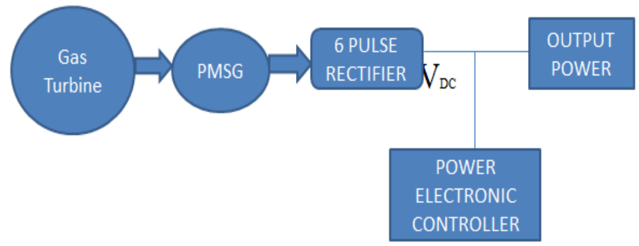
The permanent magnet synchronous generator is regarded as a primary source of electrical energy which is commonly used to convert the mechanical power of steam turbines, gas turbines, reciprocating engines and hydro turbines into electrical power for various purposes.

Commonly these generators are referred to as synchronous generator as they functions at a synchronous

speed which equals the speed of the rotor matches the supply frequency. They are known as the synchronous generators because the frequency of induced voltage in the stator is proportional to speed, the rotation rate of the rotor.

High speed permanent magnet machine have better Power weight ratio, smaller in size, and higher efficiency compared to induction machine which makes them a preferred choice for aircraft and marine applications that use gas turbine for the mechanical input.

The design is attempted for missile or rocket launcher application with a need of maximum radius 80mm, weighing about 5kg, subjected to operating to less temperature range and constant voltage for varying speed range with rating of 5kW and 30000 rpm. A symmetrical six phase machines are designed for functioning in autonomic systems, like electric energy generation in wind system, electric traction, alternators, and exciters in electric propulsion submersible systems.



II. DESIGN ASPECTS

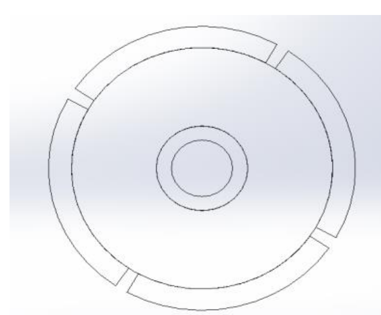
A. Machine Type

The number of suitable machine for high speed operations is severely restricted; the choice of alternator type would be limited to one that is ruggedly constructed and capable of high speed operation. For this purpose durability of the rotor at high speeds is first considered.

The main challenges in the design of the electrical machine are the losses due to the high frequency in the stator core and windings, the rotor dynamics and the rotor design minimizing the mechanical stresses. A PM machine is chosen with the aim of a low system volume, low maintenance cost, high efficiency and low loss.

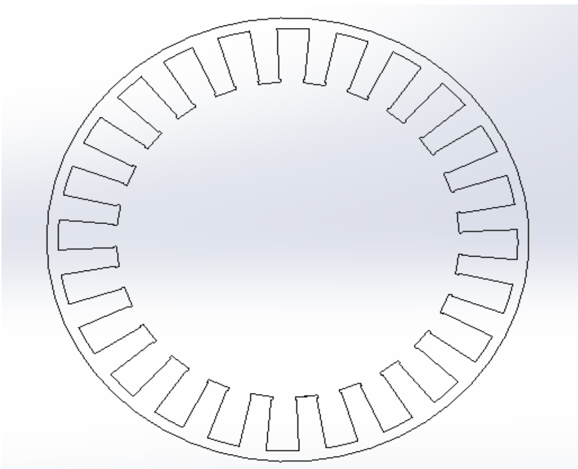
B. Rotor Configuration

Permanent magnet chosen as it gives efficient machine in which the pole pitch can make small leading to a light core and low end winding losses. The magnet material preferred is Neodymium Iron Boron (NdFeB). It has higher flux density and lower price compared to Samarium Cobalt (SmCo). Radial flux design allows simple generator structure, good utilization of active materials, small diameter since stator can be long and easy construction with a slotted stator. The radial flux machine with surface magnet is as shown in the figure.



C. Stator Configuration

The stator is the stationary part of the machine's electromagnetic circuit and usually consists of windings. Six phase machines are generally analyzed as two sets of three phase windings that are displaced 30 degrees in space. The PMSG modeled is a symmetrical six phase stator with each winding having 60 degree displacement in space. The advantage in this is an improved fault tolerance.



III. ANALYITICAL DESIGN

This section focuses on entire machine dimensions such as rotor and stator dimensions. The dimensional formula are predicted based on this relation

A. Stator Dimensions

Stator dimensions are calculated by using following analytical formula:

$D_i = D_o – 2$(slot height + stator yoke height).

The slot top diameter = D_i+2.

The slot width at the top = (π*slot top diameter/S) – T.

Where, S is the number of slots, T is the tooth width, D_i is inner diameter of stator, D_o is outer diameter of stator

Diameter of the bottom slot =D_i+S_h+2

Where S_h= height of the slot

Width of bottom slot = (π*diameter of bottom slot/S) – T

Winding Detail:

Conductor Area = (π*(conductor dia)2*strands)/4

B. Rotor Dimensions

Rotor dimensions are calculated by using following analytical formula:

$D_r= D_i– 2(\delta)$

Where, D_r is the rotor outer diameter, δ is an air gap length

Ma = (D_r – M_h) *π*α*Stack length/180P

Where, Ma is area of magnet, M_h is height of the magnet and P is the number of poles, α is the pole magnet angle.

Calculation of permeance:

$P_m = P_{mo}(1+P_{rl})$

Where P_m is Total permeance, P_{mo} is Magnet permeance, P_{rl} is rotor leakage permeance.

$\varphi_g = \varphi_r/0.1+P_m*R_g$

Where, φ_g is flux in airgap and R_g is the reluctance in airgap.

$B_g = C_p*B_r/0.1+P_m*R_g$

Where, B_g is airgap density, C_p is the concentration factor, B_r is remanent flux density.

$B_m = 1+P_{mo}*P_{rl}*R_g/(1+P_m*R_g)*B_r$

Where B_m is the magnetic flux density.

C. Calculation Of Losses

Total loss is given by,

Ptot = Copper loss + Core loss + Teeth loss + friction loss.

Copper loss = $6*I^2R$

Friction loss = $Kf_{ri}*P_{out}$

$P_{in} = P_{tot} + P_{out}$

$\eta = P_{out} / P_{in}$

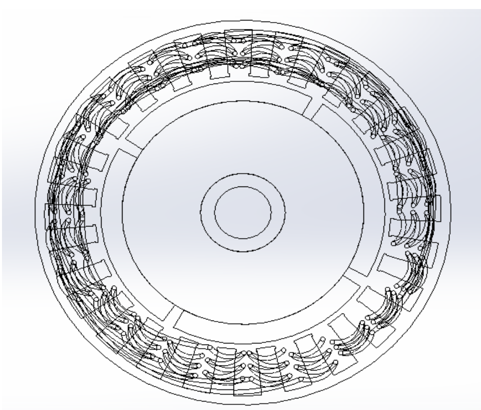
Where, P_{out} is the power output, P_{tot} is a Total loss, P_{in} is the power input, η is an efficiency.

IV. DESIGN USING CATIA

In this section general specifications and design data are tabled. In that manner design specifications are presented in TABLE I. Also detailed design data like stator, rotor etc. are presented respectively.

GENERAL DATA	
Design parameter	Assigned values
Speed	30000 rpm
Power	5 kW
Power density	>0.03kw/kg
Efficiency	>0.94
Permanent magnet	Neodymium iron boron (NdFeB)
Machine length	80mm

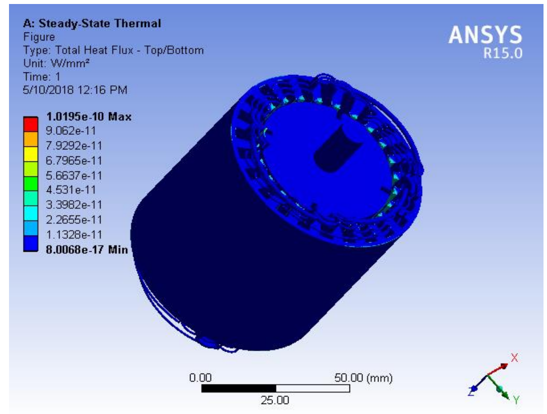
The following figure shows the assembled view of the following components such as shaft, rotor, magnet, stator and winding coil.



V. THERMAL ANALYSIS

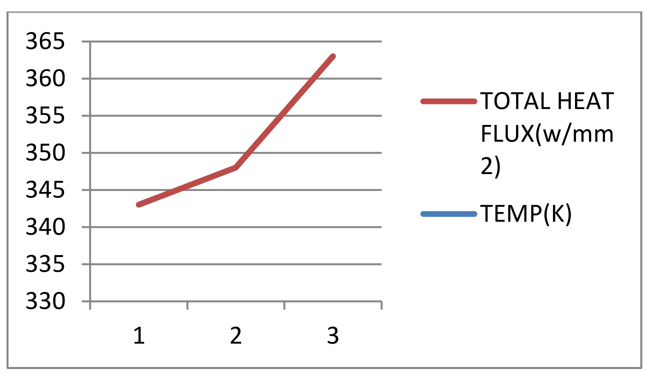
The thermal analysis of the generator depends strongly on the design and the mechanical coupling to the gas turbine. Due to the small size of the whole system and the close proximity of the generator to the turbine, high speed generator operating temperature are to be expected. Therefore, the temperature limits for different materials are determined and compared, in order to insure the highest possible operating temperature. A meaningful thermal analysis can only be undertaken for an integrated system with a gas turbine.

Thermal analysis of designed PMSG done by using software ANSYS Version 15. The analyses are done under three operating temperature and under different loading conditions. Let us consider three different operating temperature according to the loading condition. The following results are given below



The heat flux generated under different loading condition is measured and tabulated. The given table shows the heat flux generated under different loading condition and the graph is drawn with respective measures.

TEMP(K)	TOTAL HEAT FLUX(w/mm2)
343	1.02E-10
348	1.09E-10
363	1.32E-10

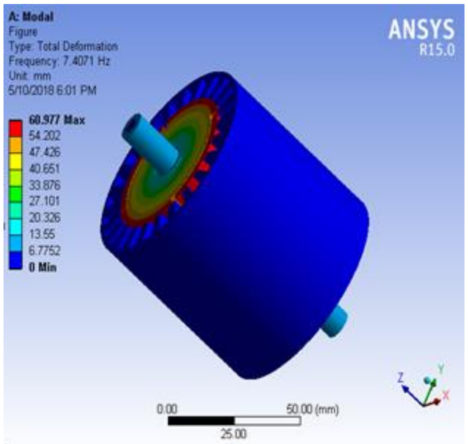


The temperatures variations in the significant parts of the machine are obtained, the thermal values estimated are within the thermal limits for the selected class of material and design specifications.

VI. MODAL ANALYSIS

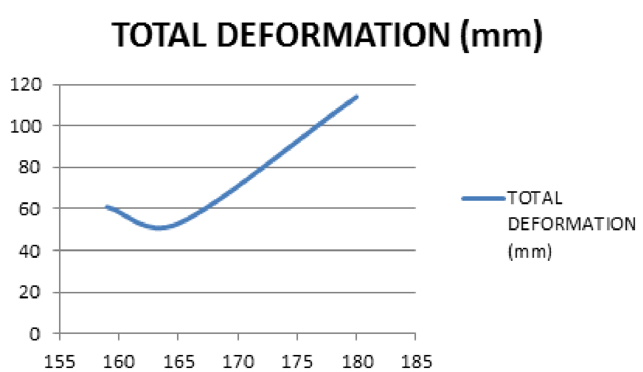
The dynamic properties of structure under vibrational excitation. Modal analysis is the field of measuring and analysing the dynamic response of structures. Modal analysis of a machine is done under different load force and the total deformation of the machine is obtained using ANSYS software.

The analysis variation is as show in the figure below



LOAD FORCE(MPa)	TOTAL DEFORMATION (mm)
159	60.977
165	52.953
180	114.04

The deformation occurred under different loading condition is measured and tabulated above. The given table shows the deformation occurred under different load force and the graph is drawn with respective measures.



The temperatures variations in the significant parts of the machine are observed and the total deformation is within designed parameter.

VII. CONCLUSION

This paper is a simplified analytical method is used for obtaining the electrical and magnetic parameters of the high speed permanent magnet synchronous generator, the geometric and performance parameter are also analysed. In this it also provides substantial insight into a full design of high speed permanent magnet synchronous generator using CATIA software. The thermal, modal and magnetic analysis for Permanent magnet synchronous generator by using ANSYS software package is evaluated and the results were obtained. The variations in the significant parts of the machine are obtained; the thermal and modal values estimated are within the limits for the selected class of material and design specifications

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