Transient Performance Simulation and Analysis of AC Exciter in Aeronautic AC Power Supply Based on Maxwell 2D

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***Abstract*—Software package which includes RMxprt for Motor design, Maxwell 2D for electromagnetic computation, Simplorer for complex circuit simulation of Ansoft Corporation has played an role in system simulation fields like a set, but it has disadvantage in design AC exciter in aeronautic AC power supply with armature rotating. There has no input module in RMxprt, therefore this paper establishes two-dimensional transient electromagnetic model for this kind of generator with Maxwell 2D directly and simulates magnetic dimensional distribution, electromagnetic and circuit parameters variation under unloading condition. By contrast with the actual experimental values, it verifies the practicability of the model. Meanwhile, the model can be available to design and optimize this type of machine and other transient investigation analysis.**

***Keywords*—Aeronautic AC Power Supply, AC exciter with Armature rotating, Unloading, Maxwell 2D**

I. INTRODUCTION

Recent years with requirements of national and international improvement of aeronautic and astronautic filed devotion, aeronautic and army power supply system have promptly developed. Because it is essential to make more sense of independence and innovation than before, software characteristics and half physical simulation have been applied in aeronautic research and development organization. Currently, several types of power supply system are widely used in aeronautic and astronautic field, including low voltage DC, high voltage DC system. Among high voltage DC system there are three types as variable speed and constant frequency (VSCF), constant speed and constant frequency (CSCF) and high voltage DC (HVDC) system [1]. Moreover, brushless synchronous generator with rectifier rotating is the core component of CSCF, VSCF and HVDC system. It adopts the brushless excitation and cancels the slip touching parts, so it has the advantage of convenient maintenance, high reliability, long continuous operation time, fit for the vocation of self-management and has an extensive application foreground. B707, B737 airplane adopt two-level brushless AC generator system, and B747, B757, B767, MD-82, A320 adopt three-level one, French battleplane of phantom-2000 adopts three-phase electromagnetic CSCF system, and American battleplane of F-16 adopts three-phase mechanical and hydraulic CSCF system [2]. It applies not only in aeronautic field, but also in electrical engine traction, naval vessel boosting, platform of oil artesian well and large scale of electric power station brushless excitation devices [3]. Therefore its transient characteristic problems are the core point for research.

Ansoft is an American software package especially designed for airplane, aeronautic and astronautic, electric power, electric drive and control system which includes not only simulated, digital mixed signal electric circuitry, but also mechanic structure, electro-mechanical apparatus, hydraulic and other multi physical field system. However, AC exciter has the specific structure of armature rotating, and there is no corresponding design model in RMxprt of Ansoft. Therefore this article directly establishes two-dimensional transient model by Maxwell 2D. The practicability can be seen from a concrete instance.

II. CHOICE OF FINITE ELEMENT MODEL OF AC EXCITER

Manufacture design and optimization of generator require most credible data which can be attained by electromagnetic numerical analysis and simulation. Most highly cost physical experiments can be substituted by numerical simulation, therefore simulation has been put on emphasis abroad in corporation, research organization and universities. Finite Element Method (FEM) is a common numerical method, which divides the whole area into many small units, makes each unit computation simple by choosing proper figure function. With the summation of all these simple computations of the whole units, it gets the solution of the whole area with entire matrixes. According to transient characteristic simulation research of three-level synchronous generator system, the ideal condition is to establish electromagnetic finite element model of single generator, choose static filed, transient filed or other solver to analyze static, stable, transient, normal and fault operational performance. Maxwell 2D has adaptive grid subdivision technology. User can define material library, high performance matrixes solver, multi CPU process ability and prompt solution speed. Because AC exciter has symmetry structure of axis orientation, transient field solver can be adopted for finite element analysis with Maxwell 2D.

III. TWO-DIMENSIONAL TRANSIENT FINITE ELEMENT MODELING OF AC EXCITER

From this chapter, a certain aeronautic AC exciter has been investigated for the whole two-dimensional transient finite element modeling process.

A. Choose Transient Solver and XY Coordinate

According to the transient performance of AC exciter, Transient solver has been chosen with Maxwell 2D. In the geometry modeling process, ".dwg" file with AutoCAD or ".prt" file with Unigraphics can been converted into ".dxf" file and imported into Maxwell 2D to create original model of the generator.

Although this imported function is compatible with Maxwell 2D, the minimum unit in Maxwell 2D modeler window is somewhat limited that some mistakes may occur. In this case, arc line in stator pole has been distorted when importing ".dwg" file with AutoCAD into Maxwell 2D.

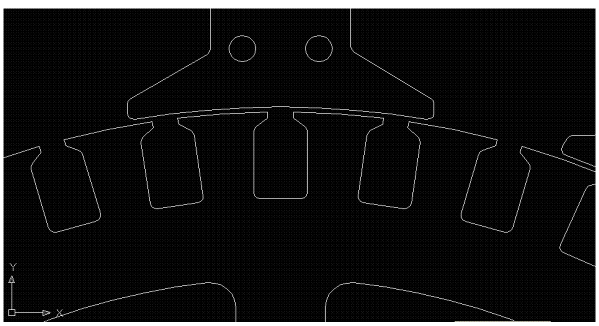

Figure 1. Original stator lamination file with AutoCAD

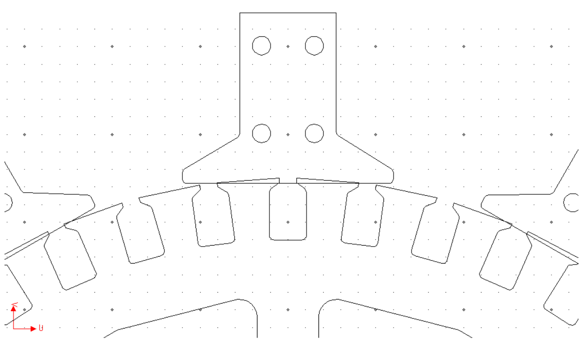

Figure 2. Distorted model when imported into Maxwell 2D

As figure 1 has shown, stator lamination file is regular with AutoCAD. While converting into ".dxf" file and importing into Maxwell 2D, arc part in stator pole shoe generates serious distortion. This is because Maxwell 2D cannot reduce geometry modeler unit without limit. It can lead to the failure of save file and uselessness of the importing file, which is the disadvantage for complex generator modeling.

Solution has been made in this article. First, it imports rotor lamination part file with AutoCAD which can avoid of complex rotor structure plot with Maxwell 2D. Second, it directly draws stator pole and yoke in Maxwell 2D modeler. Figure 3 shows the correctness of geometry structure establishment.

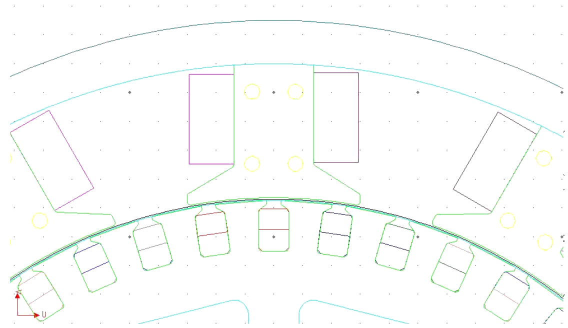

Figure 3. Geometry model with the combination of AutoCAD and Maxwell 2D

With contrast to normal pole rotating structure in most generators, AC exciter has armature rotating structure, i.e. pole belongs to stator and armature winding belongs to rotor. Although the relation of relative motion does not change at constant speed, the complexity of transient finite element modeling is much high than that with pole rotating structure. Too small grid will lead to non-convergence of iteration equations and final results will not be computed. On the contrary, too large unit will cause worse error since grid distortion during rotation and make computation no sense eventually. Therefore, how to establish the mathematic finite element transient model is the pivotal problem discussed in the article.

B. Material Property Definition

In the instance, stator magnetic pole adopts DT3 pure iron slice with distance of 0.5mm. And stator yoke adopts 10# hot-rolled steel tube. Moreover, rotor armature lamination adopts DW310-35 silicon steel sheet with distance of 0.35mm. DC magnetization characteristic data of the three materials can be checked from "usual material manual of motors".

C. Boundary Condition and Excitation Definition

There are three boundary conditions currently, Dirichlet boundary condition, Neumanm boundary condition and the combination of the two above.

The expression of Dirichlet boundary condition is,

$$A\big|_{\Gamma_1} = g(\Gamma_1) \qquad (1)$$

In (1), Γ_1 presents Dirichlet boundary and $g(\Gamma_1)$ presents common position function. In special conditions, $g(\Gamma_1)$ can be constant or zero. Dirichlet boundary condition states the magnetic force in a certain boundary is fixed. In this case, some distance away from AC exciter can be defined zero magnetic force.

The expression of Neumanm boundary condition is,

$$\left.\frac{\partial A}{\partial n}\right|_{\Gamma_2} + \sigma(\Gamma_2)\cdot A\big|_{\Gamma_2} = h(\Gamma_2) \qquad (2)$$

In (2), Γ_2 presents Neumanm boundary, n is the outside normal vector boundary, $\sigma(\Gamma_2)$ and $h(\Gamma_2)$ present common function. In special conditions, $\sigma(\Gamma_2)$ and $h(\Gamma_2)$ can be set constant or zero. Neumanm boundary condition usually expresses the symmetry of geometry size and excitation. In this case, stator of AC exciter has six pairs of poles. To decrease the computation time, one sixth structure of magnetic force can be computed accordingly, while the others can be attained by symmetry.

If common function in both Dirichlet boundary condition and Neumanm boundary condition are zero, the boundary can be simplified to homogeneous Dirichlet boundary condition or homogeneous Neumanm boundary condition expressed as (3).

$$\begin{cases} A\big|_{\Gamma_1} = 0 \\ \dfrac{\partial A}{\partial n}\Big|_{\Gamma_2} = 0 \end{cases} \qquad (3)$$

In (3), the first condition states the magnetic force function in a certain boundary is zero. Because 1.5~2 times radius distances can be set the zero magnetic force and zero electrical force position, homogeneous Dirichlet boundary condition is fit for this kind of boundary. While the second condition of (3) states magnetic force function rate of change in a certain boundary normal orientation is zero. In this case, AC exciter has six pairs of poles, therefore magnetic force and electrical force in any pair of poles can be computed and thus get the whole electromagnetic distribution by symmetry.

Since the phenomenon is not so evident in outer magnetic leakage, homogeneous Dirichlet boundary condition is adopted. The magnetic force 1.5 times radius distance out of AC exciter equals to zero, i.e. $A\big|_{\Gamma_1} = 0, \Gamma_1 = \odot 1.5\, R_{outer}$. Moreover, all the structure has been drawn that homogeneous Neumanm boundary condition is rejected.

D. Finite Element Adaptive Grid Subdivision Definition

The number of grids directly influences the precision of computation. The larger number it has, the more space and internal memory it should offer, thus the less convergence and the longer time it has. Some area may occur with the incorrect results caused by too many grids and non-convergence arithmetic. On the contrary, the smaller number it has, the less variable range sensitivity in large radian area it has and the less solved correctness it has. Generally speaking, it is primary for modeling to choose grid subdivision units reasonably.

Maxwell 2D has adaptive subdivision technology which can improve grid precision in partial large curvature and small air gap areas. Meanwhile, it also includes P unit and U unit adaptive subdivision, which are based on medium result and automatically confirm the densified grids area during mesh making (called h-adaption) or increase grid polynomial order in the area (called p-adaption). By credible arithmetic it monitors h-adaption and p-adaption until the error meets the tolerance predicted. Figure 4 shows the basic grid subdivision by choosing area subdivision number 6.

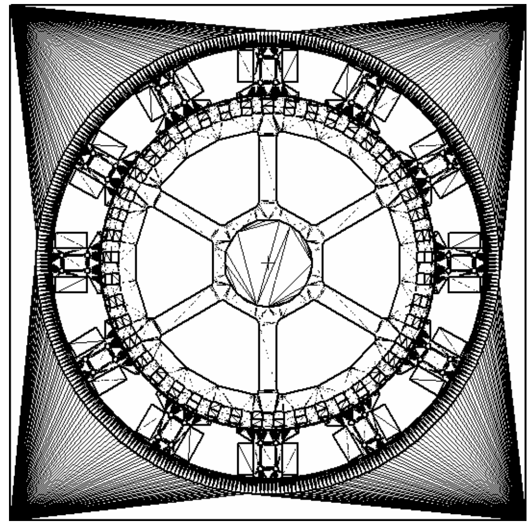

Figure 4. Finite element grid subdivision choosing area subdivision number 6 of AC exciter

Seen from figure 4, the grid subdivision choice near pole shoe, armature tooth, inside slot, inside magnetic pole, inside excitation winding of stator and inside rotor armature areas are all unsuitable, therefore partial refinement is finished as figure 5 shown.

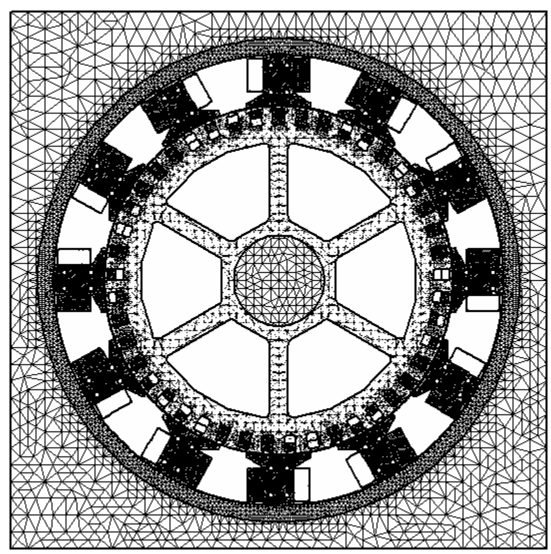

Figure 5. Grid subdivision refinement of AC exciter

E. Primary Conditions and Solution Criterion Definition

There are several details in primary condition definition, including motion band partition, mechanical definition, simulation time span, step, error requirement, solver arithmetic, mirror and etc.

AC exciter has armature rotating structure that previous overall subdivision methods in the air gap area are unfit for. On one hand, re-subdivision is needed in each simulation step, thus the computing period is largely increased. On the other hand, partial convergence will be changed since grids change in air gap area during rotation, which will lead to error increasing. Air gap boundary layered method has been introduced in this article. The process is to draw two completely coincide arcs in the middle of air gap which can divide the air gap into two parts. One belongs to stator and the other belongs to rotor. Stator air gap is fixed in stator coordinate, while rotor air gap is synchronously rotating with rotor. In each simulation step, grids among stator air gap are stead while those among rotor air gap are adjusted. Such method can effectively decrease overall subdivision in every step and increase simulation efficiency.

Synchronous speed is set to 8000rad/min, simulation time span is [0-0.15]s. Because each 360 electrical degrees rotation cost 1.25ms, the simulation step is set to 0.3125ms and field preservation period is 0.625ms considering periodic influence of tooth and slot of AC exciter. The error tolerance requirement for linear area is 0.001 and that for nonlinear area is 0.005. The solver chooses direct solver and mirror is set to 1.

IV. Solution Hardware Configuration and Simulation Waves Anaylsis

Hardware configuration is: Intel(R) Xeon(TM) CPU 3.06GHZ, 2.00GB memory. In the above primary condition, simulation costs 7 hours and 31 minutes. Three terminal voltage characteristic waves in [0-0.15]s under unloading condition are presented in figure 6.

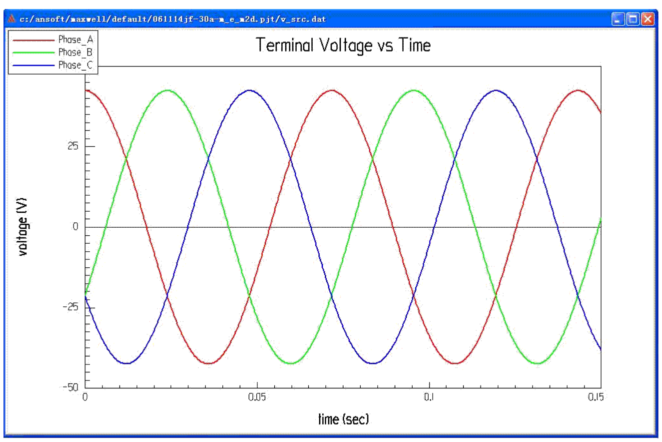

Figure 6. Three terminal voltage in [0-0.15]s under unloading condition of AC exciter

Seen from figure 6, the simulation unloading effective value is 32.5V, and the actual experimental value is 31V. Thus the error is 4.8% or so.

Simulation excitation back magnetic force is 14.5V or so, and the actual experimental value is 15.3V. Thus the error is 5.2%. Seen from the above circuit parameters waves, the computed values from two-dimensional transient finite element model have a good accordance with actual experimental values. Therefore it verifies the practicability of the established model.

Moreover, several contrasts with field distribution in [0-0.15]s have shown in the following figures, including magnetic lines of force and flux density variation characteristics.

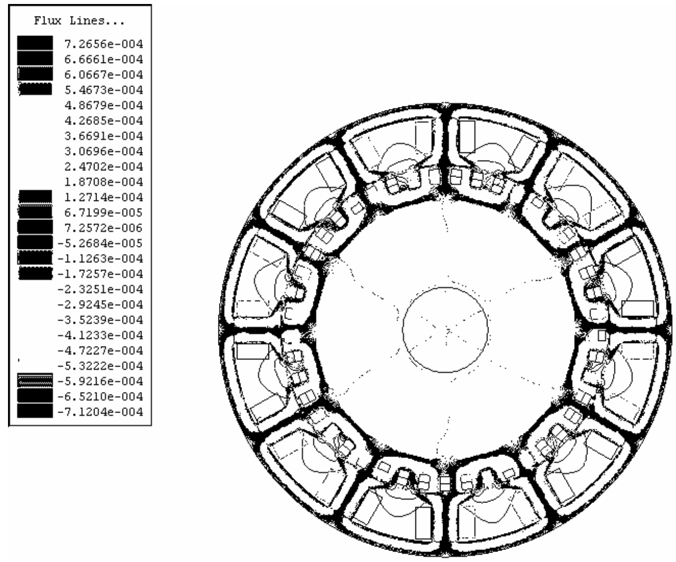

Figure 7. Unloading magnetic lines of force at 1.25ms of AC exciter

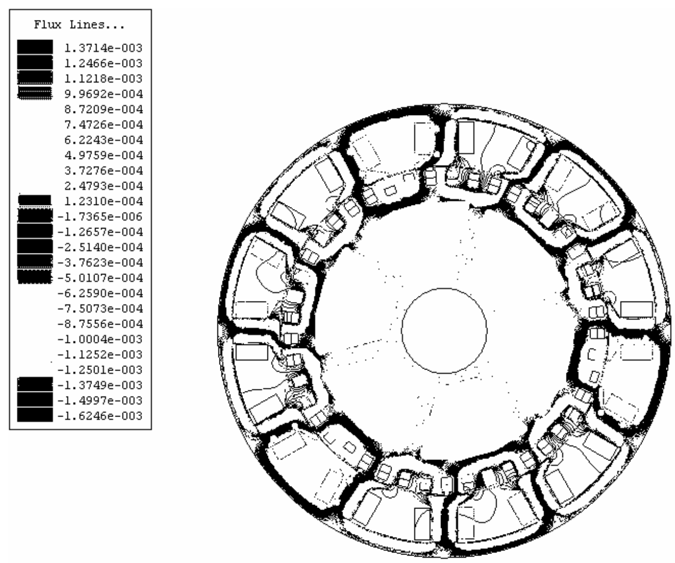

Figure 8. Unloading magnetic lines of force at 90.9375ms of AC exciter

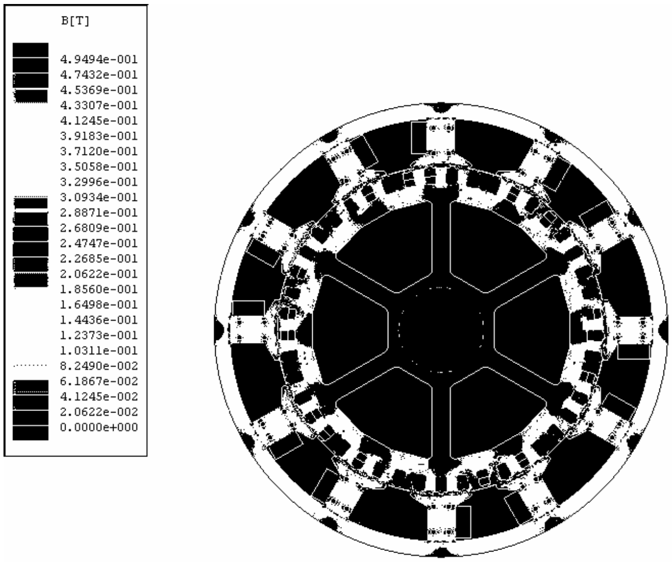

Figure 9. Unloading flux density magnititude at 1.25ms of AC exciter

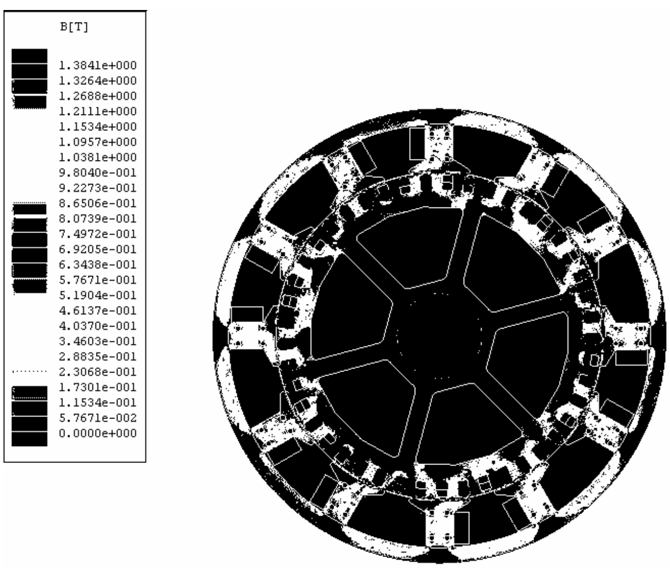

Figure 10. Unloading flux density magnititude at 90.9375ms of AC exciter

Since the specific armature rotating structure of AC exciter, rotor winding currents cannot be measured directly. While through model, these can be simply simulated to get i_a、i_b、i_c and other parameters such as vector magnetic position A, magnetic density B, magnetic chain ψ and magnetic equivalent force line of the whole field space can also be attained. It proves that the finite element model established in this article can truly response the operational principle, transient characteristic inside generator field and circuit. Meanwhile, the model can also be used to investigate the fault operation accordingly.

V. CONCLUSION

This article has established two-dimensional transient finite element model for armature rotating AC exciter with Maxwell 2D and analyzed circuit and field performances under unloading condition. By contrast with simulation and actual experimental values, the model can be proved correctness and practicability. Furthermore, transient magnetic vector computation and variation trends are analyzed quantitatively. The model has played an important role in corresponding generator transient performance analysis and will be extent to other types of armature motors. Moreover, electromagnetic characteristic analysis under stable short-circuit, fault operations will be studied in future to improve fault prediction ability in aeronautic power supply system.

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