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# Research of double claw-pole structure generator

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**ABSTRACT**

*This paper introduces a kind of double claw-pole structure generator for self-excited retarder.Claw pole staggered on both sides of the rotor,axial magnetic circuit constituting the N-pole and S-pole magnetic pole.Based on the JMAG software, we simulated the air gap magnetic field of no-load and load generator, and studied the influence of armature reaction on the air gap magnetic field.Through the analysis of magnetic flux leakage of the generator, and the optimization of correlation structure, we drew the relationship curve about the structure parameters of the no-load motor and magnetic flux leakage coefficient, the conclusion we obtained will provide theoretical reference for the further research and optimization of this kind of motor.Finally, the no-load characteristics and load regulation characteristics of the motor were given, and it turned out that it could meet the required excitation power for self-excited retarder.*

**Key words:** claw-pole alternator; air-gap field; structural parameter; magnetic flux leakage coefficient; load

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## INTRODUCTION

Self-excited type car retarder as an auxiliary brake device for automobile energy saving, environmental protection, and high efficiency, has a good application prospect [1]. As an important part of the retarder the generator's working stability and reliability are essential for the retarder. During the research of the electromagnetic liquid cooled retarder in recent years, the author put forward a kind of self-excited retarder structure which equips a claw pole generator. Based on this generator structure, we simulated and calculated the air gap magnetic field of the no-load and load generator by taking the three dimensional modeling and finite element analysis with JMAG, a electromagnetic simulation software; and we also studied the magnetic flux leakage problem by the analysis of the influence the structural parameters of the motor on the magnetic flux leakage. Finally, we took the numerical simulation of the no-load characteristics and load regulation characteristics of the generator, the results showed that the motor meet the required excitation power for the self-excited retarder.

### Construction principle and physical design of a generator

The schematic diagram of the self-excited retarder with a claw pole generator is shown as in Fig.1 (please refer to literature [2] about the operating principle of retarder). In the retarder, after the full-bridge rectifier, the three-phase AC that generator had generated provides the required excitation current for the retarder, in result, the retarder has no need to achieve self-motivation by taking power from the car battery. According to the retarder technical parameters, we get the basic parameters of the generator: the generator output power $P \geq 2.2kw$, setting retarder load resistor $R = 3\Omega$, the DC output voltage U in the automotive transmission is not less than 90V when the number of revolutions $n = 750rpm$. Claw pole generator proposed in this paper is constructed of the retarder bracket, claw-pole rotor, stator core and the excitation coil. As shown in Fig.2 and 3, this structure has no additional air gap, compared to the claw pole generator [3] of a normal car, it has higher electromagnetic utilization rate as well as higher reliability, therefore, it can realize a brushless construction.

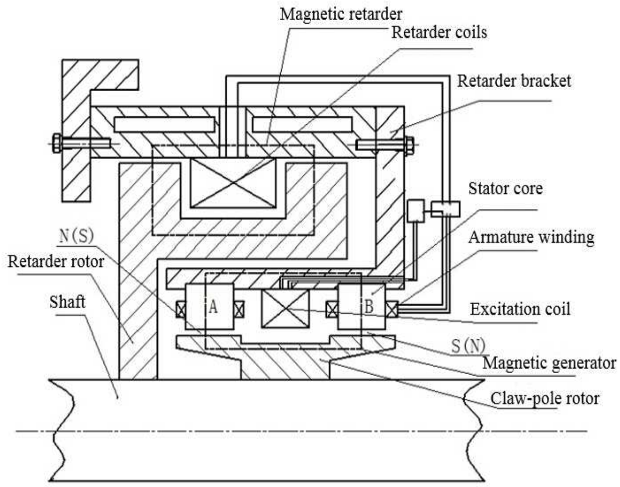


**Fig. 1: Self-excited Eddy Current Retarder**

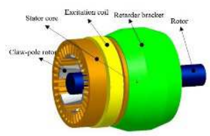


**Fig.2: claw-pole alternator**

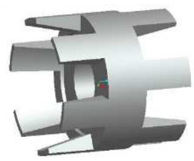

**Fig.3 rotor**

The designed parameters base on working conditions of the claw-pole generator are shown as in Tab.1.

**Table 1 parameters of Claw-pole generator**

| Power /Kw | Voltage /V | Stator outer diameter/mm | Stator inner diameter/mm | Rotor outer diameter/mm | Gap length/mm |
|---|---|---|---|---|---|
| 2.5 | 100 | 318 | 278 | 276 | 1 |
| Number of grooves | length of Unilateral armature /mm | Number of poles | Number of conductors per slot | Pole arc coefficient | Pitch |
| 36 | 70 | 12 | 15 | 0.78 | 6 |

**Three-dimensional electromagnetic field simulation of generator**

Based on JMAG, a kind of finite element simulation software, we conducted the modeling and simulation for the generator. As the structure of the claw-pole generator in this paper is extremely complex and irregular, the magnetic circuit presents typical three-dimensional magnetic field characteristics. For there are three components Ax, Ay, Az in the three-dimensional electromagnetic field vector A, so the finite element method in three-dimensional electromagnetic field is much more complex than in much planar electromagnetic field.

Magnetic field in the motor can be regarded as a kind of three-dimensional constant magnetic field, and thus the field satisfy the following Maxwell equation:

$$\Delta \times (v\Delta \times A) = J(1)$$

Where, $A = \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix}$, $J = \begin{bmatrix} J_x \\ J_y \\ J_z \end{bmatrix}, v = \begin{pmatrix} v_x & 0 & 0 \\ 0 & v_y & 0 \\ 0 & 0 & v_z \end{pmatrix}$

Spread out formula （1）, we can get the following three partial differential equations.

$$\begin{cases} \frac{\partial}{\partial y}\left\{v_z\left(\frac{\partial A_y}{\partial x}-\frac{\partial A_x}{\partial y}\right)\right\}-\frac{\partial}{\partial z}\left\{v_y\left(\frac{\partial A_x}{\partial z}-\frac{\partial A_z}{\partial x}\right)\right\}=J_x \\ \frac{\partial}{\partial z}\left\{v_x\left(\frac{\partial A_z}{\partial y}-\frac{\partial A_y}{\partial z}\right)\right\}-\frac{\partial}{\partial x}\left\{v_z\left(\frac{\partial A_y}{\partial x}-\frac{\partial A_x}{\partial y}\right)\right\}=J_y \\ \frac{\partial}{\partial x}\left\{v_y\left(\frac{\partial A_x}{\partial z}-\frac{\partial A_z}{\partial x}\right)\right\}-\frac{\partial}{\partial y}\left\{v_x\left(\frac{\partial A_z}{\partial y}-\frac{\partial A_y}{\partial z}\right)\right\}=J_z \end{cases} \quad (2)$$

Similarly, according to the definition of vector A, the three components Bx, By, Bz of the magnetic induction B can be written in the following form:

$$\begin{cases} B_x=\frac{\partial A_z}{\partial y}-\frac{\partial A_y}{\partial z}=A_{zy}-A_{yz} \\ B_y=\frac{\partial A_x}{\partial z}-\frac{\partial A_z}{\partial x}=A_{xz}-A_{zx} \\ B_z=\frac{\partial A_y}{\partial x}-\frac{\partial A_x}{\partial y}=A_{yz}-A_{xy} \end{cases} \quad (3)$$

Flux density $B_R$:

$$B_R=\sqrt{B_x^2+B_y^2+B_z^2} \quad (4)$$

Further three components of the magnetic field strength H can also be expressed by these forms:

$$\begin{cases} H_x=v_xB_x=v_x(A_{zy}-A_{yz}) \\ H_y=v_yB_y=v_y(A_{xz}-A_{zx}) \\ H_z=v_zB_z=v_z(A_{yx}-A_{xy}) \end{cases} \quad (5)$$

Under the given boundary conditions, with the above partial differential equations, we can get vector A at any point within the magnetic field, put the value of A into the formula (4), we can get the flux density of the point.

**The magnetic field of the no-load claw pole motor**

A no-load claw-pole motor means that the armature current is zero, or very small and therefore it can be ignored. As the armature current is zero, the claw-pole magnetic field inside the motor is only generated [4] by the magnetic motive force of the field winding, as shown in Fig. 6.

By means of building networking model with a solid model of claw pole generator and solving this model through electromagnetic three-dimensional finite element calculation, we can get all of the magnetic field distribution [5]. Fig.4 shows the overall mesh; Fig.5 shows the general motor (not including air and windings) flux density distribution; Fig.6 is a general motor magnetic field vector density distribution.

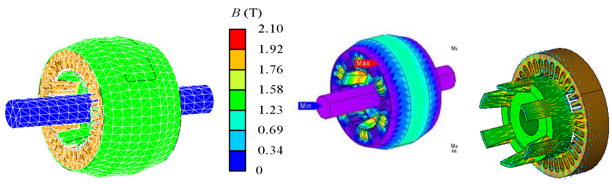


**Fig.4: mesh of generator Fig.5: magnetic cloud of generator Fig.6 flux density vector of rotor**

From Fig.4, Fig.5 and Fig.6, we can see the magnetic field distribution of the no-load claw pole generator. The axial exciting magnetic flux of the rotor turns into radial exciting magnetic flux of air-gap magnetic field through a special structure of claw pole. Magnetic field generated by the coil form a complete magnetic circuit inside the motor, achieved N, S poles alternation through the claw-pole.

**Magnetic field and armature reaction of loaded claw pole generator**

When the claw pole generator is on load, there will be current flowing through the armature windings, and then the armature will produce magnetic motive force. At this time, the air gap magnetic field is constructed with claw-pole magnetic motive force and armature magnetic motive force. The influence that the armature magnetic motive force on the main magnetic field becomes armature reaction [4]. Study the influence that armature reaction on the air-gap magnetic field by taking a gap plane in the air gap, compare the changes on flux density when the claw pole generator is on load and without load, as a result, the claw pole generator armature reaction will be reflected qualitatively. Take the no load and a purely resistive load when the rotor and stator are at the same position and then simulate the magnetic flux density waveform, as shown in Fig.7.

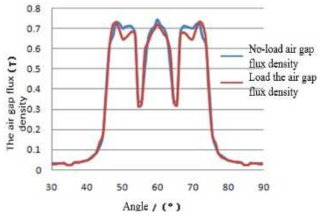


**Fig.7 air gap magnetic density of claw-pole generator**

As shown in Fig.7, when the generator is on load, the air gap flux density waveform will become aberrant compared to no-load generator. When on load, the air-gap magnetic induction of the main pole is determined by the synthetic magnetic motive force that generated by both the armature winding and the field winding. Due to the influence of the armature reaction, armature winding will produce a series of odd harmonic electromotive force and currents, and then the voltage waveform will become aberrant, motor loss will increase, resulting in fundamental amplitude of the air gap flux density becomes smaller and waveform distorted.

**Numerical analysis of magnetic flux leakage coefficient**

The generator of claw-pole type structure usually has some defects such as low efficiency, large energy loss, and poor generating capacity when the speed is low, mainly due to the negative impact brought by the magnetic flux leakage. In order to improve and enhance the output characteristics of the generator, especially the low speed output characteristic, it is necessary to quantitatively analyze the negative impact brought by the magnetic flux leakage [6]. The following analysis will be focused on the magnetic flux leakage problems of claw-pole generator. Fig.8 clearly depicts the internal magnetic field direction inside the claw pole generator, it can be seen that the magnetic leakage flux of the claw pole rotor is very complex, generally can be divided into: (1) leakage flux $\Phi_{\sigma 1}$ in the closed space from the root of two claw poles to the stator core; (2) the leakage flux $\Phi_{\sigma 2}$ between the two claw-pole outer surfaces; (3) The leakage flux $\Phi_{\sigma 3}$ in the space from the rotor yoke to the excitation coil.

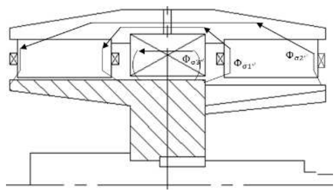

**Fig.8leakage flux distribution of claw-pole generator**

The total magnetic flux of the claw-pole generated by excitation is $\Phi_m$, the main magnetic flux through the air gap is $\Phi$. Then

$$\Phi_{\mathrm{m}} = \Phi + \Phi_{\sigma 1} + \Phi_{\sigma 2} + \Phi_{\sigma 3} = \sigma\Phi \quad (6)$$

Where $\sigma$ is the magnetic flux leakage coefficient. If $\sigma$ is too large, the design will be not economically viable, and will have adverse effects [3] on the operating characteristics of the motor.

Where the analysis will be focus on the influence the structure parameters of the no-load claw pole generator on the magnetic flux leakage of the motor, these parameters include: the inner diameter of the stator, the rotor diameter, the effective length of the stator core, the stator claw pole tooth width and thickness of the base. Take the three-dimensional finite element method to solve the 1/6 motor model, periodic boundary conditions in the symmetry plane meet:

$$\begin{cases} B_r(r,\varphi+\Delta\varphi,-z) = -B_r(r,\varphi,z) \\ B_\varphi(r,\varphi+\Delta\varphi,-z) = -B_\varphi(r,\varphi,z) \\ B_z(r,\varphi+\Delta\varphi,-z) = -B_z(r,\varphi,z) \end{cases} \quad (7)$$

Where Br, Bφ, Bz——magnetic induction B in the cylindrical coordinates of the three components; r, φ, z are components of an arbitrary coordinate system; $\Delta\varphi$ is a polar angle.

We can get the generator field after a series of programs such as modeling, meshing, loading, solving, post-processing etc. Fig.9 is the magnetic field distribution of the no load motor obtained by magnetic vector finite element method.

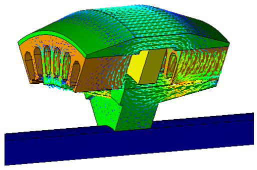

**Fig.9 no-load magnetic field of generator distribution**

By changing the different structural parameters of the claw pole generator, and then calculate the magnetic field of no load generator, we can get the total flux and effective magnetic flux of each pole, further we can get leakage coefficient of no load claw pole generator.
Fig.10 shows the influence of the inner diameter of the stator on the leakage coefficient of the claw pole generator. We can see that with the increases of the inner diameter of the stator, the air gap increases, the total magnetic flux and effective magnetic flux of each pole decrease, while the leakage coefficient increases.

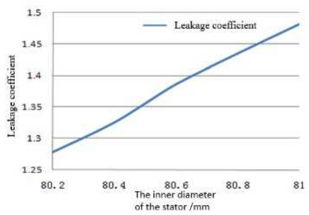


**Fig.10 stator inner diameter and magnetic flux leakage coefficient curve**

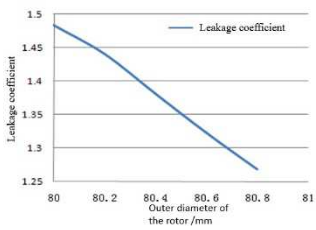


**Fig.11 rotor outer diameter and magnetic flux leakage coefficient curve**

Fig.11 shows the influence of the the outer diameter of rotor on the leakage magnetic coefficients of the claw-pole generator. We can see that, with the increase of the outer diameter of the rotor, the air gap decreases, the total magnetic flux and effective magnetic flux of each pole increase, while the leakage coefficient decreases.

Fig.12 shows the influence of the the root thickness of the claw pole on the leakage coefficient of the claw-pole generator. We can see that, with the increases of the root thickness of the claw pole, the total magnetic flux and effective magnetic flux of each pole increase, while the leakage coefficient almost remains unchanged.

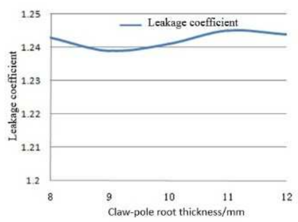


**Fig.12 root thickness and magnetic flux leakage coefficient curve**

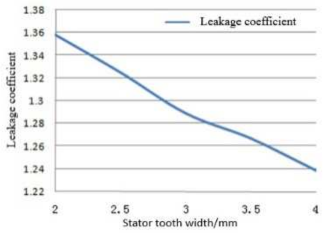


**Fig.13 stator tooth width and magnetic flux leakage coefficient curve**

Fig.13 shows the influence of the a stator tooth width on leakage coefficient of the claw-pole generator. We can see that, with the increases of the stator tooth width, the total magnetic flux and effective magnetic flux of each pole increase, while the leakage coefficient decreases.

Fig.14 shows the influence of the effective length of the stator core on leakage coefficient of claw pole generator. We can see that, with the increases of the effective length of the stator core, the total magnetic flux and effective magnetic flux of each pole increase, but the leakage coefficient decreases.


**Fig.14 stator core length and magnetic flux leakage coefficient curve**

Take an overall consideration of the figures from 10 to 14, we can draw a general rule by the change in leakage coefficient that the motor leakage coefficient shows positive growth relative to the inner diameter of the stator, negative growth relative to the outer diameter of the rotor, stator tooth width and the effective length of the stator core, the root thickness of the claw pole almost has no influence on leakage coefficient. The above rule provides a theoretical basis for the structural design of claw-pole generator, electromagnetic field calculation and optimize the structural parameters of claw pole generator, thus, it has theoretical reference value.

**No-load characteristics of generator and load regulation characteristics**

No-load characteristics of the generator and load regulation characteristics are respectively shown as in Fig.15 and Fig.16

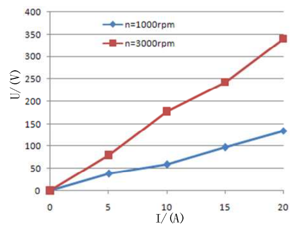


**Fig.15 no-load characteristics**

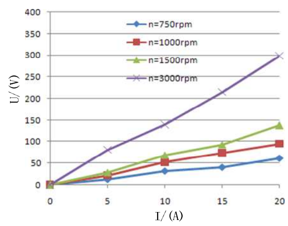


**Fig.16 regulation characteristics**

The numerical simulation of the no load characteristics and load regulation characteristics of the generator verifies that the design of the motor meets the technical requirements and job requirements of retarder when the automotive transmission revolutions n = 1000rpm, excitation current I = 20A, the DC output voltage U≫100V.

## CONCLUSION

1)The analysis of the internal magnetic field and magnetic path of the claw pole generators verified the feasibility of the design.
2)We took the three-dimensional finite element method to simulate and analyze the magnetic field of the claw-pole generator, studied the air-gap magnetic field of the on-load and load motor, the results reflected the demagnetization effect of armature reaction to the generator.

3)By the leakage analysis of the motor and the optimization of related structural parameters, we drew a graph showing the relationship between the structural parameters and motor leakage coefficient, finally obtained a general rule. Namely, the motor leakage coefficient showed positive growth relative to the inner diameter of the stator, showed negative growth relative to the outer diameter of the rotor, stator tooth width and the effective length of the stator core, the root thickness of the claw pole almost had no influence to leakage coefficient.
4)The simulation results showed that the design met the technical requirements of the motor, the DC output voltage $U \geq 100V$, compatible with the theoretical analysis in the first section, met the requirements of retarder and proved the feasibility of the design.

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