

3C14

Design of small electric generator by free CAD and analysis software

Kunihiko TACHIBANA^{*1}, Koichi OKA^{*1} (Mem.)

This paper presents a procedure of design of small electric generator by free CAD and analysis of these by software for the amateurs. The proposed method and procedure are confirmed by trial production of an electric generator. The consequences of electric generation capacity by free software are equivalent to results obtained by the paid one. The design time has been decreased by using standard dimensions of components. The combination of standard dimensions and design is sophisticated for novice designer and students. This study demonstrates that the design plan and analysis for a small electric generator are reliable and significant. Therefore, students and beginners can use this method and procedure for the purpose.

Keywords: CAD, Analysis Software, Simulation, Electric Generator, Design Procedure

1. Introduction

Recently, the number of people who generate electric power with renewable energy has increased in the private use. Generally, hydraulic power, wind power and solar power are popular as a source of renewable energy. Since a commercial electric generator for hydroelectric power generation is expensive, many people make their original one. However, it is difficult for to design appropriate generators for their purpose. This study proposes the easy design procedure and method of a small one with free CAD and analysis software for non-specialists. These are useful for students and beginners in academic purpose.

2. Free software

Most paid CAD and analysis software have their term and functional limitation. Since the trial periods are short, the term must come before the beginners master the method of the application. Also, some of the software with the unqualified calculation method cannot carry out verification of a result. Therefore, it is possible to design the generators frequently with the free CAD and software that have no limitation.

2.1 Free CAD (2D)

Recently, the Internet has offered many kinds of free CAD. For beginners of the design, an appropriate CAD can replace paper, pencil and ruler with screen and mouse. It is important for them to operate a CAD easily without using 3D CAD. Jw-CAD^[1], AutoCAD LT, and RootPro CAD are suitable for the beginners, because many books offer the various information. This study chooses Jw-CAD to design a trial production of electric generator.

2.2 Free magnetic field analysis software

Analysis of magnetic flux passing through a coil is indispensable in the calculation of generated power voltage. This study utilizes free analysis software of 2D static magnetic fields. 2D analysis is enough to get the rough value since high-precision analysis is unnecessarily with 3D. As magnetic field analysis software, there are EMP3, Super Moment, femm^[2], etc. These characteristics are very complicated for beginner and non-specialist because of these following reasons how to create meshes, how to apply boundary condition. Then, this study selects femm which needs to set up only minimum conditions such as specification of the material and dimensions.

2.3 Free magnetic force calculation software

The calculation of thickness of stator needs attractive force by a magnet to steel materials. Flux density of attractive surface and attractive force must be calculated from this flux density. It is sufficient if the rough value of the force is calculable, even if it does not carry out precise calculation. It is possible to calculate the force in the home page of a magnetic manufacturer. This study recommends this home page's software^[3].

Correspondence: K.TACHIBANA, Intelligent Mechanical Systems Engineering, Kochi University of Technology, 185 Miyanoguchi, Tosayamada-cho, Kami-city, Kochi 782-8502, Japan

Email: 156006p@gs.kochi-tech.ac.jp

^{*1} Kochi University of Technology

2.4 Free stress analysis software

In Japan, DEXCS and Adventure regarded as the free analysis software and requires technical knowledge. The experts can calculate the bending value of a simplex beam by hand. Hari^[4] is suitable stress analysis software for the beginners, because, it is unnecessary that boundary condition and mesh set up. Since Hari cannot calculate two or more distribution loads, distribution loads are calculated by transposing to concentrated load.

3. Design procedure

This is a procedure of a small generator for beginners who have minimum knowledge about an electric generator. The target of the maximum electric generating capacity of small electric generator is 1000(rpm) and 500(W).

3.1 Prior research

First of all, it is indispensable before designing to research about electric generator characteristics and generating capacity. In many cases, it seems that most designers apply an electric generator manufactured by others or a sold product. The Internet provides the designers a lot of technical information; dimensions and characteristics of these electric generators, etc., it is possible to get necessary information in the internet for their own design. Then, it is necessary to consider the availability of useful material, its price, and manufacturing and assembling method. The designers conduct these researches enough with imagining the target electric generator, and then they begin their design.

3.2 Design plan

The first step designs some imaged subjects by an electric generator drawing with the information by the prior research. The designers clarify the global image, considering outline dimensions. The existence of the necessity for parts composition, an assembly procedure and dimensional coordination are defined by that. This study uses a round shape magnet and conclusion shaped coil because of being got and manufactured them easily. Balance adjustment requires in an out rotor type, but not in an inner one. Therefore, this study selects an inner rotor type electric generator.

The first step determines temporary outside dimension. The next is the selecting of magnets, these are a neodymium magnet and round one which is the thickness of the direction of flashing, 10(mm) and 15(mm) and obtained easily. Aluminum is recommend-

able for the material of inner rotor and stator. It is suitable for the rust, austenite stainless steel (SUS304 and SUS316) which is not attractive by the magnetic force. A used electric wire for a coil (UEW wire or PEW wire) chooses the thickness in which temperature does not increase by the estimated current at maximum power. Directivity electromagnetic plate and sheet is optimal for the using material for the back yoke which fixes a coil. The degradation by the iron loss of soft iron (SS400) is 3(%) to 5(%); therefore, soft iron can also be utilized for a back yoke.

The design flow is shown in Fig. 1, and each outline is described respectively.

3.3 Design

By the procedure of the flow in Fig.1, it is possible to design the electric generator without difficult analysis and calculation.

An example of design explains the electric generator of the following specification.

Outside dimension: 220 [mm] (coil outside dimension)
 Number of rotations: 300 [rpm]
 Generated voltage: 100 [V]
 Generated power: 200 [W]
 Number of phase: 3 phases
 Inner rotor
 Radial and Air gap type

3.4 Study of the number of coil and magnet

The number of coils and magnets affects the performance of an electric generator. In the small electric generator, it is the valid combination of 6 coils and 9 magnets, 9 coils and 12 magnets, or 12 coils and 16 magnets. For example, in 150 (mm) coil the combination of 9 coils and 12 magnets is the best. 200(mm) or above one, the combination of 12 coils and 16 magnets is appropriate for the generators. Even though the number of coils increases, the amount of turns per coil falls with flux density decreased by the smaller magnet. Thus, this example of a design utilizes 12 coils and 16 magnets; the number of coils is single side. (4 coils par 1 phase)

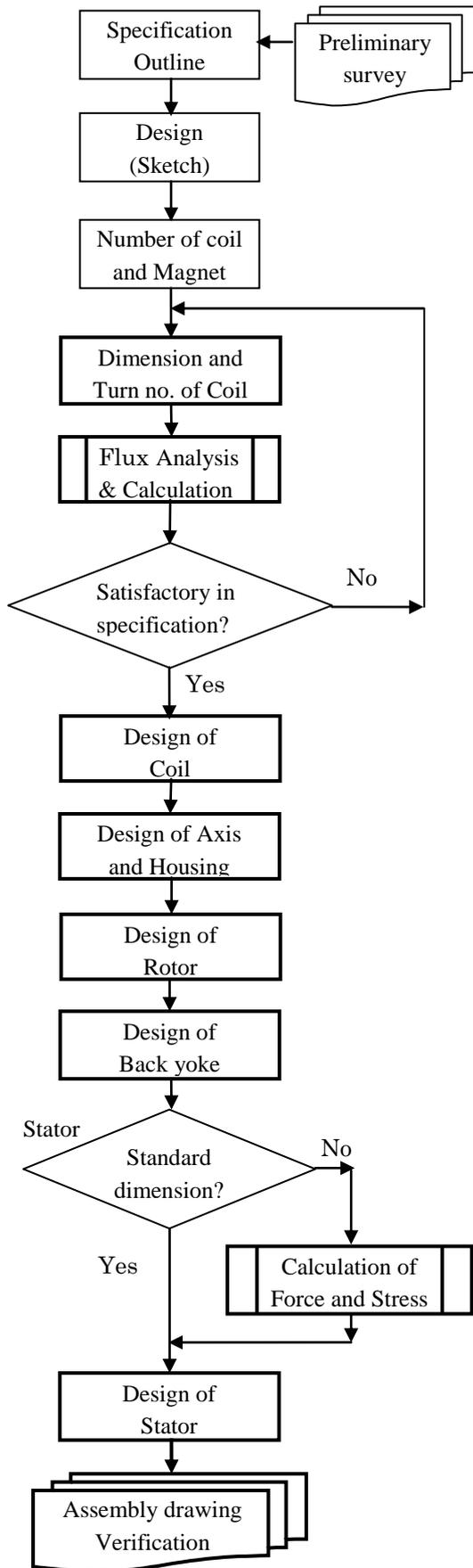


Fig. 1 Flow Diagram

3.5 Dimension and number of turns of a coil

In the temporary outside dimension, CAD writes the outward form of a coil. At this moment, by the temporary diameter and turning radius of a coil it tries to have the width of a coil be the maximum, performing dimensional coordination of coil and magnet relatively. The maximum width of a coil makes the maximum number of turns of the one. It is necessary in this study to take the thickness of a coil into consideration with magnetic circuit. If the both ways distance of magnet and back yoke is shorter than the other one between magnets, the power generation performance would be more efficient. The relation of the distance between magnets and the distance to a back yoke is shown in Fig. 2.

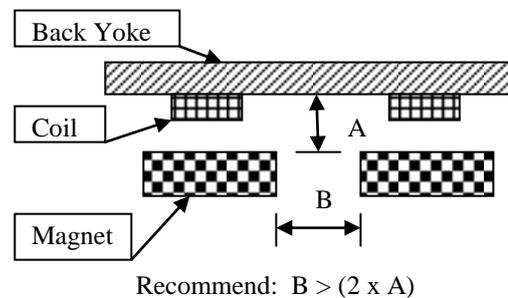


Fig.2 Placement of magnet and back yoke

It refers to 220mm of outside dimension, the position of a coil and a magnet is drawn with using CAD such as Fig. 3. As shown in Fig. 3, magnetic position is approximately 2/3 of coil outside dimension. In Fig. 3, the limit dimension which does not touch at a magnet outside becomes the temporary width of a coil. Then, check the magnet gap with the relation in Fig.2. A configuration of the coil and magnet is shown in Fig.4. In this example, the gap of a back yoke and magnet is 3 (mm), and the thickness of coil is 2 (mm). A magnet gap is 6.5 (mm), then $6.5(\text{mm}) > (2 \times 3(\text{mm}))$; it satisfies the relation of Fig. 2. The dimension of the using magnet with analysis software is a dimension of the radius passing through a magnetic center. Since the current value is 2 (A), the wire diameter of a coil is required 0.5 (mm) minimum. The maximum number of turns of the coil which can be wound around 16 (mm) thickness and 2 (mm) width is 124 times. However, it is 102 times when volume efficiency is taken into consideration. (Volume efficiency is approximately 0.8.) The calculated result using femm is shown in Fig. 5.

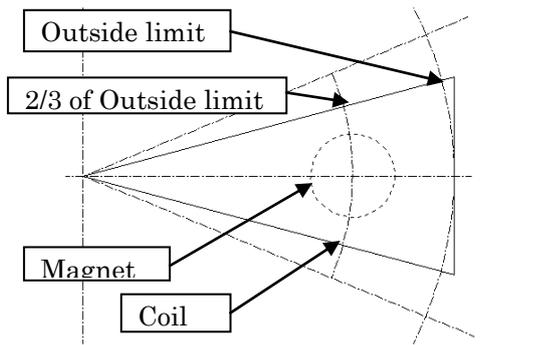


Fig.3 Temporary disposition of coil and magnet

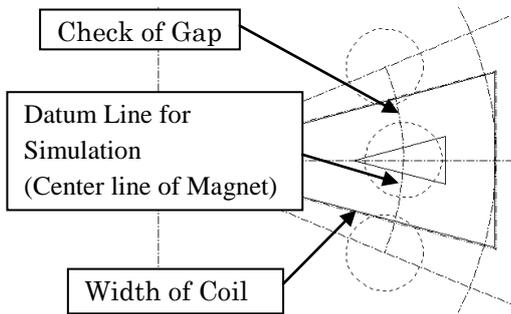


Fig.4 Sizing of coil and magnet

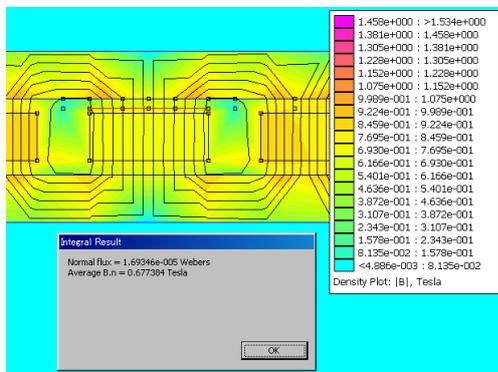


Fig.5 Simulation Result of Magnetic Flux

The following equation is used in order to calculate electromotive force from magnetic flux.

$$V=4.44xfxNxPHIxD \text{ (V)}^{[5]} \quad (1)$$

V: Electromotive force (V)

f: Frequency

N: Number of coil turn

PHI: Magnetic flux (Wb)

D: Diameter of magnet (mm)

f=40, N=102, D=25 and PHI=1.7e⁻⁵ (Magnetic flux by magnetic field analysis software) are substituted for an equation (1).

$$\begin{aligned} V &= 4.44 \times 40 \times 102 \times 1.7 \times 10^{-5} \times 25 \\ &= 7.7 \text{ (V)} \end{aligned}$$

This voltage is the electromotive force per coil. In this example, one phase is comprised four coils; therefore, this voltage is multiplied four times.

$$V_{\text{phase}} = 7.7 \times 4 = 30.8 \text{ (V)}$$

Furthermore, this value is changed to direct current.

$$30.8 \times 2 = 61.6 \text{ (V) (Coil is 2 sets)}$$

$$61.6 \times 1.732 = 107 \text{ (V) (AC value)}$$

$$107 / 1.414 = 75 \text{ (V) (R.M.S. value)}$$

It has to figure out how to increase the voltage so that the calculated result is smaller than desired one.

Output frequency is only 5Hz when the electric generator rotates by 300 [rpm]; it also needs to consider how to increase frequency. Since the current that flows in a coil is full limits, that is necessary to decrease. The number of turns of a coil is not doubled but the coil which shifted the phase is placed one more set. By this method, the frequency of voltage will be double and the current of coil will be half. Although the distance between magnet and back yoke widens with increasing the number of turns of a coil, electromotive force has been larger. The method is shown in Fig.6. The electromotive force of the coil near magnet is 5.5 (V), and that of the coil far magnet is 5.2(V). It is 105(V) when the output voltage of the electric generator is calculated from these values; and this voltage satisfies the planed voltage. Therefore, this study takes the coil which is 16 (mm) width, 2 (mm) thickness and 2 layers.

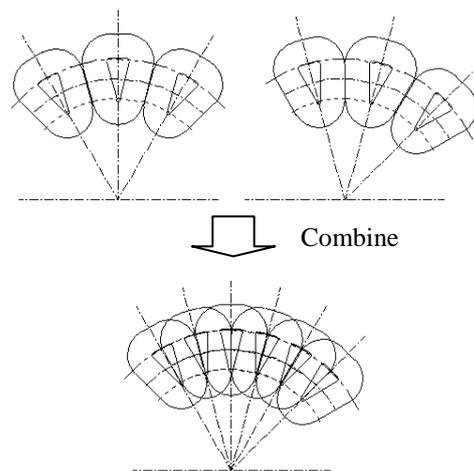


Fig.6 Idea of coil

3.6 Design of coil

The coil is designed with the values of the principal dimensions of a coil. Taking into consideration of the minimum bending radius of an electric wire, the design requires a jig in order to reel a coil. The example of a design is shown in Fig.7.

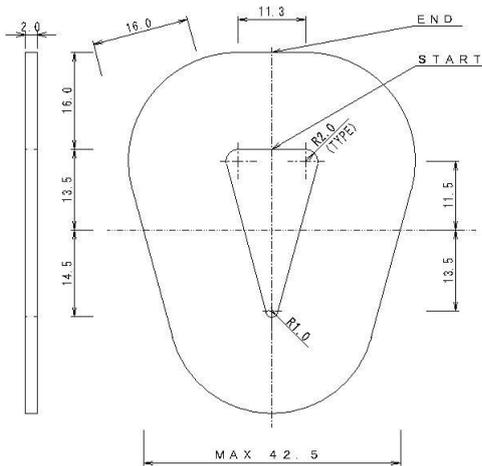


Fig.7 Example of coil

3.7 Design of shaft and bearing housing

The design of the shaft diameter needs to be set up with the consideration on the rotor weight, rotating speed and distance between bearings. However, a design of bearing housing has been unnecessary by using the marketed one. The diameter of shaft is 15mm in this example.

3.8 Design of rotor

Rotor is a part which fixes magnets; it is made the same thickness as the used magnet or a little bit thin thickness. If thickness of a rotor is designed 10 (mm), this can use with magnet which thickness is 10 (mm) to 15 (mm). The rotor utilizes the position of the magnet at that specific dimension of a coil. The example of rotor is shown in Fig. 8. Then, it is indispensable to design a rotor holder, and the size may not interfere with other component. The example of rotor holder is shown in Fig. 8

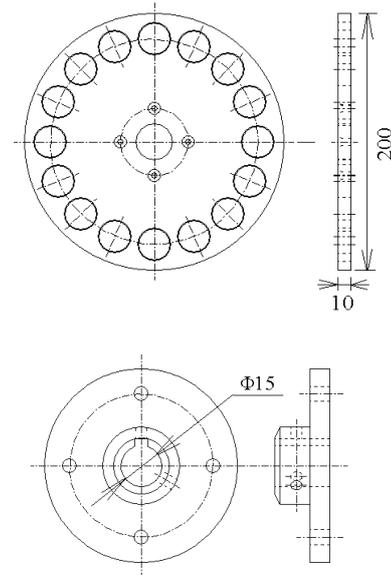


Fig.8 Example of rotor and rotor holder

3.9 Design of back yoke

A back yoke has saturation thickness which does not increase electromotive force. This example shows that electromotive force will be in a saturation state by 7 (mm). If thickness of back yoke is enlarged too much (2 times of saturation thickness or more), electromotive force will reduce conversely. Therefore, this uses 10(mm) thickness of back yoke. This study proposes that a standard dimension that the back yoke has the same width as the magnet diameter or 2 (mm) greater.

3.10 Design of stator

An attractive force from magnets applies to the back yoke attached in stator, so that the stator is stressed in the magnet position. This example designs the gap of magnet and coil by 1 (mm). It is made for magnet not to collide with coil because the stator bends by magnetic force. The standard plate thickness is 10 (mm). In using thin thickness than 10 (mm), Hari has to verify plate thickness. That case needs to calculate magnetic attractive force in the firm's HP. The value multiplied by the number of the magnet is a total attractive force; in this example, total attractive force is 50 (kg). The dimensions and apply points of force in Hari are shown in Fig. 9. In Hari, it calculates as both-ends simple beam and two-point concentrated load.

The result by Hari is 0.1 (mm), and the other one by DEXCS analysis software is 0.08 (mm). Therefore, since the error has appeared in the safety side, the result in Hari is successful.

