

Proceedings of the Transdisciplinary Symposium on Engineering and Technology (TSET) 2022 Development of Digital and Green Technology on Post Pandemic Era

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and Yohanes Galih Adhiyoga**



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Preface: Proceedings of the Transdisciplinary Symposium on Engineering and Technology (TSET) 2022



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PREFACE: Proceedings of the Transdisciplinary Symposium on Engineering and Technology (TSET) 2022

“Development of Digital and Green Technology on Post Pandemic Era”

It is with great pleasure to welcome you to Transdisciplinary Symposium on Engineering and Technology (TSET) 2022 hosted by Universitas Dian Nusantara on September 21, 2022. The event aims to a venue for engineers, researchers, scholars, and policy makers to explore the challenges and opportunities from the post pandemic era on civil engineering, mechanical engineering, electrical engineering and computer science. For civil engineers, they will play a significant part in the recovery since design and construction services will be needed in the future, and they need to develop new construction methods, materials, and technologies in order to build a sustainable and resilient infrastructure. For engineers, they need to start thinking about the long-term change of their operations and adapt to the “new normal” that has emerged because of the epidemic. We welcome all parties to share their research and thoughts in the symposium.

Participants of the symposium were invited to submit their papers and disseminate them through oral presentation covering such scope as civil engineering, mechanical engineering, electrical engineering and computer science. To enrich the discussion under the theme of “Development of Digital and Green Technology on Post Pandemic Era”, we invited speakers with reputable expertise, namely Prof. Josaphat Tetuko Sri Sumantyo, Ph.D. from Chiba University, Japan; Prof. Dr. rer. nat. Evvy Kartini, M.Sc. from National Nuclear Energy Agency of Indonesia; Prof. Dr. Ir. Bambang Sugiarto, M.Eng. from Universitas Indonesia, Indonesia; and Sulfikar Amir, Ph.D. from Nanyang Technological University, Singapore. In addition to presenting their research results, the participants of the symposium were also encouraged to submit their papers to be proposed for publication to American Institute of Physics (AIP), one of the world’s top publishers as conference proceedings. There were 125 manuscripts submitted to the committee comprising 99 papers of Biology, Chemistry, Computer Science and Technology, and Engineering.

Finally, on behalf of the editors of TSET 2022, I would like to extend my most sincere gratitude to the organizing committee, co-hosting institutions, and most importantly, participants, speakers, presenters, and authors of the symposium. I do hope the proceedings bring significant contribution, particularly to the field of advances of sustainable engineering. I look forward to seeing you all at the upcoming symposium.

The Editors,
Ade Gafar Abdullah
Desi Ramayanti
Henri Septanto
Yohanes Galih Adhiyoga

RESEARCH ARTICLE | JULY 12 2024

Constructal heat release of radial permanent magnet generator

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Constructal Heat Release of Radial Permanent Magnet Generator

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Abstract. Constructal theorem indicates a pattern of optimum efficient flow in a form geometrical design. A permanent magnet generator should keep its permanent magnet temperature below its critical. The constructal pattern in the form of rotor and stator radii ratio was studied for optimum heat flow generated from losses. A theoretical approach was applied to a 2D model of radial permanent magnet generator assumed to have specific thickness of the laminated core for its stator. The heat was released to the frame in order keeping temperature of the magnet below its critical temperature as the main requirement for performance. Geometric parameters showing thickness and width of the stator were found as the constructal pattern that meet the targeted output. Ratio of the stator and rotor radii proportional to magnetic field strength, square of convective coefficient, and inverse of conductive coefficient are shown as the solution of minimizing the rotor temperature.

INTRODUCTION

Constructal theory considered as the way to design optimum system was introduced by Bejan and has been studied for many fields [1–9]. The constructal approach was applied for analyzing of cooling system [6,10–13], solar energy harnessing system [14–16], mechanics[5], and fluids[14,17,18]. The method proposes to minimize the flow over its resistance reflecting the characteristic of the system. In a finite system, the character of the system has geometric meaning such as area, volume, length, or its specific ratio.

Thermal is one of fields which the constructal has extensively studied. For a cooling system in electronic devices, it is found that contact surface of heat sink is important [19]. Kalbasi and Salimpour also mentioned that ratio of vertical and horizontal fin surface of highly conductive material has minutes effect. However, Ghodoossi and Eggrican reported that tree network of high conductivity links inside heat generator was the result of optimization heat cooling of finite are heat generator with fins [12]. In those studies, the source and sink of the heat are separated and the flow is in single direction.

Electric machines generate heat source inside its frame and the magnetic field generator is located in the center of the generator. Heat mostly is produced due to core loss and copper loss. The additional loss of mechanical matter happens on the bearing. While the copper loss is located around the core, it is worthy to assume that the heat in electric machinery is generated in the core of the winding. This heat is transferred to the frame as the heat sink as well. The frame released heat to the atmosphere through the frame surface with some fins attributed the character mentioned by Kalbasi and Salimpour [12]. At the same time, the heat also transferred to the rotor where the magnetic sources were lied. The heat flow is not single direction anymore, at least in a specific time before the equilibrium.

Study of the heat release of a generator for optimum ratio of the stator and rotor radii is the aim of this work. It is structured in the paper consisting of 4 parts. The first part introduces the problem. The second part goes deeper on the

problem of generator with focusing on the model. The third part shows the constructal development of the problem to find the ratio of rotor and stator. The final part will conclude the work.

RADIAL GENERATOR MODEL

Radial generator has flux perpendicular to its axis. Mostly, the generator has rotor in the center of the device and its stator is designed around the rotor. Two types of generators are known, the permanent magnet and electromagnetic generator. If the rotor has permanent magnet as the flux source, it is called as permanent magnet radial generator. The produced EMF of such machine depends on differential of the flux which is related to ratio of the rotor and stator. A stator diameter reflects magnetic reluctance. However, the higher ratio of the rotor and stator radii is, the EMF of its electricity is higher. The current of the generator is a function of its magnetic flux density, inverse of the wire permittivity, number of windings, and length of the magnetic flux path. However, due to its hysteresis, the magnetic flux path also affects core loss. It also implies that ratio of the rotor is important in heat of a generator.

Winding is the main source of heat due to its copper loss. The copper loss contributes more than 90% [20]. However, the same author also reported that the temperature of the winding was equal to temperature of the frame. But the temperature of the winding is different from the magnet. It means that the heat transfer from the core to rotor and from the core to the frame before releasing it to the atmosphere is important in determining the temperature of the rotor where the permanent magnet placed.

A permanent magnet generator needs to keep the temperature of its permanent magnet below the permanent magnet critical temperature. Above the critical temperature, the permanent magnet loss its magnetic capacity significantly. Its magnetic flux density decrease affects the capacity to generate EMF. To keep the temperature of the rotor below its critical temperature, it is consecutive to remove heat from the heat source in the winding core. It is the stator core.

The analysis of the heat flux in a generator, especially focuses on its core, frame and rotor. To simplify the system, the structure of the core, frame, and its rotor is mentioned in Fig. 1 neglecting the axial direction. It represents part of complete rotor and stator assuming the machine is highly symmetrical. The permanent magnet is applied on rotor. All of the parts have equal angle, therefore the boundaries between rotor, air gap and stator are proportional to the respective radii, named r_{ra} , r_{as} , and r_{sf} .

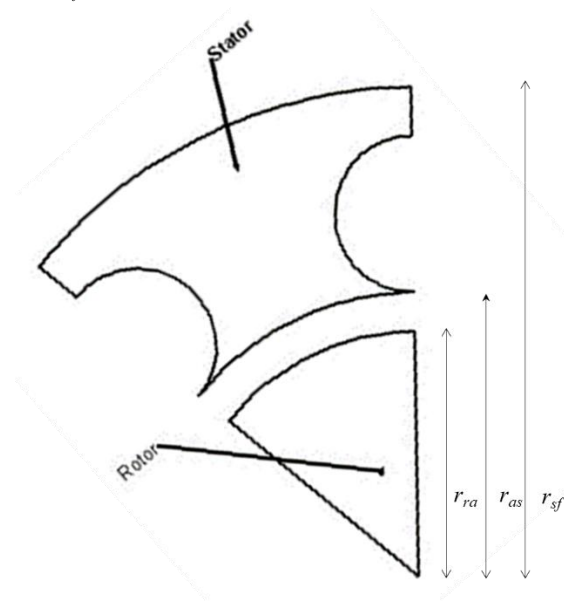


FIGURE 1. Boundary of the rotor and stator

Heat transfer between two material depends on the boundary between the materials. For transferring between two solid material, conduction heat transfer take places. It follows Fourier law as mentioned in equation (1). T , A , q , and k are temperature, cross-section of the boundary, heat, and conduction coefficient, respectively. For the boundary of solid and fluid, the convection happens as described following Newton equation (2). The combination of convection and radiation heat transfer coefficients can be used for the boundary between stator and frame. The convection and

radiation take places in the border of the stator air gap and rotor air gap. While the radiation occurs on the boundary, therefore the equation (2) should consist also radiation coefficient as shown in equation (3) with h_{conv} and h_{rad} as the convection coefficient and radiation coefficient, respectively.

$$q = -kA \frac{dT}{dx} \quad (1)$$

$$q = hA\Delta T \quad (2)$$

$$h = h_{conv} + h_{rad} \quad (3)$$

It is assumed that all the heat flux generated on the stator core because it is directly connected to the windings and where the core loss occurs as Irasari and Kasim found [20]. Accordingly, the resistive model can be pictured in Fig. 2. The model unites frame as part of the stator. It also assumes that the air gap and the rotor are a single entity due to its dimension.

The temperature of the rotor is function of heat capacity of the rotor. It can be expressed in a simple way as shown in equation (4). The q_{sr} is heat transfer between stator and rotor. Total heat stored in the rotor is inverse function of heat transfer. The similar approach can be done for the heat transferring from stator to the frame and air. It is shown in equation (5).

$$T_r = \frac{1}{hA} \int q_{sr} dt \quad (4)$$

$$T_s = \frac{1}{kA} \int q_{sa} x dt \quad (5)$$

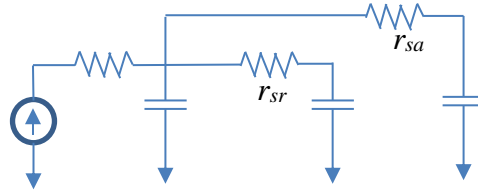


FIGURE 2. The resistive model of heat transfer coefficient. R_{sr} , and R_{sa} are heat flux resistance between stator and rotor, and the heat flux resistance of stator and air, respectively

CONSTRUCTAL DEVELOPMENT

The constructal expresses design effect for minimum intended flow. It means that geometry of the system is explored for finding minimum loss of the flow. In the context of the research, the design is aimed for minimum temperature of the rotor for keeping it from critical temperature where the permanent magnet remanence start to decrease. Using the model on Fig. 1, the environment temperature is the base line. The heat capacitor 1 is the heat capacity of the stator, the heat capacitor 2 is the heat capacity of the rotor, and the last heat capacitor belongs to atmosphere. In transient time, the heat flows to the rotor until its temperature is equal to the stator. It implies the heat of copper loss is equal to heat flux to rotor and environment as in equation (6). The subscript cl , sr , and sa refer to copper loss, stator to rotor, and stator to atmosphere, respectively.

$$q_{cl} = q_{sr} + q_{sa} \quad (6)$$

According to the model of Fig. 1, equations (4) and (5) can provide equations (7) and (8) respectively.

$$T_s = q_{sr} \cdot r_{sr} + \frac{1}{hA} \int q_{sr} dt \quad (7)$$

$$T_s = q_{sa} r_{sa} + \frac{1}{kA} \int q_{sa} x dt \quad (8)$$

The second term of the equation (8) is the temperature of the atmosphere. Assuming this temperature is constant, it can be derived equation (9), with T_a as the atmosphere temperature.

$$r_{sa} = \frac{T_s - T_a}{q_{sa}} \quad (9)$$

Meanwhile, in steady condition, q_{sr} should be zero, therefore $T_s = T_r$.

Heat resistance is function of conductor length. The heat resistance of the rotor is equal to its radii, and the stator resistance is proportional to difference of stator and rotor radii. The boundary of the stator to rotor can be simplified as arc of stator shoe. While the air gap is very small, therefore the arc of both is equal to average radii of stator and rotor (r_{ra} and r_{as}). It can be written as equation (10). Accordingly, the frame addition to the stator with assumption that the frame has higher conductivity than stator [20], the radii of the stator can be written as equation (7) with c_1 as the conductivity ratio of frame and core.

$$r_r = \frac{r_{ra} + r_{as}}{2} \quad (10)$$

$$r_s = r_{sf} + c_1 (r_f - r_{rs}) \quad (11)$$

The flux resistance is function of boundary as shown in equations (4) and (5). For the considered system, the boundary is function of the angle and its radii. Therefore, the boundary is function of radii. To meet maximum temperature of the rotor, it is noted that the flux from core to stator should be 0. It occurs when ΔT of the stator and rotor is 0. When it happens, the flux totally flowing to frame. The ratio of outer radii of the stator and rotor should follow equation (12).

$$\frac{r_s}{r_r} = \frac{h \int q_{sa} x dt}{k \int q_{sr} dt} \quad (12)$$

The maximum temperature of the rotor and specific time of maximum load condition can be applied for determining specific flux. The solutions of the equations (4) and (5) provide relation of r_r and r_s as shown in equation

(13). Assuming $r_r = 1$, then $r_s = \frac{h^2}{2k}$. It can be sure that $r_s > r_r$.

$$r_s = h \left(\frac{h}{k} r_r^2 - r_r r_s \right) \quad (13)$$

While specific output is reached when specific speed of the rotor following equation (14),

$$s = \omega r_r \quad (14)$$

It can be derived that $r_s = \frac{Bsh^2}{k}$, or $\frac{r_s}{r_r} = \frac{Bh^2}{k}$ to meet minimum temperature of the rotor.

CONCLUSION

It could be derived the ratio of stator and rotor radii to meet minimum temperature of the stator in radial permanent magnet generator. The ratio was found in condition of specific voltage output and assumption of close air gap which can be simplified as the stator radii. This ratio can ensure the temperature of the stator safe from overheating. The ratio of the rotor and stator radii is proportional to magnetic flux and convection coefficient square. It is inverse of conductive coefficient of the core.

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