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Performance Assessment of Universal Motor with AC and DC Supply

Roa′a Nadhim Nassrullah[a], Amer Mejbel Ali[b]

[a]*Electrical Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq*
Email: eema2005@uomustansiriyah.edu.iq ; https://orcid.org/0009-0007-9562-9061

[b]*Electrical Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq*
Email: dramerma@uomustansiriyah.edu.iq ; https://orcid.org/0000-0002-9984-3109

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ABSTRACT

The universal motor, versatile and capable of running on both AC and DC sources, is utilized in various household appliances and power tools. This paper presents a featured methodology for analyzing a universal motor (UM) that does not have design data by extracting it via reverse engineering. These gained data were used to model the motor by Maxwell program and analyzing it by finite element method (FEM). Adopting the Maxwell program's drawing capability to design the square-shaped stator of a universal motor not part of the program library will also enable the Maxwell program to be widely used and unrestricted to use with particular motor designs. After modeling and solving the motor model, the performance characteristics of UM when operated with alternating current (AC) and direct current (DC) power supplies were investigated. The UM simulation results were compared with test results with good agreement. The success of a proposed methodology paved the way for the analysis of any electric motor included in the Maxwell program, even if this motor does not have design data.

1. Introduction

Single-phase motors are known as universal motors (UMs). That can run on single-phase alternating (AC) or direct (DC) power sources. The brush position fixes the torque angle, typically at its ideal 90° value [1]. The motor's efficiency depends on various mechanical and electrical faults. When the mechanical energy production is known, the energy Efficiency must be raised while motor losses and consumption are decreased. Optimized design and premium materials are needed to achieve high efficiency, greater copper wire diameter in the stator, and higher aluminum content in the rotor to lower the resistance losses. Friction loss can be decreased with high-quality bearings. They are often combined with the drivers because, in the absence of a load, the motor may operate at an

Corresponding author: Roa'a N. Nassrullah; eema2005@uomustansiriyah.edu.iq ; +07707017375

unmanageable speed [2]. As a fractional horsepower motor for short-duty cycle applications, efficiency is not a significant consideration. However, reliability and low cost are of utmost priority. The ease of maintenance is also of paramount importance [3]. Due to its affordability in terms of cost and simplicity, UM is used for many applications in the home. For instance, in vacuum cleaners, the actual motor speed is equivalent to the load speed within 40,000 rev/min. Another application where the UM speed is reduced is its application as the drink/food mixers by connecting it to a gear train [4,5]. Close inspection shows that factors like the pickup speed of the motor, maximum speed, starting torque, etc., vary depending on the supply type. Many research studies have been carried out to analyze universal motors using the finite element method [6-10]. Still, the present work distinguished from these studies by adopting reverse engineering to get the missing motor data and then using it for modeling and analyzing the UM by Maxwell 2D/RMXprt software and comparing the UM performance results between DC and AC supply.

2. literature Review

Several studies have improved the performance of universal motors, as reported in the literature in recent years. The author used Simulink to compare the functionality of BLDC motor drives and universal motors for mixers and grinders [11]. The author demonstrated how the universal motor behaves when operating on an AC and DC supply. This was made possible with the assistance of MATLAB Simulink, which allowed the author to determine which supply the motor performs best. Finding that a motor runs more efficiently on a DC supply [12]. The author suggested a 550-watt universal motor with a deep slot operating at 9500 rpm for use with electric solid tools. MagNet software, which is based on FEM, was used to simulate the motor., validated by experimentation. The investigation used several variables to improve the corresponding motor's performance [14]. Another article's author creatively suggested combining two windings in the universal motor's current configuration, greatly enhancing the motor's core losses and torque ripples [15]. Several authors discussed the universal motor's efficiency and loss analysis by mathematical modeling extraction. The universal motor's power loss was reduced. Utilizing MATLAB Simulink software for applications involving mixers and grinders [10]. A performance comparison between a two-pole and four-pole universal motor was suggested to the author, and the outcome was provided at the motor's rated speed. It was claimed that a 4-pole motor's commutation process is superior to a 2-pole motor's, creating a superior new universal motor design by altering the number of armature slots and the armature coil's simultaneous connection [16]. The author suggested a comparison between an induction motor and a universal motor model for use in washing machines. The behavior-measured parameters included efficiency, induced voltage, current, speed, and torque, which were compared to the experimental setup [17]. The author used ANSYS Maxwell computer-aided design to analyze the electrical properties of special-purpose motors in a transient solution. It primarily highlights the benefits of using a single-phase motor for household applications instead of a three-phase motor [18]. The author suggested designing a universal motor specifically for use with washers. MATLAB's Simulink was used to simulate the model using the AC and DC supply, as well as the experimental analysis and comparison of saturation effects, commutation, transformer voltage, and armature reaction results [19]. D Lin et al. presented the universal motor model to enhance the commutation process, where ignoring the FEA's d- and q-axes changes the brush angle from the neutral position [20].

3. Theoretical Background

Since the engineer can handle issues like the effect of harmonics, complicated magnetic fields, and saturation in various motor parts problems that are challenging to solve using analytical methods, the finite element method, FEM, has emerged as the primary tool for calculating magnetic fields in electrical machines. We may thoroughly investigate the motor by going inside it this way [21,22]. When the geometric discretization is precise enough, FEM analysis yields the most accurate results. Timely delivery of FEM solutions is made feasible by computer power. However, it necessitates creating a detailed apparatus model, which could take numerous hours [23]. The electromagnetic analysis produces both the finite element analysis and the 2D model of the machine. The magnetic field in electric devices is described by Maxwell's equations, as shown in equations (1) and (2) below:

$$\nabla \times H = J \quad (1)$$

$$\nabla \times E = -\partial B/\partial t \quad (2)$$

where J is the current density (A/m2), E is the electric field strength (V/m), B is the magnetic flux density (Wb/m2), and H is the magnetic field strength (A/m). Equation (3) expresses the magnetic flux density regarding magnetic vector potential.

$$B = \nabla \times A \quad (3)$$

Equation (4) expresses the relationship between the magnetic vector potential and current density.

$$\nabla \times (V \nabla \times A) = J \quad (4)$$

Since the permeability of the core material is given as v=∂B/∂H and B=f(H) is a nonlinear relation, v here denotes variable permeability. Additionally, equations (5) yield the flux density distribution.

$$\frac{\partial}{\partial x}\left(v \frac{\partial A}{\partial x}\right) + \frac{\partial}{\partial y}\left(v \frac{\partial A}{\partial x}\right) = -J \quad (5)$$

In two-dimensional analysis, the value of the magnetic flux density is determined using equation (6).

In other words, Bx displays the component of magnetic flux density in the x-axis direction, while the element is shown in the y-axis direction.

$$B = \sqrt{B^2x + B^2y} \quad (6)$$

for DC excitation , the developed torque and induced voltage are given as Equations (7) and (8), and (9).

$$T = K_a \Phi_d I_a \quad (7)$$

$$E_a = K_a \Phi_d \omega_m \quad (8)$$

$$T = \frac{E_a I_a}{\omega_m} \quad (9)$$

where T = Torque developed by the motor, Φd = Magnetic flux produced by series field Ia= Current flowing through the series field (armature current), ωm = Mechanical speed, Ea = The root mean square (RMS) value of the back EMF. The input power is calculated by using Equation (10) for the DC supply and Equation (11) for the AC supply [1].

$$Input\ power = I \times V \quad (10)$$

$$Input\ power = V \times I \times \cos\theta \quad (11)$$

Where, I= supply current, V= supply voltage, θ = is the phase angle between the voltage and current waveforms.

4. Modeling of Universal Motor

Reverse engineering, often known as back engineering, is the practice of decomposing items such as airplanes, software, equipment, and architectural structures in order to get design knowledge. In most situations, the reverse engineering technique revolves around dismantling individual components of more oversized items. For this study, the test universal motor was modeled in two steps: first, by using RMXprt (analytical software). Second, by using Maxwell 2D FEM software. The electrical machine design is built on a template, allowing quick, analytical machine performance calculations to be transferred to Maxwell software for 2-D and 3-D geometry development. The ability of RMxprt to develop a complete Maxwell project (2D/3D) is the apparent advantage. The above two software compute numerous parameters to meet market demand for reduced cost and improved efficiency in electrical machines. Table 1 shows the test motor universal data, which are extracted based on reverse engineering by decomposing the motor into individual parts and assigning the dimension and speciation of it as design documentation listed in Tables 1 and 2 and Figures 1 to 3.

Table 1. Universal Motor Data

Parameter	Value
Stator External dimension	76.15mm
Stator Inner diameter	47 mm
Number of stator poles	2
Rotor outer diameter	25.13 mm
Rotor inner diameter	12 mm
Number of Rotor slots	22
Air gap length	0.5 mm
Core length	46 mm
Stacking factor	0.95
Type of core steel	M800-65A

Table 2. Armature Winding Data

Parameter	Value
Rotor winding type	Lap
Number of turns per slot	26
Coil pitch	1-9
Number of strands	1
Wire diameter	0.36 mm

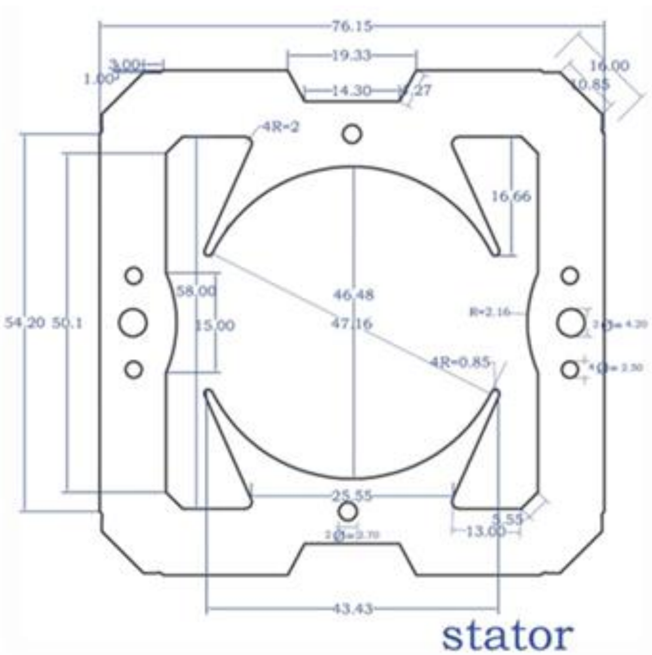


Figure 1. Stator Lamination of the universal motor under study

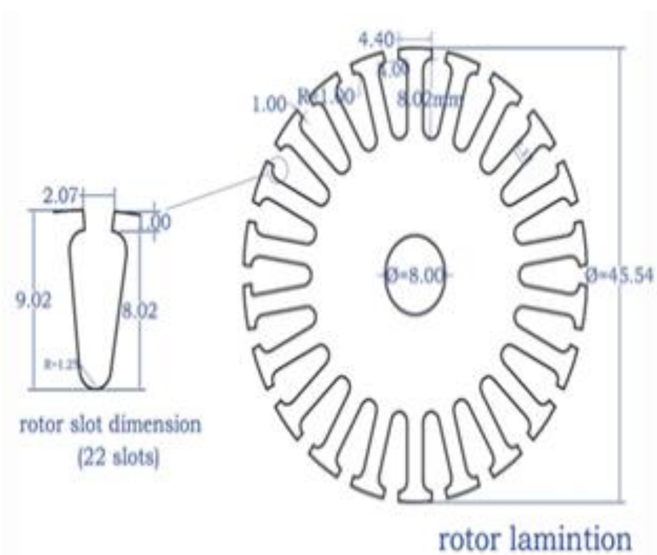


Figure 2. Rotor Lamination of the universal motor under study

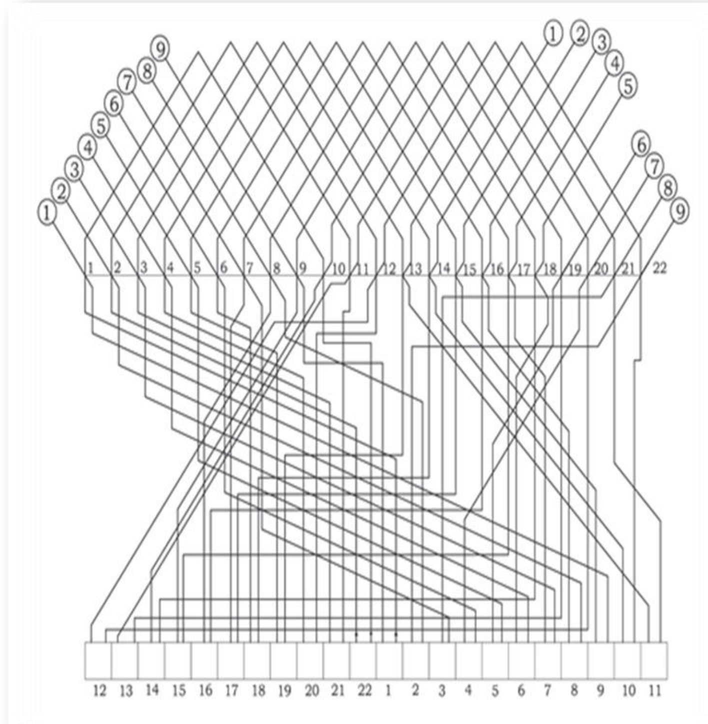


Figure 3. Armature Winding Diagram of universal motor

The test universal motor used in a food mixer shown in Figure (4) was tested in the laboratory with a 220 V DC and 220 V / 50 Hz AC supply.

Figure 4. Testing the universal motor in the laboratory

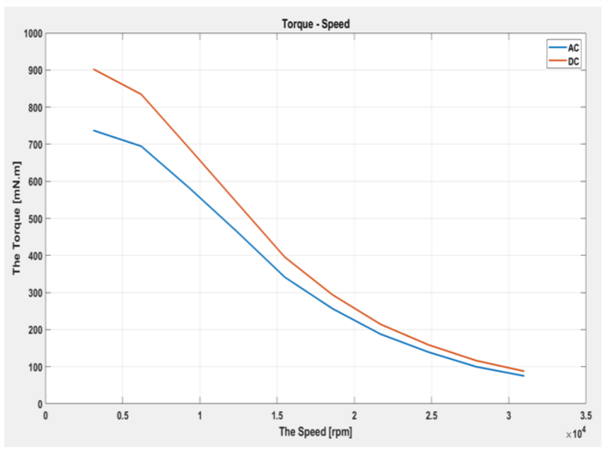


Figure 5. Torque-speed characteristics for AC and DC

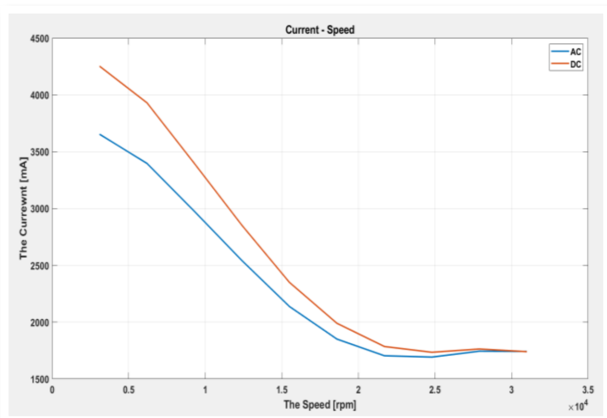


Figure 6. Current - speed characteristics for AC and DC

Table 3 compared the results FEM by Maxwell and experimental testing with AC supply at no load (NL) speed of 31000 rpm and full load (FL) speed of 28000 rpm.

Table 3. Universal Motor Results Comparison (with AC supply)

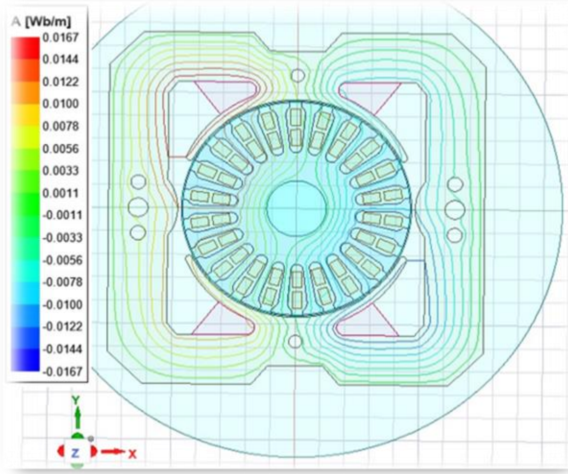
Parameters	Experimental		FEM		Error (%)	
	NL	FL	NL	FL	NL	FL
Current [A]	3.84	4.8	3.577	5.06	6.85	5.42
Power Factor	0.5	0.63	0.54	0.64	0.89	1.59
Input Power [W]	422.4	665.3	426.16	714.26	8	7.28
Output Power [W]	245	412	247.69	446.24	1.09	3.44
Torque [N.m]	0.075	0.145	0.0762	0.15	1.6	0.04
Efficiencies [%]	58	61.9	58.1	61.18	0.17	0.04

Table (4) compared the results FEM by Maxwell and experimental testing with DC supply at no load (NL) speed of 31000 rpm and full load (FL) speed of 28000 rpm.

Table 4. Universal Motor Results Comparison (with DC supply)

Parameters	Experimental		FEM		Error (%)	
	NL	FL	NL	FL	NL	FL
Current [A]	3.9	5.6	4.28	5.8	9.3	3.57
Input Power [W]	858	1232	941	1272	9.6	3.246
Output Power [W]	329	505.12	359.48	550.77	8.4	9.05
Torque [N.m]	0.101	0.1722	0.111	0.187	9	8.36
Efficiencies [%]	38.3	41	38.2	43.3	0.7	5.609

The FEM simulation results by Maxwell give an excellent illustration of magnetic flux lines and magnetic flux density in different parts of UM model. Since the magnitude of the magnetic flux is directly proportional to the current flowing through the windings, and UM current with the DC source is more than with the AC source, the more vital magnetic fields happened with the DC source, as shown in Figure 7-a.



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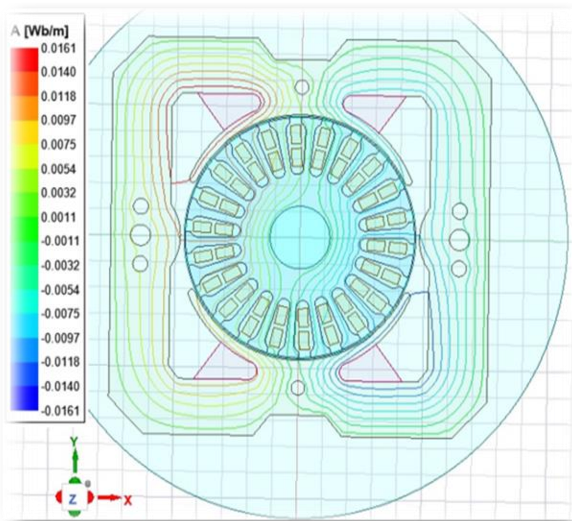

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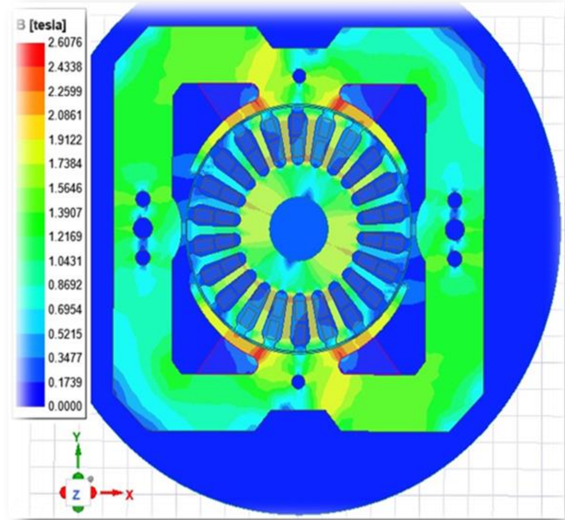
Figure 7. Magnetic flux lines at FL:(a) DC supply, (b) AC supply

Also, Figure 8-a shows the flux density distribution in the motor model is higher with a DC supply (Bmax=2.6076 T) than with an AC supply (Bmax=2.5319 T) in Figure 8-b.



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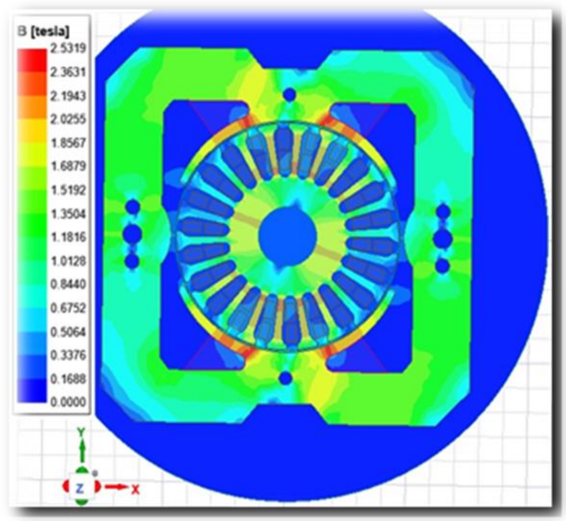

b

Figure 8. Magnetic flux density at FL: (a) DC supply, (b) AC supply

6. Conclusions

The current study succeeded in proposing a methodology for analyzing a universal motor in which design data are not available by providing it based on reverse engineering. Adopting the drawing possibility of the Maxwell program to design the square-shaped stator of a universal motor not included in the program library was also achieved successfully, which will make the Maxwell program widely used and not restricted to use with specific motor designs. The FEM simulation results of the universal motor showed good agreement with the outcomes of the motor test results at both no load and full load conditions with a good explanation of flux lines and flux density distribution, which proves the potential for adopting the proposed methodology in analyzing any electric machines included in Maxwell program even if the motor is without design data.

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Conflicts of Interest

The authors do not have a conflict of interest in this article.

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