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Finite Element Analysis of Universal Motor Based on Reverse Engineering

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Abstract

This paper present an innovative methodology in analyzing a universal motor which not having design data by extracted it via reverse engineering . These gained data were used to model the motor by Maxwell program and analyzing it by FEM to get motor performance results , which showed a good agreement with motor test results .The success of a paper methodology proved the possibility of analyzing any electric motor by Maxwell program even if the motor is without design data.

Keywords- ANSYS Maxwell, FEM , Reverse Engineering ,Universal Motor.

I. INTRODUCTION

Single-phase motors are known as universal motors (UMs). That can run on single-phase alternating current (AC) or direct current (DC) power sources. The brush position fixes the torque angle, which is typically at its ideal 90° value[1]. The efficiency of the motor is dependent on a variety of 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 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 unmanageable speed [2]. The armature current and the excitation current both reverse direction simultaneously. The motor's direction torque and speed is always the same. A universal motor with low power employs In order to produce the highest torque, a commutator's neutral line should be positioned between a pair of poles and the brush [3] . The universal motors have a wide range of residential applications, including vacuum cleaners, mixers, grinders, and small power tools. They can also be utilized in ac drive circuits, agriculture, and certain industrial items. Additionally, their uses can be found in appliances including hair dryers, dairy machines, air conditioners, and blowers. These motors offer numerous benefits and applications, but they also have certain drawbacks such as the motor's complex structure, which makes it more complicated than a single-phase induction motor, and the commutator's brushes, which cause wear and tear mechanism, which results in a motor with lower efficiency than a DC motor [4]. In medical equipment, the universal motor employed. In the industrial sector, these actuators are in high demand. Actually, around 200 million pieces are produced annually. Are offered for sale as universal motors [5]. The motor's efficiency qualities describes the various electrical and mechanical flaws in the motor [6]. One type of electro-mechanical converter found in many electrical systems is the universal motor. An assessment of the performances is required, even in cases when the design was executed flawlessly. Additionally, using various supply voltage types is advantageous for getting a clear image of the behavior of the motor. Determining the ideal operating point is another crucial component [7].

II. RELATED WORK

Several studies have improved the universal motor's performance as reported in the literature in recent years. The author used Simulink in order to compare the functionality of BLDC motor drives and universal motors for use with mixers and grinders[8]. The author demonstrated how the universal motor behaves when operating on both 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 [9]. A 550-Watt universal motor with a deep slot operating at 9500 rpm was suggested by the author for use with strong electric tools. Mag Net software, which is based on FEM, was used to simulate the motor., validated by experimentation. The investigation carried out using several variables to improve the corresponding motor's performance [3]. Another article's author creatively suggested combining two windings in the universal motor's current configuration, which greatly enhances the motor's core losses and torque ripples [10]. Several of the 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 [11]. 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, leading to the creation of a superior new universal motor design by altering the number of armature slots and the armature coil's simultaneous connection[12]. A comparison between an induction motor and a universal motor model was suggested by the author for use in washing machines. The behavior measured parameters included efficiency, induced voltage, current, speed, and torque, which were compared to the experimental setup. [13]. 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 as opposed to a three-phase motor [14]. 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, the experimental analysis and comparison of saturation effects, commutation, and transformer voltage, and armature reaction results [15]. To enhance the commutation process, D Lin et al. presented the universal motor model, where simply by ignoring the FEA's d- and q-axes changes the brush angle from the neutral position [16].

III. THEORETICAL BACKGROUND

The most accurate findings come from FEA analysis when the geometric discretization is sufficiently precise. Computer power makes it possible to provide FEA solutions in a reasonable period. Nevertheless, it requires building a thorough model of the device, which might take many hours [17]. Because it allows engineers to address complicated issues such as the influence of Saturation, complicated magnetic fields, and harmonics in various motor parts, the FEM is a main tool for computing magnetic fields in electrical machines such as universal motors. This method allows us to enter the motor and conduct a thorough investigation [18]. The FEM analysis also allows us to do in-depth study of the motor, FEM is a computer-based mathematical approximation method for calculating machine characteristics such as flux density, torque, and generated EMF across different motor components, and flux linkage [19-21].In magnetic materials, B and H are collinear, meaning they point in the same direction and are situated inside the same material. A variety of Quantities are utilized, such as the density of a magnetic field represented by flux density B passing through a certain area of material. While field intensity H, reflects the change in magnetic field strength caused by the magnetic field. They are linked by magnetic flux ($\emptyset$) in magnetic materials [22]. Because it allows engineers to address complicated issues such as the influence The FEM is a key tool for analyzing harmonics, complicated magnetic fields, and saturation in various motor components. For computing magnetic fields in electrical machines such as universal motors. This method allows us to enter the motor and conduct a thorough investigation. Maxwell's equations are one of the most elegant and succinct methods to express the fundamentals of magnetism and electricity. The majority of functioning connections in a static or dynamic electromagnetic environment may be developed using Maxwell's equations. These equations, include Ampere Maxwell law, Faraday's law, Gauss' law for electric fields, and Gauss' law for magnetic fields, which are the most significant in physics. Maxwell equations provide the basis for the development of scalar and vector potential differential equations as follows:-

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

$$B = \mu H \qquad (2)$$

$$H = B/\mu = \upsilon \cdot B \qquad (3)$$

$$H = \upsilon B \qquad (4)$$

$$J = \sigma E \qquad (5)$$

Utilizing magnetic vector potential A

$$B = \nabla \times A \tag{6}$$

Substituting (6) in (1) of Maxwell's equations and again substituting in:

$$\nabla \times (\upsilon \nabla \times A) = J \tag{7}$$

Where:-

(H) is the magnetic field intensity in (A.m).
(J) is the current density in ($A.m^{-2}$).
(μ) is the permeability in ($H.^{-} m^{1}$).
(υ) is the magnetic material's reluctivity in ($m.H^{-1}$).
(σ) is the material's conductivity in ($S.m^{-1}$).
(E) is the electric field intensity in ($V.m^{-1}$).

Maxwell 2D program use the FEM to analysis the UM based on the Maxwell equations.

IV. 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 upon the dismantling of individual components of larger items. For this study, the modeling of the test universal motor was done 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 that allows for quick, analytical machine performance calculations that can be transferred into Maxwell software for 2-D and 3-D geometry development. The ability of RMxprt to develop a complete Maxwell project (2D/3D) is the obvious advantage. The above two software compute numerous parameters with 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 the reverse engineering by decomposing the motor into individual parts and assign the dimension and speciation of it as design documentation listed in table 1 and table 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
Air gap length	0.5 mm
Rotor outer diameter	46 mm
Rotor inner diameter	12 mm
Number of Rotor slots	22
Core length	25.13 mm
Stacking factor	0.95
Type of core steel	M800-65A

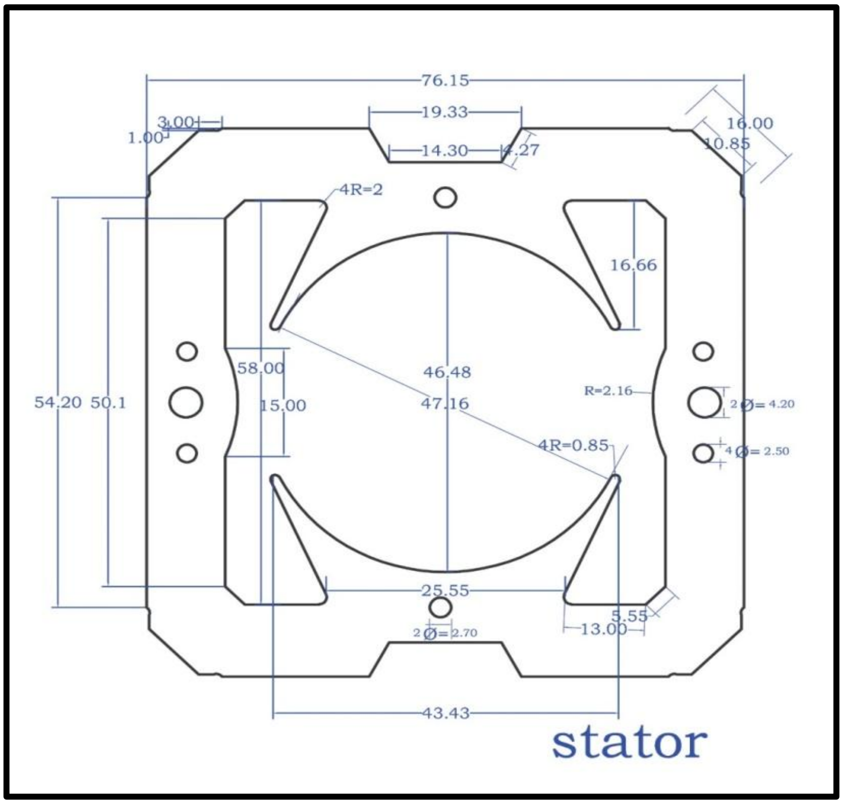

Figure.1 Stator Lamination

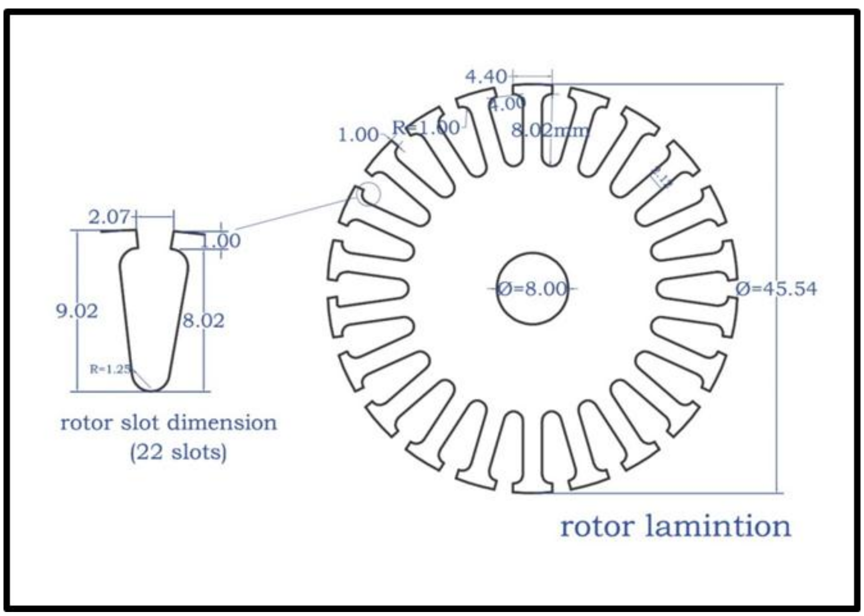

Figure .2 Rotor Lamination

Table 2 . Armature Winding Data

Item	Value
Rotor winding type	**Lap**
Multiplex number	**1**
Coil pitch	**9**
Number of strands	**1**

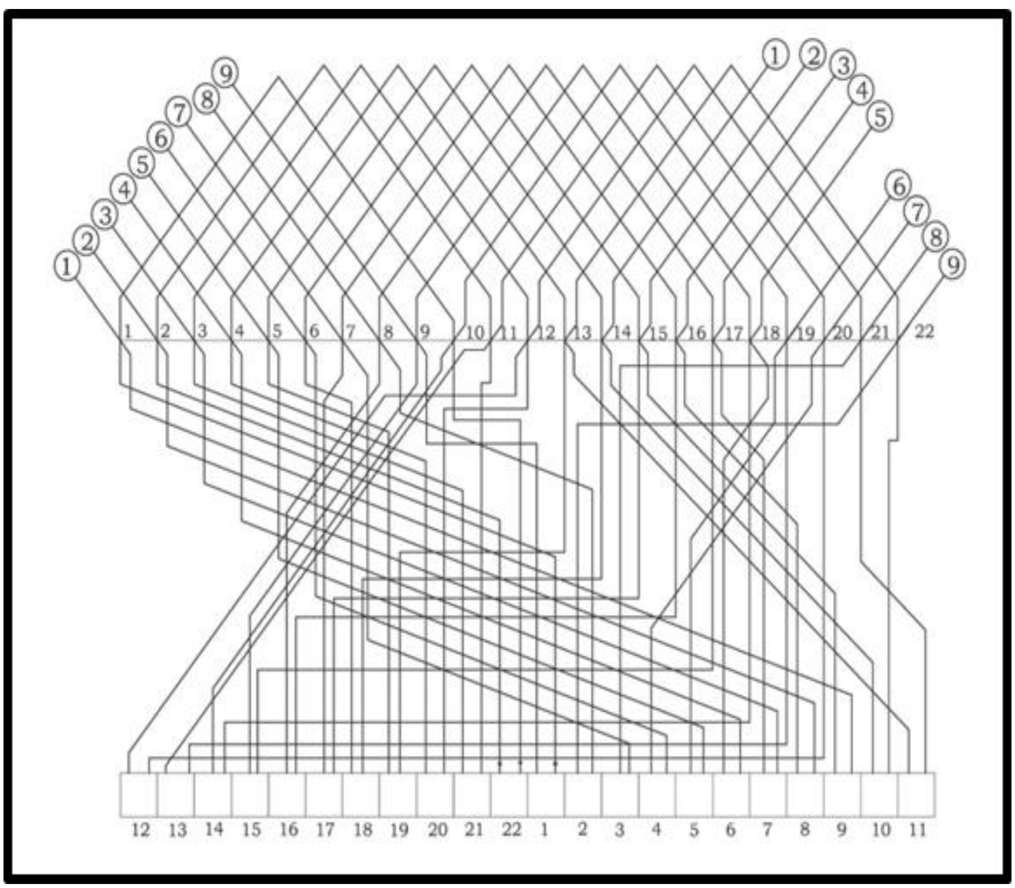

Figure .3 Armature Winding Diagram

IV-Test Motor Experimentation

The universal motor used in a food mixer(shown in figure 4) was tested in the laboratory at no load and full load , the test results were shown in table .3

Figure.4 Testing the universal motor in the laboratory

Table .3 Test Motor Experimentation Results

Supply	**Loading condition**	**Current(A)**	**Speed(RPM)**
220V , 50 Hz	No load	3.84	31000
	Full load	4.8	28000

V. Results and Discussions

The simulation results for the universal motor that was modeled and simulated in the technique utilizing two software: RMXprt (analytical results) and Maxwell2D (FEM) are listed below, RMxprt results such as the relationship between torque and speed, as in Fig.5, which demonstrates how torque varies with speed change and how torque rises by decreasing speed. The link between input current and speed is seen in Fig 6.

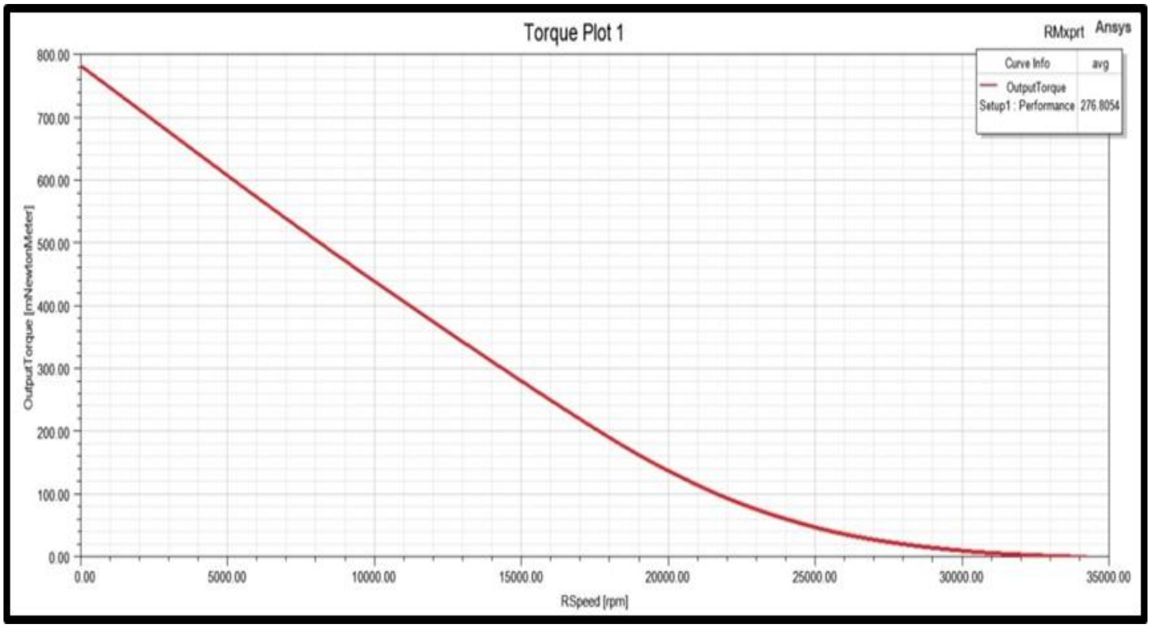

Figure.5 Effect of changing output torque with speed by RMXprt

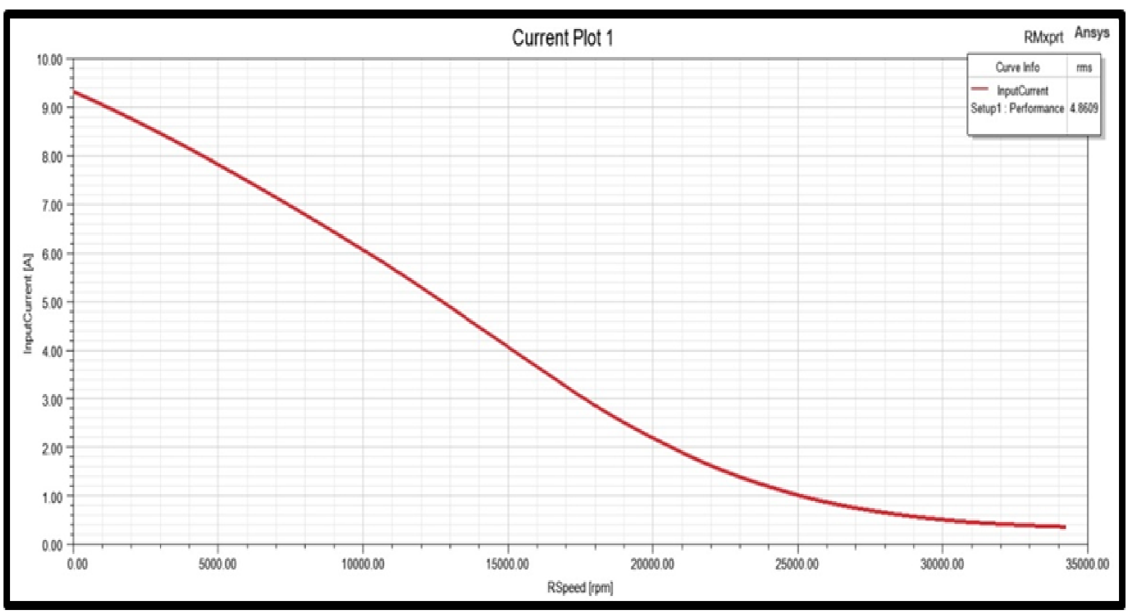

Figure.6 Effect of changing current with speed by RMXprt

The FEM simulation results obtained from Maxwell 2D for motor current and torque at no load and full load were illustrated in figures 7 to 10.

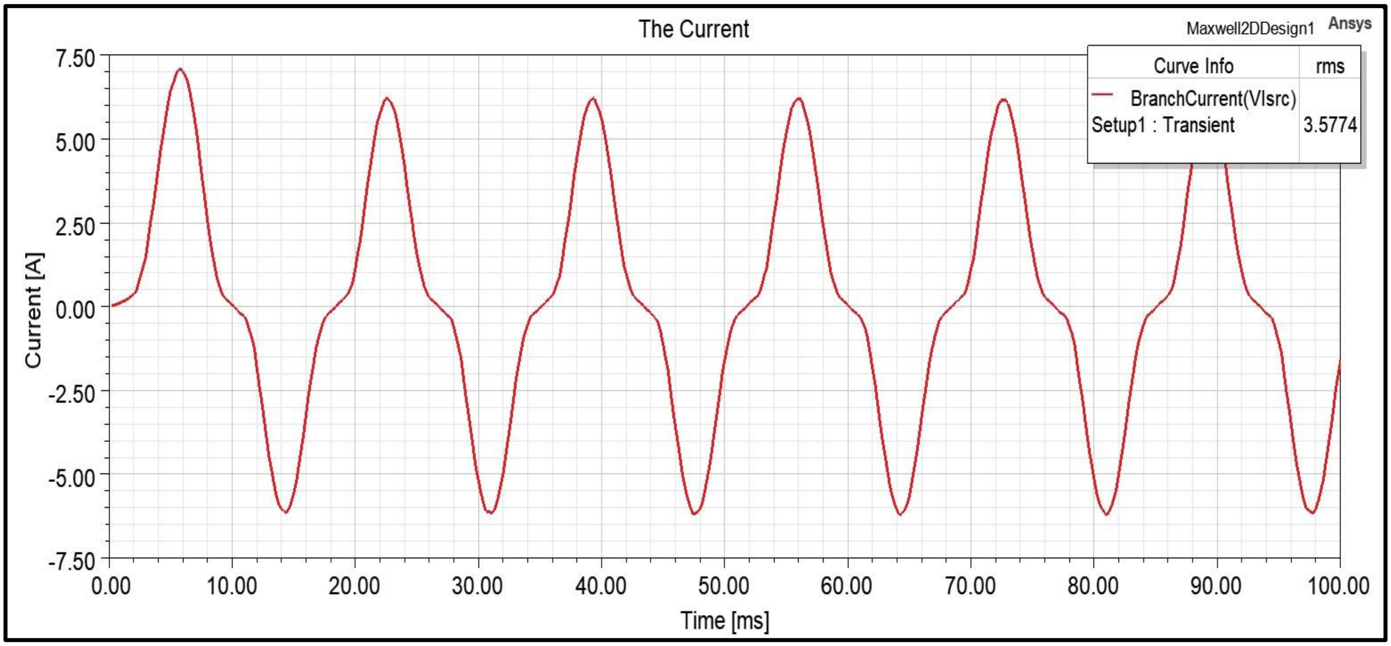

Figure.7 Universal motor current by Maxwell 2D (at no load)

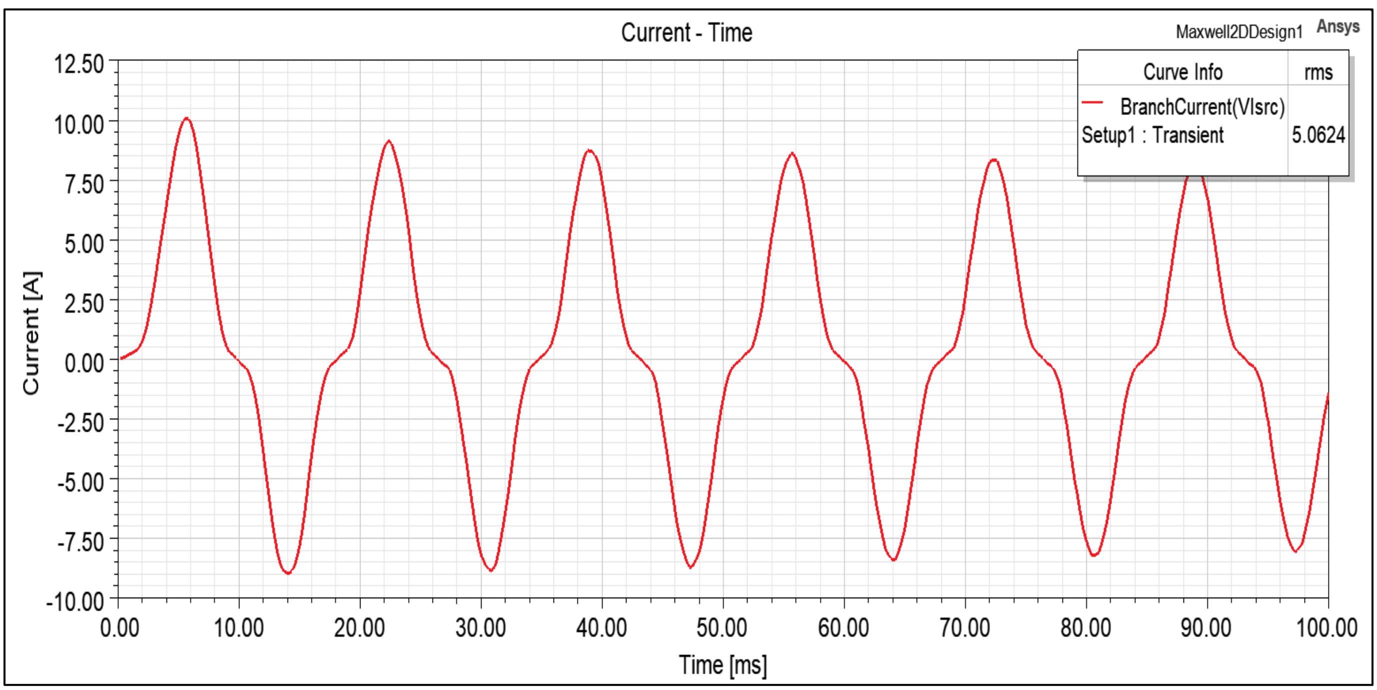

Figure.8 Universal motor current by Maxwell 2D (at full load)

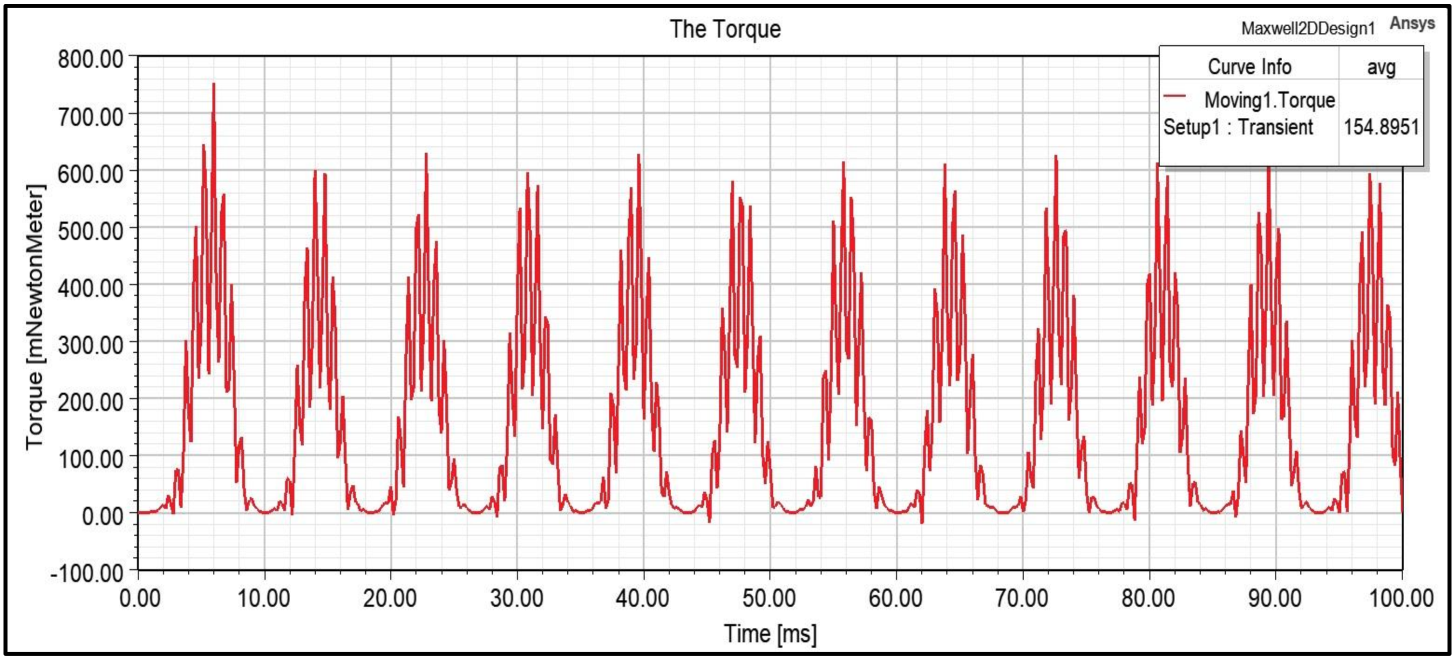

Figure.9 Universal motor torque by Maxwell 2D (at no load)

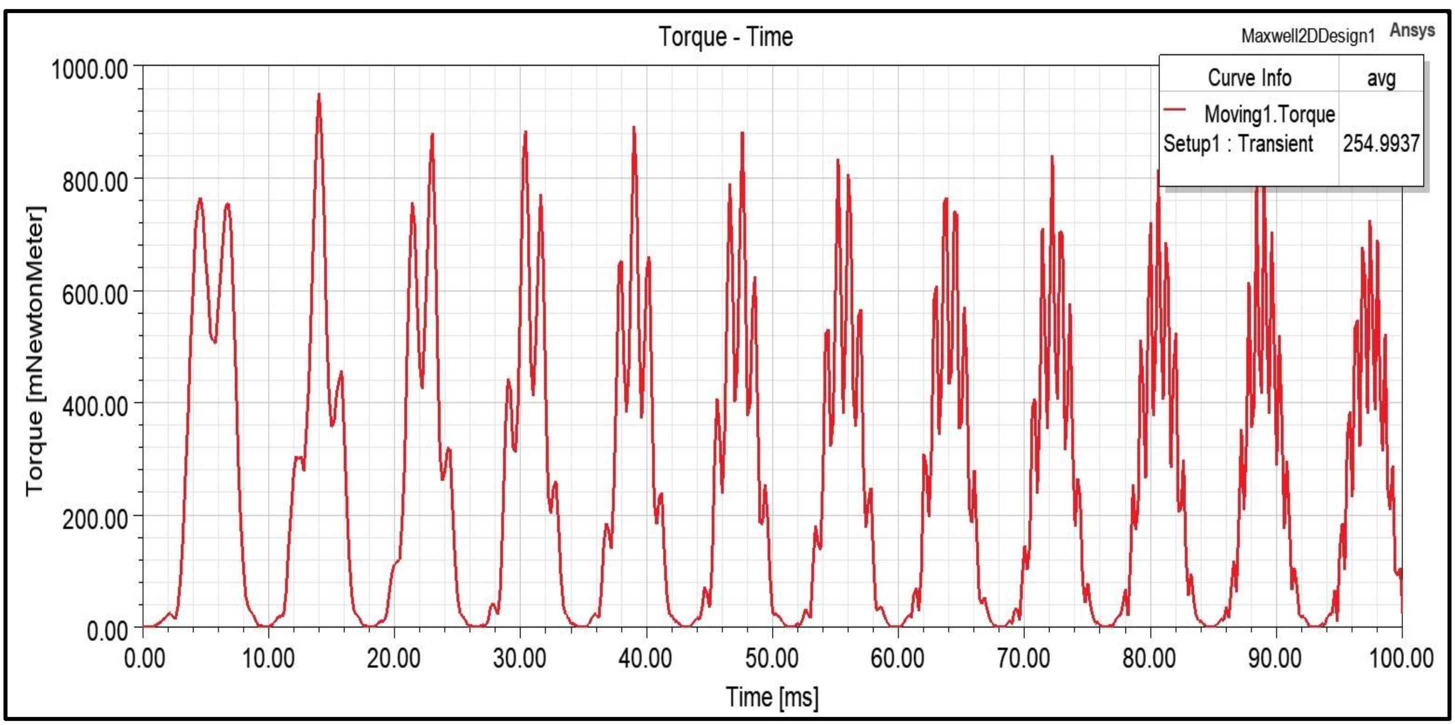

Figure.10 Universal motor torque by Maxwell 2D (at full load)

Also FEM result from Maxwell 2D provide agood illusrations for magnetic flux lines and flux density as shown in figure 11 and 12 .

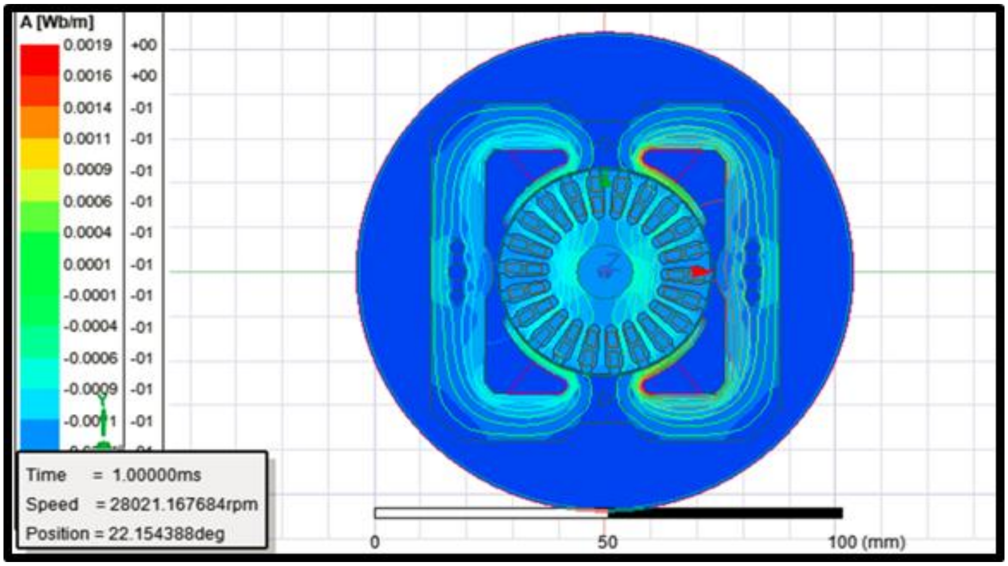

Figure.11 Universal motor magnetic flux lines (at full load)

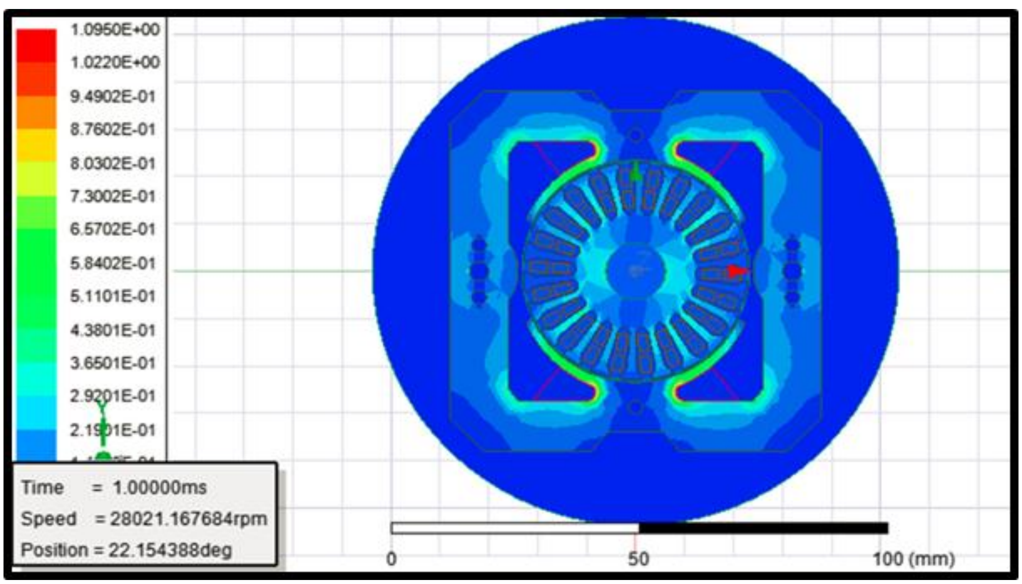

Figure.12 Universal motor magnetic flux density(at full load)

The values of the (FEM) simulation result by Maxwell 2D and experimental findings at various loads were displayed in Table 3(no load at 31000 rpm) and Table 4 (full load at 28000 rpm) .

Table 3. Universal motor results comparison at no load

Parameter	Experimental	FEM	Error (%)
Current (Amp)	3.84	3.577	6.85
Input Power (W)	422.4	426.16	0.89
Power Factor	0.5	0.54	8
Output Power (W)	245	247.69	1.09
Torque (N.m)	0.075	0.0762	1.6
Efficiency (%)	58	58.1	0.17

Table 4: Universal test motor results comparison at full load

Parameter	Experimental	FEM	Error (%)
Current (Amp)	4.8	5.06	5.42
Input Power (W)	665.3	714.26	7.28
Power Factor	0.63	0.64	1.59
Output Power (W)	412	446.24	3.44
Torque (N.m)	0.145	0.15	0.04
Efficiency (%)	61.9	61.18	0.04

VI. CONCLUSION

The current research succeeded in presenting a methodology for analyzing a universal motor which design data are not available by providing it by adopting the reverse engineering . The process of adopting the drawing possiibity of Maxwell program to design the square shaped stator of universal motor that is not included in the program library was also achieved successfuly ,which will make the Maxwell program being widely used and not restricted to use with specific motor design. The FEM simulation results of universal motor showed good agreement with the experimental results when the motor operated at no load and full load.

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