VISUALIZATION AND ANIMATION OF SINGLE-PHASE CAPACITOR MOTOR [+]

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Abstract:

In this paper a new simulation tool is described, which enables direct animation and visualization of single-phase capacitor motor operation. The method used finite element results of magnetic vector potential and magnetic flux density vector to create animation file which displays the events inside the motor at different conditions. The implementation is by software package (ANSYS V.8). The main purpose of this tool is to give the students a clear understanding of the operation of motor, and to create the consecutive images that one needs to produce to give the students the necessary visual effect.

المستخلص:

يقدم البحث الحالي محاكاة جديدة في عرض توزيع خطوط الفيض المغناطيسي وكذلك كثافة الفيض داخل المحرك الحثي أحادي الطور. تعتبر هذه العروض مفيدة في مجال تكنولوجيا التعليم الهندسي في التصميم والتعليم. الهدف الأساسي من المحاكاة هو لإعطاء المتعلمين الإدراك والفهم الأوضح لما يحدث داخل المحرك، كذلك خلق المهارة المعرفية التي يحتاج لها المتعلمين لإعطائهم التأثير المرئي الضروري. وتبين إن هذا العمل المصمم لأغراض الحركة يسهم في عمليتي التعليم والتعلم من خلال تفاعل المتعلمين مع أسلوب العرض.

Introduction:

Electromagnetic fields have long been considered to be a very difficult subject, primarily for many reasons, such as electromagnetic concepts are perceived to be abstract, and the understanding of electromagnetic phenomena involves visualization in space and time. The real challenge in understanding the electromagnetic fields phenomena is to enable visualizing the events that take place inside the motor. Comprehension of the theory can be well assisted by the excellent graphic images produced by a computer as a product of the modern CAD systems.

These graphics are usually obtained isolated, and need to combine these images to obtain the impression of animation, which is this main topic of this work.

Instructional animations are these produced for the specific purpose of fostering learning. The popularity of using animations to help learners understand and

remember information has greatly increased since the advent of powerful graphics-oriented computers. This technology allows animations to be produced much more easily and cheaply than in former years. The software package is intended to make the subject more interesting and more effective by allowing moving displays of the events inside the machine.

The image visualization and animations are powerful tools for teaching design and analysis courses. [1, 2]

Producing animated display and movies for instruction are being of interest to the universities. The basic principles of operation of rotating electric machines have been demonstrated via animation images. The moving color display shows the events inside the machine as the machine is shown running on the screen. [3, 4]

The animation for teaching students the principles of power electronic circuit is used in [5]. The animation gives valuable information about the simulation of power electronics and electrical drives. It reveals more insight into the circuit operation then only displaying simulation results in graphs.

The animation and visualization of inverter-driven induction motor can be created for showing the inverter voltages, inverter currents, the motor position, torque and magnetic fluxes [6].

The work [7] employs greatly expanded interactive graphics capabilities as well as audio and animated video additions. The major focus of the project has been to develop microcomputer-based instructional aids which enhance student performance and participation in early course, and provide problem-solving resources that students can use as they progress through succeeding courses. In [8] the work proved the effectiveness of the flux vector plot to simulate the dynamic behavior of transformer. The generated animation displays have been demonstrative and deductive, so they could be helpful in instruction and design. In [9] the finite element method has been presented to simulate dynamically the flux inside a three phase induction motor under steady state locked rotor condition. The result of the method was a dynamic display of the rotating flux inside the machine that is very demonstrative and aimed to present an impression of the actual behavior of the flux.

All the above papers used the idea of animation to explain to the students the basic principles of machines operation. The difference with all of them is by using kind of software and programming , and how can used the software as a tool to explain the behavior of the motor. As we know, the design of motors is difference, so the analysis type will differs and the programming will differs as the analysis type.

This work describes the necessary procedure for generating the dynamic flux display of the single-phase capacitor motor at different loading conditions. A method is presented to combine the result of the finite-element solution of the motor with animation capability of the personal computer. The product is movie files which are considered to represent the rotating behavior of the flux lines and flux density close to reality. The analysis found it is more convenient to examine the model using flux plots which is important to have qualitative understanding of magnetic field distribution in different conditions and very important to be identified for the learning process.

The Finite Element of Single-Phase Capacitor Motor Model :

The single-phase capacitor motor is modeled by using Finite Element Method (FEM). The geometry is built by using (ANSYS V.8) with the data sheets obtained from State Company of Electrical Industries. These data consist of values of slot size, inner and outer diameters of the stator and rotor of the motor, the B-H characteristics

of the motor, number of slots of the stator, number of bars of the rotor, and length of the air-gap.

The dimensions of the capacitor motor as given above are fed into FEM program for building and analyzing the motor. The real constants are assigned to the coil areas (number of turns, resistivity, coil cross sectional area, etc.), and then specify the degree of freedom (DOF) for each area.

The flux parallel boundary condition is applied to the interior and exterior nodes of the model. Voltage source element is attached to the stator slots and a capacitor element (8μF) is attached to the auxiliary winding. The relative permeability of the iron core is considered, a B-H curve (non-linear material properties of the iron core), other parts have relative permeability of unity, and no resistivity is assigned to iron core. The solution is obtaining using circuit fed (transient and steady state) analysis.

Variational Formulation:

The solution of a boundary value problem is best obtained by first formulating the associated partial differential equation in variational terms by an energy-related expression called a functional. The field region is then subdivided into finite elements by means of triangular elements, in this application. In each of these elements, an approximate solution of the field problem is defined in terms of the potentials at the nodes. The functional is then minimize by setting its first variation to zero. This process yields a system of nonlinear algebraic equations, which is quasilinearized by the Newton-Raphson algorithm. The resulting linear equations are then solved by a Gaussian elimination scheme yielding the solution of the field problem. The finite element procedure is best illustrated by the block diagram of figure (1) [10]. According to variational principles, the Poisson's Equation for the magnetic field can be written in the following form:
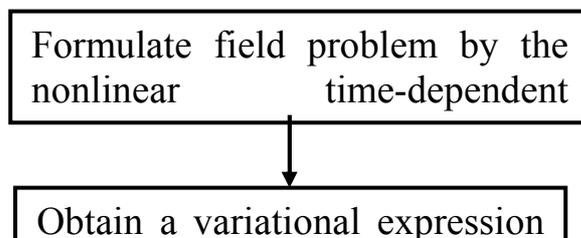
$$\delta\Pi = \int_{\Omega} \left(v_x \frac{\partial^2 A_z}{\partial x^2} + v_y \frac{\partial^2 A_z}{\partial y^2} + J^\wedge \right) \delta A_z \ dxdy \qquad (1)$$

Where Π is an equivalent functional, Ω is the area region, δ is the variational operator, J total current density. This equation is differential equation. Applying integration by parts to the above equation:

$$\delta\Pi = \int_{\Omega} v_x \frac{\partial}{\partial x}\left(\frac{\partial A_z}{\partial x}\right)\delta A_z \ dxdy + \int_{\Omega} v_y \frac{\partial}{\partial y}\left(\frac{\partial A_z}{\partial y}\right)\delta A_z \ dxdy + \int_{\Omega} J^\wedge \cdot \delta A_z \ dxdy \qquad (2)$$

Since the variational operator is commutative with both differential and integral operator, the functional is obtained from equation (2) after some steps and the linear integral cancels between adjoining elements and can be ignored, so:

$$\Pi = \frac{1}{2} \int_{\Omega} \left[v_x \left(\frac{\partial A_z}{\partial x}\right)^2 + v_y \left(\frac{\partial A_z}{\partial y}\right)^2 \right] dxdy + \int_{\Omega} J^\wedge \cdot A_z \ dxdy \qquad (3)$$

Formulate field problem by the nonlinear time-dependent

$\downarrow$

Obtain a variational expression

Electromagnetic Field Animation Program:

The software is written in ANSYS Programming Design Language (APDL), the programming language used by the (ANSYS V.8) software package is used for

moving displays of the events inside the motor at different operations of the motor. The menu tree of the program is shown in Fig. (2).

The program can be used without the need of a user's manual. The moving images on the screen can be discussed and analyzed at any angle of the individual frames and their relations to each other. In the following sections, the functions of each block in the menu tree are described.
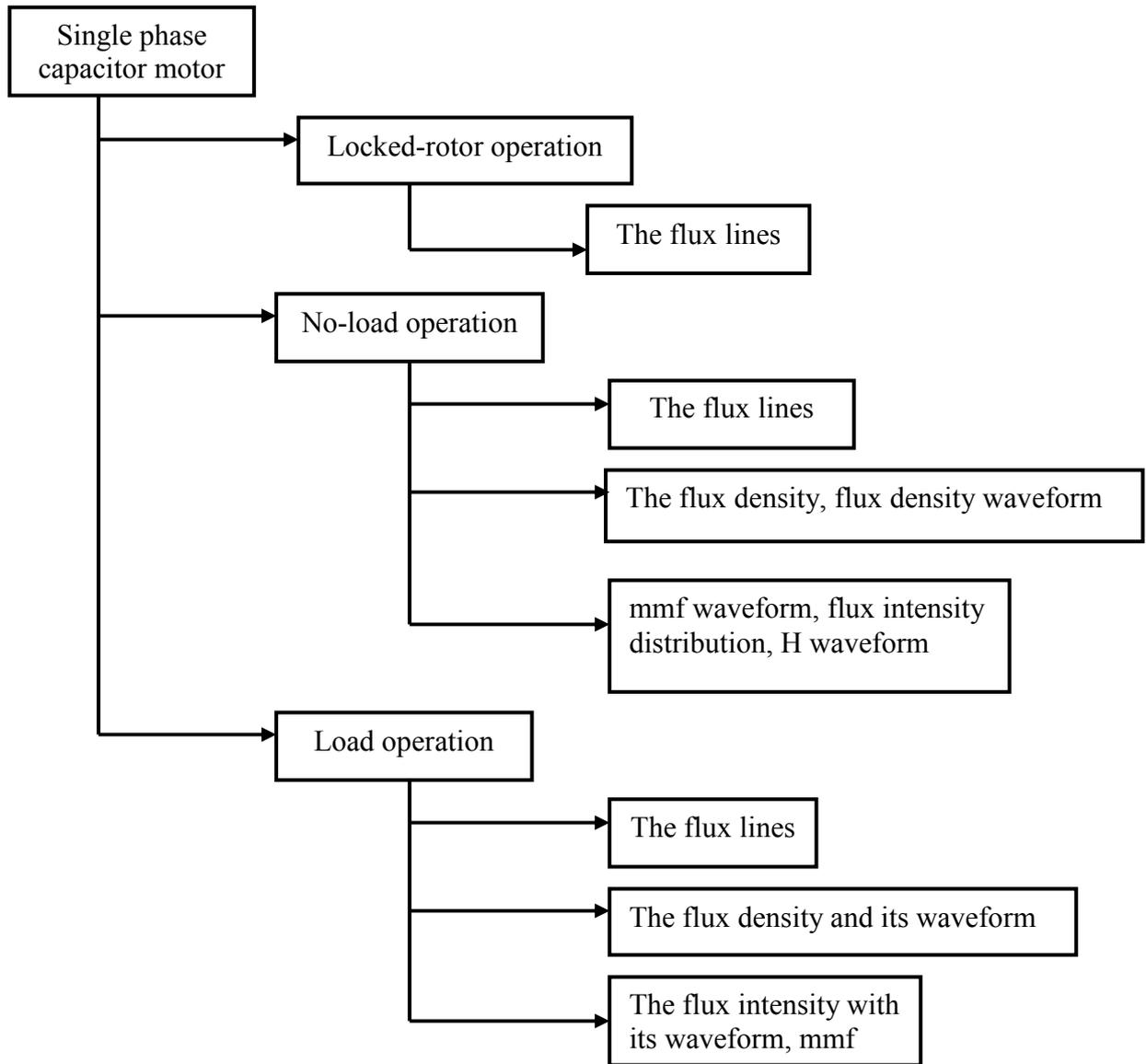
```
┌──────────────────┐
│  Single phase    │
│ capacitor motor  │
└──────────────────┘
        │
        │        ┌──────────────────────────┐
        ├───────▶│  Locked-rotor operation  │
        │        └──────────────────────────┘
        │                    │        ┌──────────────────┐
        │                    └───────▶│  The flux lines  │
        │                             └──────────────────┘
        │        ┌──────────────────────────┐
        ├───────▶│     No-load operation    │
        │        └──────────────────────────┘
        │                    │        ┌──────────────────┐
        │                    ├───────▶│  The flux lines  │
        │                    │        └──────────────────┘
        │                    │        ┌──────────────────────────────────────┐
        │                    ├───────▶│ The flux density, flux density waveform│
        │                    │        └──────────────────────────────────────┘
        │                    │        ┌──────────────────────────────┐
        │                    └───────▶│ mmf waveform, flux intensity  │
        │                             │ distribution, H waveform      │
        │                             └──────────────────────────────┘
        │        ┌──────────────────────────┐
        └───────▶│     Load operation       │
                 └──────────────────────────┘
                             │        ┌──────────────────┐
                             ├───────▶│  The flux lines  │
                             │        └──────────────────┘
                             │        ┌────────────────────────────────┐
                             ├───────▶│ The flux density and its waveform│
                             │        └────────────────────────────────┘
                             │        ┌──────────────────────────┐
                             └───────▶│ The flux intensity with   │
                                      │ its waveform, mmf         │
                                      └──────────────────────────┘
```

Fig. (2): The block diagram of capacitor motor menu tree

1. Locked-Rotor Condition:

In this part the distribution of the flux lines is demonstrated for the single-phase capacitor motor at the original capacitor value ($8\mu F$),and with two values of capacitor ($2\mu F$, and $32\mu F$). Fig (3) shows the flux pattern for (0°, 90°, 180°, and 270°) at full voltage source with $8\mu F$ capacitor, the flux direction for (0°) and (180°) is opposite and the flux patterns are similar, also with the flux direction for (90°) and (270°). The flux line distribution for the capacitor ($2\mu F$) and the capacitor ($32\mu F$) are shown in Figs (4) and (5) respectively. The change in the capacitor's value will affect the flux

line distribution, so the magnitude of flux line has been increased with increasing the capacitor value. The generated animation files are considered to simulate the flux behavior inside the capacitor motor close to reality.

2. No-Load Condition
The single-phase capacitor motor operates at no-load condition. The following are seen on the screen while the motor is running:
- The direction and magnitude of the flux lines, flux density in the motor at each 30°, as shown in Figs. (6) and (7).
- The effect of the mmf waveform in the air-gap, and the flux density waveform.
- The magnetic field intensity in the air-gap with its waveform. Snapshots of these cases are show in Fig. (8).

3.   Load Condition
Operations under different values of capacitor at (8μF, 2μF, and 32μF) are simulated. The flux line distribution at different angles with 8μF is shown in Fig (9). The resulting magnetic field, the magnetic field intensity (H) under these values of capacitor is demonstrated. It is found that the distribution of the flux line and the flux density does not change in their shapes under different capacitor values but their magnitude will be changed. The snapshots for the different values of capacitor are shown in Figs (10).

Conclusion:

The dynamic displays as proposed in this work offer their selves as a new basis for the instructional packages in the field of electromagnetics. They are instructive, deductive and illustrative. The actual value of these displays comes from their capability of presenting the behavior of the electromagnetic quantities very close to reality as a consequence of the accuracy of the FE solution in conjunction with the computer animation technology. The dynamic display in this work is considered to be an important contribution to the people who are interested in teaching rotating electrical machines.

The analysis results have been compared with both the experimental results (from State Company of the Electrical Industries) and the analytical model in order to verify proposed calculation method.

Animation during simulation opens up new possibilities for teachers and students. It enables students to actively participate in the learning process. Here, interactive animation might help a lot-its utilization in simulation enables to create an interactive training environment. Animation technology make subject more attractive to students, complex technical problems should be presented in a way that is easy to follow and understand, the moving color display show the events inside the machine as the machine is running on the screen, and this will help for getting a clearer understanding about the event which happened inside the machine, also for self-study tool. Development of an understanding of the role of numerical techniques for solution of problems in electromagnetism is the aim in teaching electromagnetic theory.
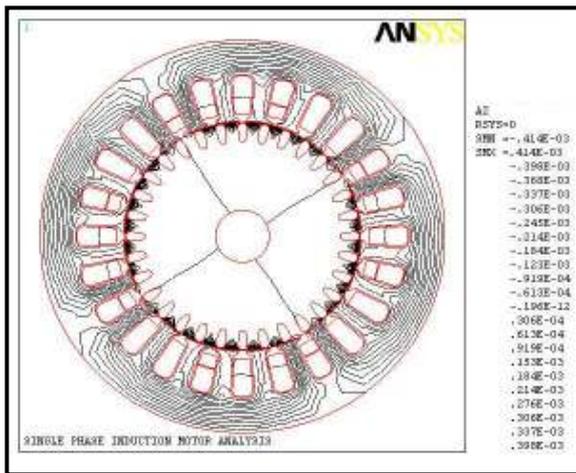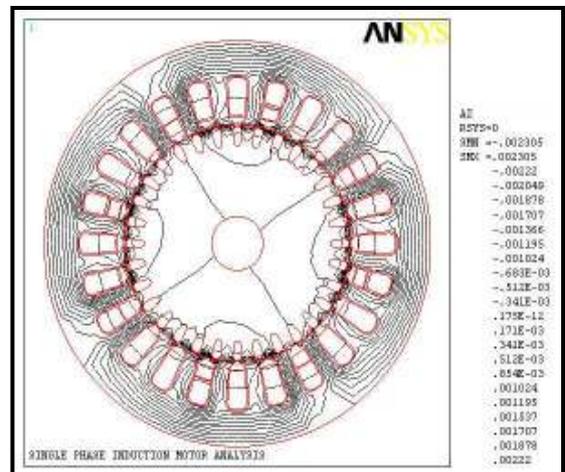
0°
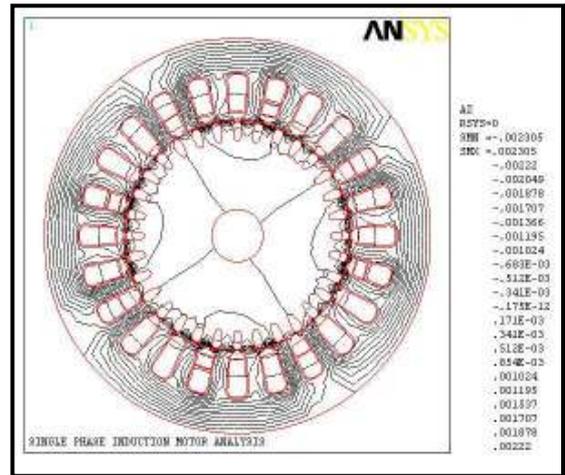
90°
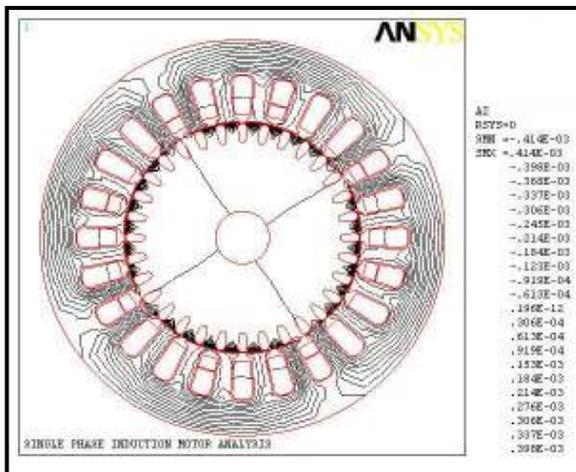
180°

270°

Fig. (3): The flux line distribution at locked-rotor full voltage with capacitor 8µF
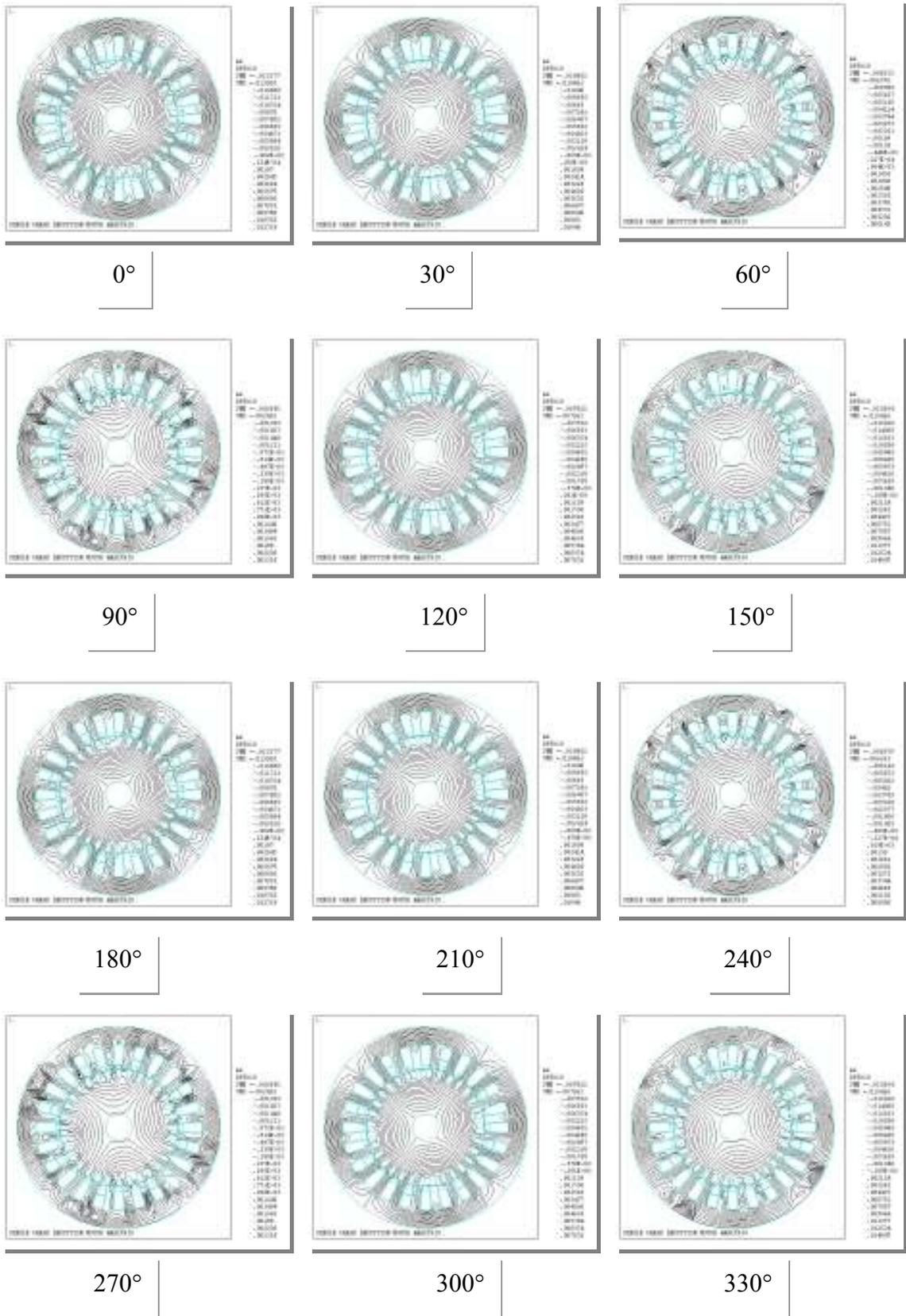
| 0° | 90° |

Fig. (4): The flux lines distribution at locked-rotor full voltage condition with capacitor 2μF.

| 0° | 90° |

Fig. (5): The flux lines distribution at locked-rotor full voltage condition with capacitor 32μF.

0°	30°	60°
90°	120°	150°
180°	210°	240°
270°	300°	330°

Fig. (6): The distrbution of flux at no-load operation

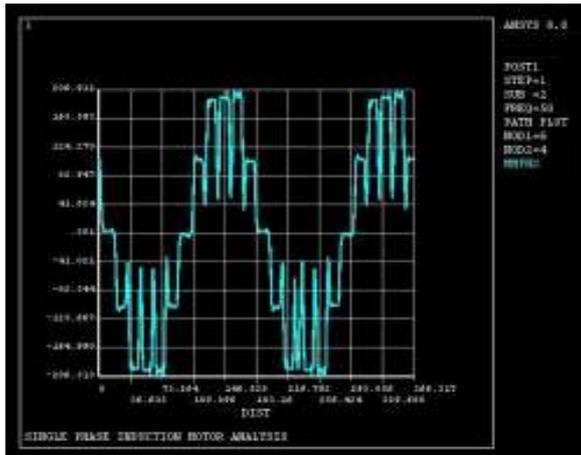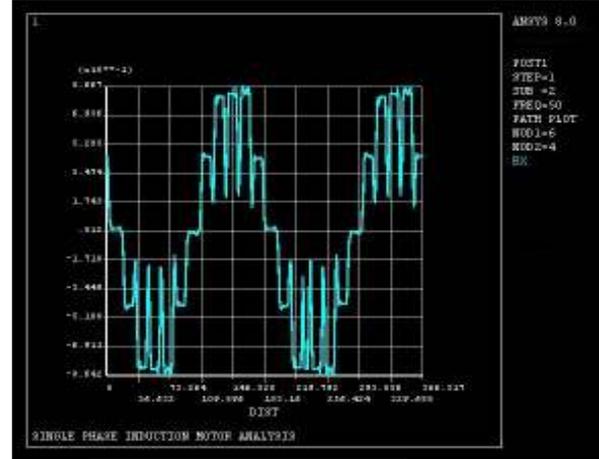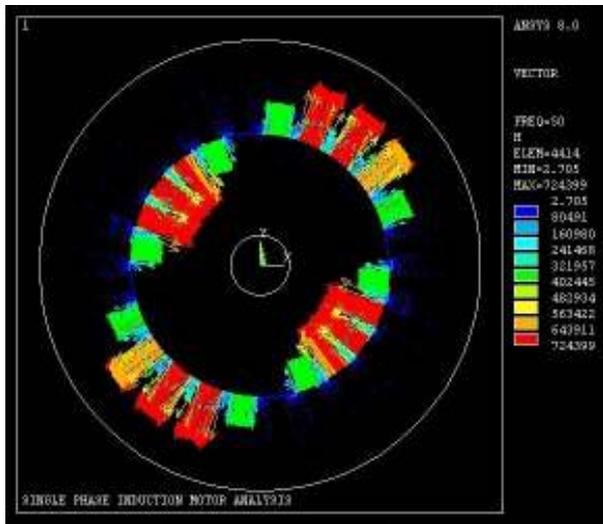| 0° | 30° | 60° |
90°	120	150
180°	210°	240°
270	300°	330
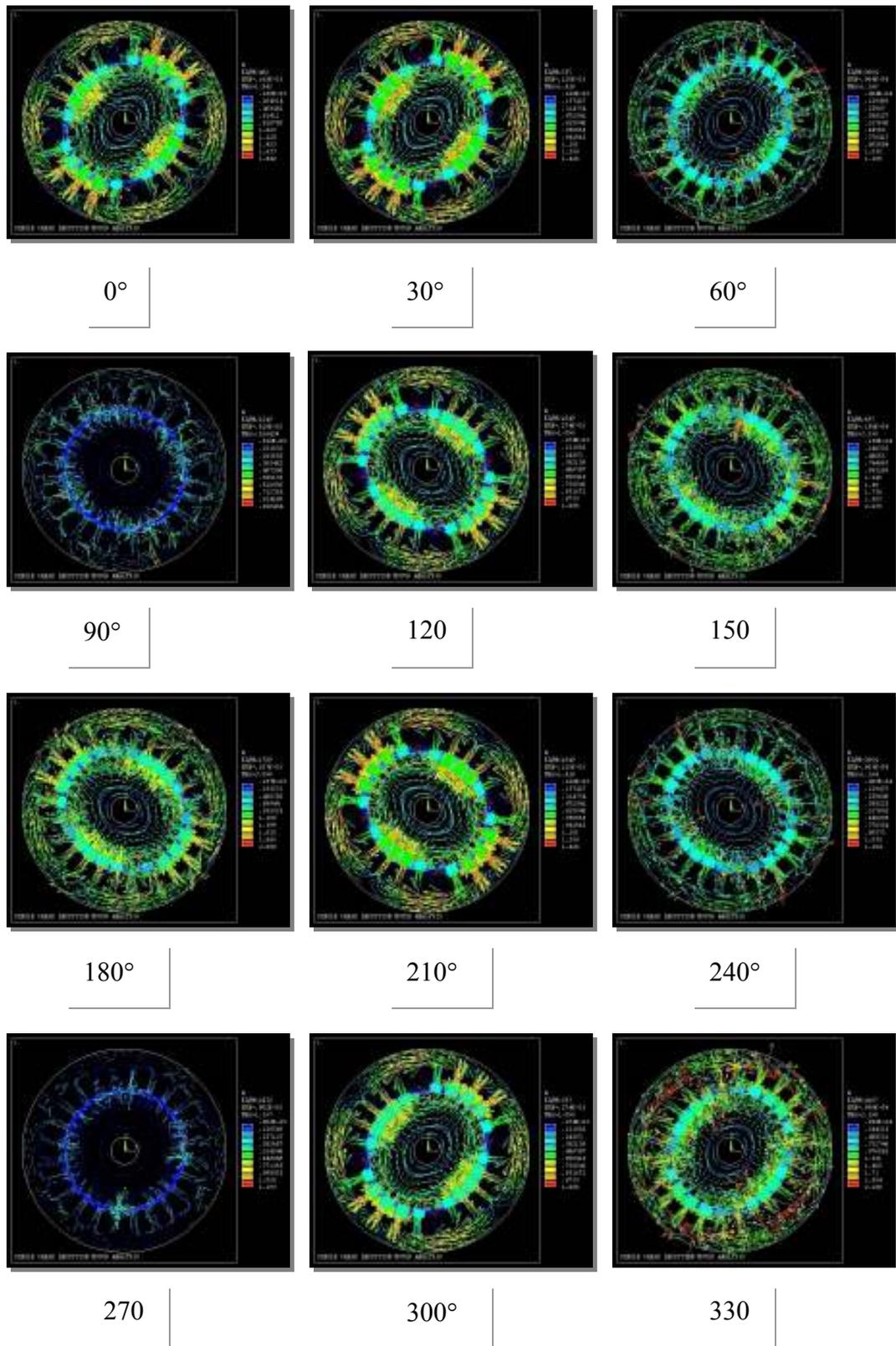
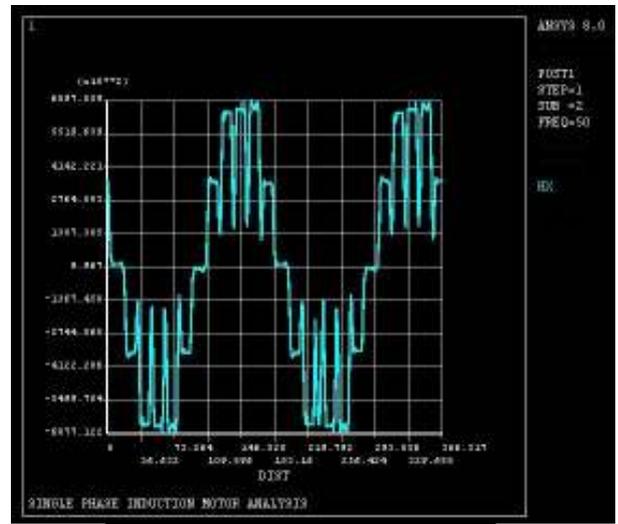**Fig. (7):** the distribution of flux density at no-load operation

a. mmf

b. Flux density waveform

c. Flux intensity

d. Field intensity waveform

Fig. (8): The no-load operation (mmf waveform, flux density waveform, flux intensity

distribution, and H waveform)

0°	30°	60°
90°	120°	150°
180°	210°	240°
270°	300°	330°

Fig. (9): The flux lines distribution at load condition with 8μF

A. flux line at 2μF

B. flux density at 2μF

C. field intensity at 2μF

A. flux line at 32μF

B. flux density at 32μF

C. field intensity at 32μF

Fig. (10): The operation at difference capacitor values at load condition.

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Appendix (1) Programming of the modal

```
/prep7
et,1,plane53
keyopt,1,1,0
keyopt,1,4,0
et,2,plane53
keyopt,2,1,3
keyopt,2,4,0
et,3,circu124
keyopt,3,1,4
et,4,circu124
keyopt,4,1,2
et,5,circu124
keyopt,5,1,5
/input,rotor17,txt
/input,stator18,txt
/prep7
asel,s,area,,1,72,1
cm,rotora,area
cmsel,s,rotora
```

```
csys,1
a=0
agen,,all,,,0,a,0,,,1
allsel
csys,0
/input,cpst0,txt
nummrg,all,1e-9
numcmp,all
d,15365,volt,0
d,15399,volt,0
nummrg,all,1e-9
numcmp,all
finish

/solu
antype,harmic,new
harfrq,50
hropt,full,,on
hrout,on
eqslv,sparse
kbc,1    !step

cnvtol,A,,.5
outpr,all,all
outres,all,all
solve
save
finish

/post1
set,1,1
presol,elem
set,1,1,,1
presol,elem
finish
```