

## DYNAMIC FLUX DISPLAY OF TRANSFORMER

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### ABSTRACT

This work presents procedures to utilise the finite element results of magnetic flux density vector to create animation file which displays rapidly successive frames, prepared by postprocessing, leading to the effect of moving flux to the viewer. The method is applied to 2-D transformer model showing excellent animation effect of the alternating flux in both the core area and the leakage flux area. The method is useful in analysis as the dynamic flux monitoring gives more details than static display. The method can be used to produce instructional materials giving the student an impression of the natural behaviour of the electromagnetic devices.

### خلاصة

يقدم البحث الإجراءات اللازمة للحصول على عرض حركي للفيض المغناطيسي في المحول الكهربائي (أدادي الطور) ويتم الحصول على العرض الحركي باستثمار النتائج الحاصلة من التحليل الكهرومغناطيسي بواسطة طريقة "العناصر المحددة" حيث تم استخدام الرسوم الاتجاهية للفيض المغناطيسي بدلا من الطريقة المأوفة التي تعتمد الرسوم الخاصة بخطوط الفيض المغناطيسي. وقد أظهرت الطريقة كفاءة واضحة في تبيان الفيض الحركي وذلك من خلال عرضين أحدهما للفيض في اللب الحديدي والآخر للفيض في مناطق التسرب المغناطيسي.

يمكن استخدام الطريقة لاعداد عروض حركية لمعدات كهرومغناطيسية اخرى مثل المحركات، حيث تستثمر هذه العروض لأغراض تعليمية و تصميمية.

### KEY WORDS

Finite element method, Transformer analysis, Computer animation

### INTRODUCTION

As electric and magnetic fields are not directly accessible to the human senses and must be inferred from analysis of data, simulation by using computer is a powerful tool to gain expertise in these fields. Comprehension of the theory can be well assisted by the graphic images produced by computer as a product of the modern CAD systems, these graphics are usually obtained isolatedly, combing these images to gain the impression of animation is the objective of this work.

Producing animated display and movies for instruction is of interest to universities. Miller et al (1988) described a sophisticated and costly system to produce movies using minicomputer and special type of video tap recorder. It seems that such system would not be demanded in view of the latest technological advances in personal computers. In this work movie files are generated using a PC having the commonly used programs.

With the exception of Smolleck (1988) and Preis et al (1995) the topic of the dynamic display is the electromagnetic wave propagation, fields are solved by obtaining integrals or direct application of the analytical solution. In Smolleck (1988), a point is traced on the screen representing the MMF of stator showing circle for balanced case and ellipse for the unbalanced case of a three phase induction motor. In Preis et al (1995) some simple examples of animation are given, among those the flux of a reactor is displayed based on the flux lines plots.

Cole et al (1990) defined the term "visual electromagnetic" (VEM) to be an interactive and visual learning environment to provide a more appealing and intuitive means of studying electromagnetics. The degree of interactivity of the programs is classified into two modes, the stored- solution mode (SSM) and the generated solution mode (GSM). The interactivity of the instructional package is classified into the GSM when the package can make the dynamic display ready within reasonably short time (on-line) after the parameters have been changed, in the SSM only limited solutions can be manipulated. Any instructional package utilising movie files as described in this work should be classified into the SSM due to the long solution run time of the F.E. program.

### THE POSTPROCESSOR GRAPHICS

Commonly in the electromagnetic F.E. packages, the postprocessor can display graphics of the following types:

- 1- The contour plots: results are displayed as contours filled with graded colours according to the values.
- 2- The flux lines plots: in which equipotential lines of the magnetic vector potential are plotted as they lie along with the flux lines.
- 3- The vector plots: results are displayed as coloured vectors, length and colour of the vector is indication to the magnitude.
- 4- Graph plots: it is limited to the path points.

To generate dynamic behaviour of electromagnetic device the vector plot is relied on in this work, direction is already indicated as well as magnitude, while direction is missed in other plots, additionally all other plots could not display results in adequate details at narrow regions. Dynamic displays based on flux lines plot are observed in the internet search, the flux lines plots can declare some primitive concepts such as the flux cutting rule, while the flux vector plot possesses the generality to display the main quantity of interest in electromagnetic devices. The two dimensional finite element model is used to simulate the transformer, as the three dimensional model would result in vector plots that is not well distinguished in the depth, consequently a section in the transformer of the three dimensional model must be selected, this would be considered equivalent to the two dimensional model with reasonable accuracy.

### GENERAL REQUIREMENTS

To apply the method, the software requirements as illustrated in **Fig.(1)** is to be available under the environment of Windows 95 or later, it would be worthy to mention that there is no critical restrictions upon the choice of the software, as an example the "display utility" can be replaced by the (3D MAX) application.



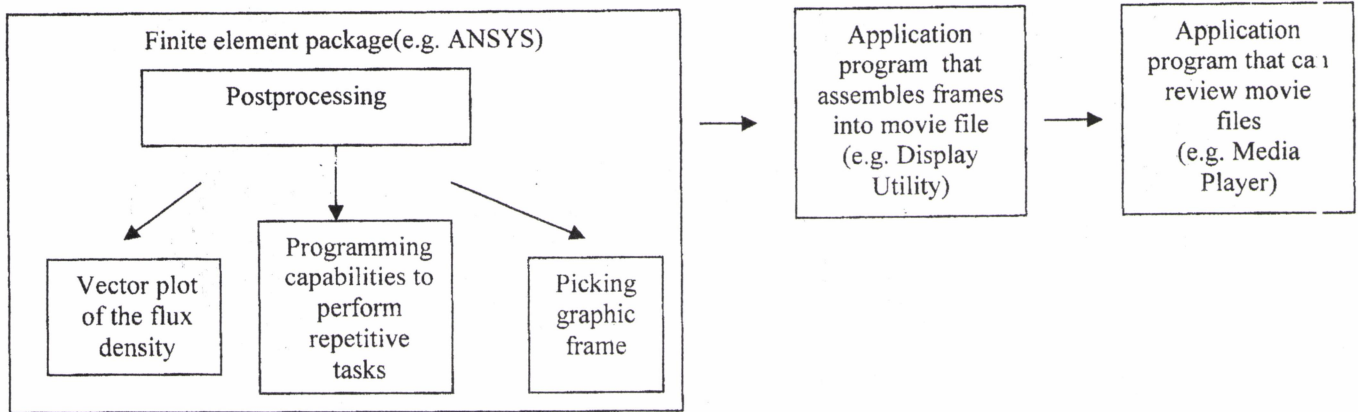


Fig. (1). Software Requirements to generate and review dynamic display

## DYNAMIC FLUX OF TRANSFORMER

### The model

A shell type 220/110 single phase transformer is modeled by F.E. method, geometry and number of turns are obtained from measurements of a prototype. Due to symmetry only half of the transformer is modeled, areas are divided into rectangular portions to allow for mapped meshing, real constants are assigned to the coils areas (no. of turns, resistivity, coil cross sectional area, etc.) quadrilateral 8-nodes element is used, with magnetic vector potential degree of freedom (DOF) in the core areas and magnetic vector potential, current and EMF DOFs in the coils areas. The flux parallel boundary condition is applied to the exterior of the model. Voltage source elements are attached to the primary coil and resistance element of 33 ohm is attached to the secondary coil, the relative permeability of the iron is considered fixed ( $=1000$ ), other parts have relative permeability of unity. Frequency is fixed to 50 Hz, no resistivity is assigned to iron core so no eddy currents are simulated.

The current densities (magnitude and time shift) of the coils are obtained from the F.E. solution of the model using the circuit fed harmonic analysis. Details of the circuit-field F.E. modeling is found in Krikor et al (2001).

### The macro program

Once the current densities are obtained they are passed to the macro program, which assigns these densities to the coils areas and repeatedly performs static analysis with time advance of one degree (or more), each time a vector plot is obtained. **Fig. (2)** illustrates the process, Appendix-1 shows the macro program listing. By changing the current densities we can simulate any loading and excitation condition. By selecting core element, flux dynamic in the core is obtained **Fig. (3)**. When choosing elements of the air and coils areas, the leakage flux is obtained **Fig. (4)**. The vectors length in the two figures are not of the same scale, the vectors of the leakage flux area are greatly magnified to illustrate the turbulent behavior of the flux.

The postprocessor displays the vectors with lengths independently on the value of the flux magnitude in other plots, considering the color of the vector as an indication of the magnitude, a legend helps to assess the indication of each color. Such display is not useful to declare variations in the flux as all the plot sequences will have vector lengths not proportional to the other plots, consequently only flux direction will be apparent and flux variation will not be exact. To overcome

this difficulty vectors must be scaled according to the same criteria for all the sequences. The following steps carry out such scaling

- Initially we establish a scaling factor that will decide the maximum length corresponding to the highest flux density vector in all plots, this value can be judged from the peak of the sum of the two current densities sinusoidal. However any arbitrary choice would result in relative scaling.
- In any solution obtained select elements under consideration, save result in element table.
- Search for maximum flux density in the element table.
- Scale vectors according to the ratio of (max. flux in present plot / max. flux in all plots).
- Plot and save.

### THE DIFFICULTIES

When using F.E. CAD package to produce dynamic displays the following difficulties have been encountered:

The long run time: this topic requires many investigations, trying different solvers, other F.E. formulations such as magnetic scalar and different element types, however the run time can be reduced by using optimal mesh and utilizing the symmetries .

Large files sizes: the 359 frames of ordinary resolution of the movie file of the transformer has size of about 32 Mb, which can not be handled by the common 3.5 inch floppy disk, to reduce the file size we have to reduce number of frames and the display resolution .

Care must be taken in meshing the models, mapped meshing with quadrilateral elements is the most convenient mesh, otherwise the locations of the vectors look randomly distributed and the regularity would be missed .

### CONCLUSIONS

The paper declares the effectiveness of the flux vector plot to simulate the dynamic behavior of electromagnetic devices, transformer is taken as an example. The generated animation displays a demonstrative and deductive, and helpful in instruction and design .

The programming facilities incorporated in the CAD package plays an important part in assisting the generation of the animation file, care must be taken in meshing and vector scaling.

Difficulties encountered when choosing F.E. CAD are long run time and large files sizes, therefore smaller number of DOFs, less resolution and high speed PC are demanded.



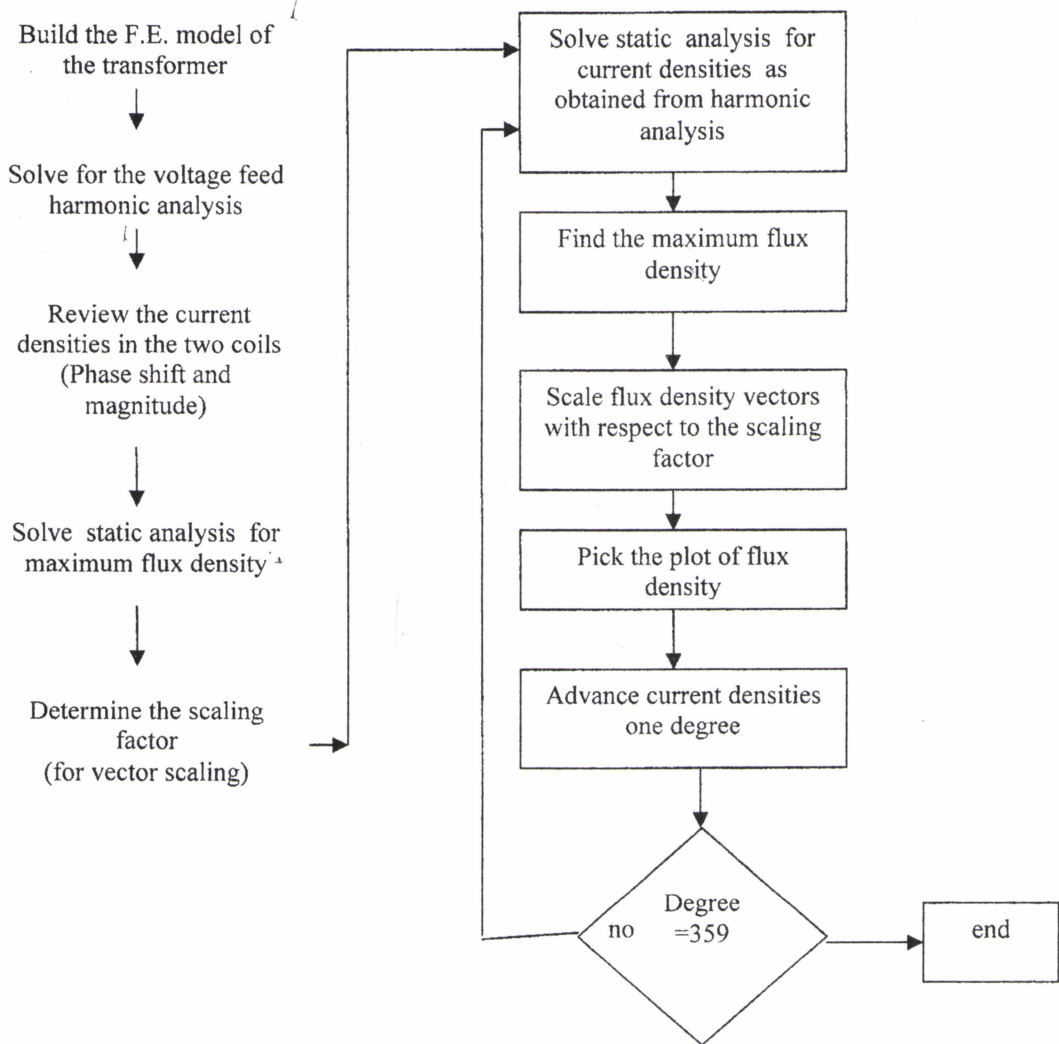


Fig.(2). Procedures to obtain dynamic flux of transformer

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#### APPENDIX -1

Macroprogram to generate dynamic sequences of transformer flux

```
*do,i,0,359, 4
```

```
/solu
```

```
allselect
```

```
asel,s,,1,1,1,0
```

```
esla,s
```

```
bfe,all,js,,0,0,coil1d,coil1p+i
```

```
allselect
```

```
asel,s,,2
```

```
esla,s
```

```
bfe,all,js,,0,0,coil2d,coil2p+i
```

```
allselect
```

```
solv
```

```
finish
```

```
/post1
```





```
asel,s,,3
asel,a,,4
asel,a,,5
asel,a,,6
esla,s
etable,,b,sum
esort,bsum
*get,sss,sort,,max
/vscale,1,sss/mmm,0
gplot
/gfile,300
/show,transformer-8,GRPH,1
*enddo
```

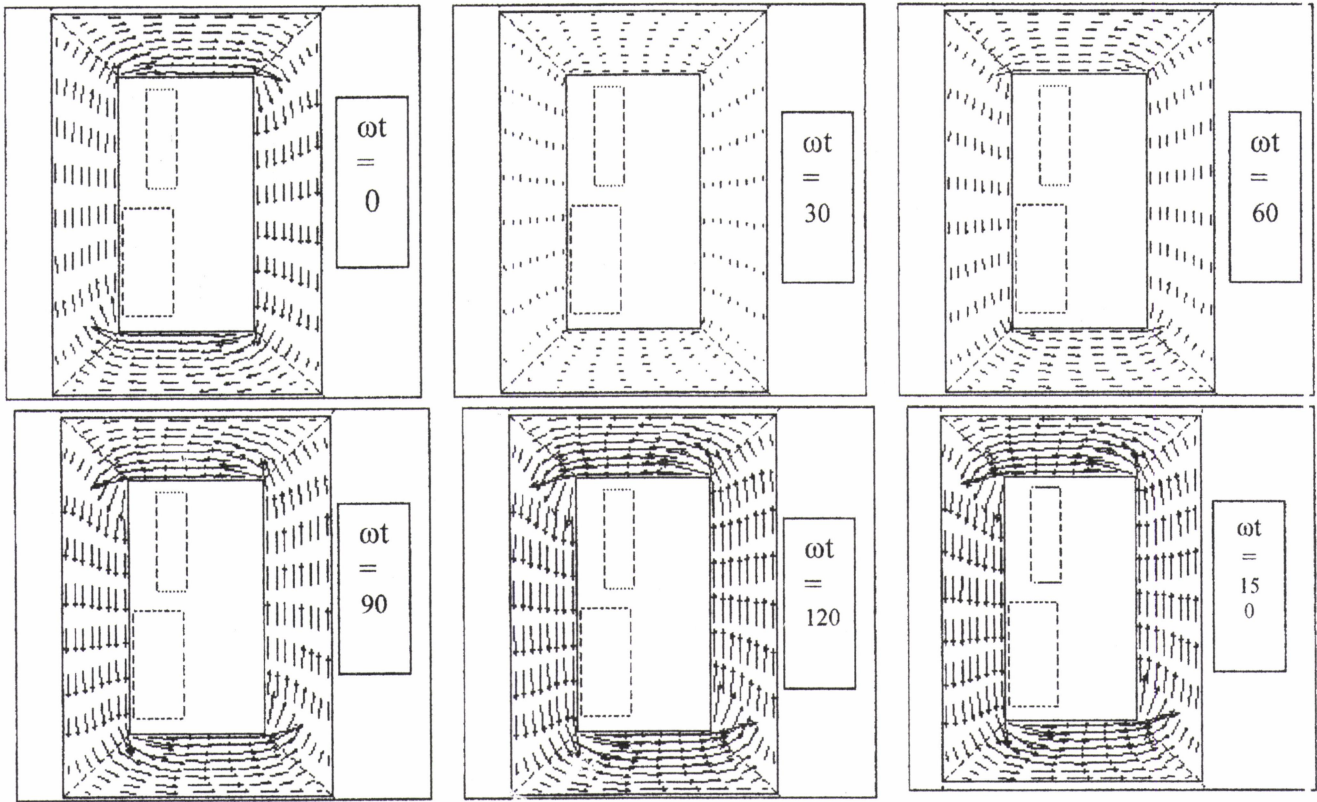


Fig. (3). Six plot sequences in the core within half

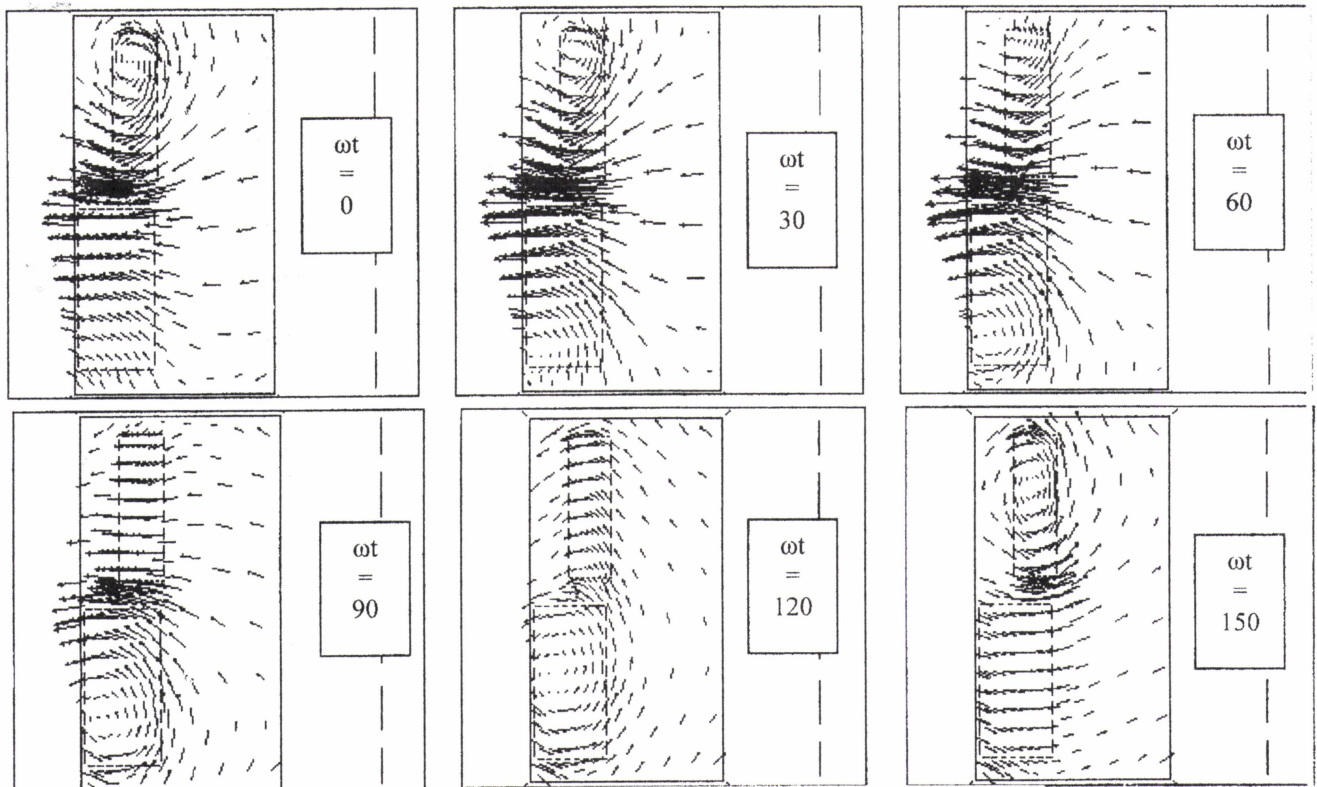


Fig. (4). Six plot sequences in the leakage flux area