ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XIX, NR. 1, 2012, ISSN 1453 - 7397

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# Finite Element Analysis of a Single-Phase Alternating Current Meter

*The present paper presents the optimal distance between the components of the single-phase alternating current meter.*
*This influence of the space between the coils and the aluminum disc form single-phase alternating current meter is made by using the finite element analysis, ANSYS, which is a modeling and simulating program.*

***Keywords****: single-phase alternating current meter, coil, finite element, meshing, magnetic flux*

## 1. Introduction

The electric and electronic measurements, in the context of scientific and technical revolution in the present, are indispensable in all branches of industry. That important link in the production processes, the quality control of raw materials, intermediate and final products, in conducting research in various areas.

Single-phase alternating current meter is a tool widely used to measure electricity at consumers, mostly households.

Regarding constructive phase, the single-phase alternating current meter (figure 1) is made of a watt meter device, whose torque is proportional to the active power and of an integrating mechanism – gear system – which allows obtaining energy for a determined time interval. [4]

The induction device consists of two coils (a current coil, having the winding crossed with the current I absorbed by the receiver and voltage coil, with winding crossed by voltage across the receiver) and an aluminum disc. [2]

In figure 1 we noted:1 – current coil armature; 2 – voltage coil armature;

3 – stop device of the disc.

The two coils, current and voltage, can be placed either in the same plane located perpendicular to the disc radius - the tangential construction type – either in perpendicular planes, one with the disc radius - radial type construction.

The flux produced by the current $I_1$ has a useful component namely u, which crosses the disc closing in the contrapole and an inactive component that closes either trough both side columns at the tangential type or trough the magnetic shunt at the radial type.

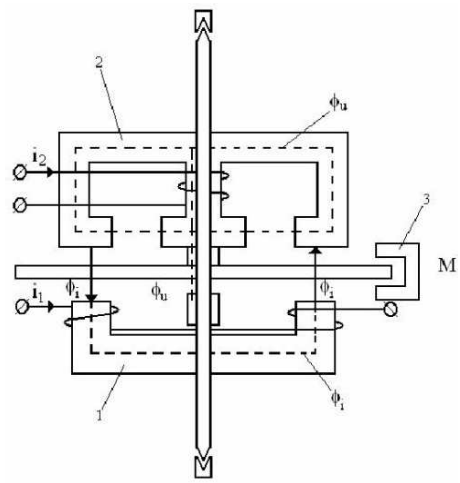



**Figure 1.** Components of the single-phase alternating current meter.

The flux produced by the current I crosses the disc twice and is closed down by air and by the lower part of the voltage coil, located across the disc.

From alternative magnetic field interaction, which represents its maximum intensity in the air gap, is obtained the active torque which rotates the disc of the single-phase alternating current meter. To obtain the resistant or antagonistic torque is used a permanent magnet. [3]

## 2. Mathematical relations applied to the study of the single-phase alternating current meter

At the base of the single single-phase alternating current meter study stand the following relations:

a) Gauss law:

- differential form:

$$\nabla \cdot E = \frac{\rho}{\varepsilon_0} \tag{1}$$

- integral form:

$$\oint_S E \cdot dA = \frac{Q_S}{\varepsilon_0} \tag{2}$$

b) Gauss law for magnetism (the inexistence of the magnetic monopoles):

- differential form:

$$\nabla \cdot B = 0 \tag{3}$$

- integral form:

$$\oint_S B \cdot dA = 0 \quad (4)$$

c) Electromagnetic induction law:

- differential form:

$$\nabla \times E = -\frac{\partial B}{\partial t} \quad (5)$$

- integral form:

$$\oint_{\partial S} E \cdot dl = -\frac{d\Phi_{B,S}}{dt} \quad (6)$$

d) Ampere law (with Maxwell correction):

- differential form:

$$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t} \quad (7)$$

- integral form:

$$\oint_{\partial S} B \cdot dl = \mu_0 I_S + \mu_0 \varepsilon_0 \frac{d\Phi_{E,S}}{dt} \quad (8)$$

External magnetic moment is defined to be produced by a magnetic field having the voltage U, according to the relation:

$$U = -m \cdot B \quad (9)$$

If the external magnetic field is uneven, there is a force proportional to the magnetic field gradient, which acts as a magnetic moment. To calculate this force, there are known two expressions, their application depending on the model used for the dipole. The force, in this case, for the model that uses circular current:

**Eroare! Obiectele nu se creează din editarea codurilor de câmp.**

(10)

In the case in which the force is obtained using a pair of electric monopoles or dipole, the relationship is:

$$F_d = (m \cdot \nabla) B \quad (11)$$

In relations (1) to (11), the following symbols:

- E - electric field intensity [V / m];
- B - magnetic induction [T];
- F - the force created by the magnetic field intensity [N];
- U - potential energy of the magnetic field [V].

Note: The relations set of Maxwell depend on the characteristics of the magnetic field, and the whole closed surface S, which is the area where field lines are closed.

### 3. Modeling and simulating the electromagnetic field of the single-phase alternating current meter

### 3.1 Geometrical model of the single-phase alternating current meter

The geometrical model of the single-phase alternating current meter is shown in figure 2.

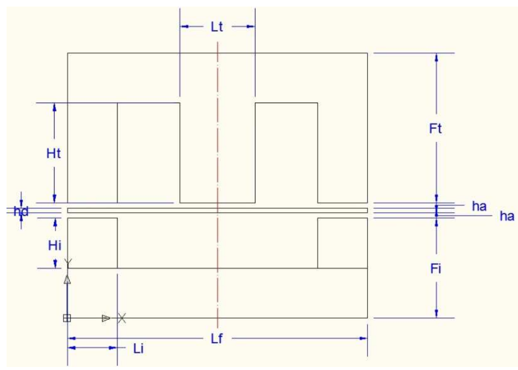



**Figure 2.** The general form of the single-phase alternating current meter.

The main elements of the geometrical model for the single-phase alternating current meter are:

- iron core (consisting of two components, of width Lf and height Fi, Ft);
- coils (on either side of the aluminum disc, with height Hi and width Li sizes for the current coil, respectively height Ht and width Lt for voltage coil);
- aluminum disc (the general size is height Hd and width Lf).

On these components, during operation external factors are acting, which are related to the design and the manufacture of the single-phase alternating current meter, such as: friction in levels and in the integrating mechanism, which affects the accuracy of the mobile equipment.

Because at small currents the active torque moment decreases greatly and begins to feel the influence of friction, due to external environmental influences, the single-phase alternating current meter is constructed in a manner that influences from variations of values (frequency, voltage, temperature, external fields, etc.) must fit in limits imposed by standards.

The method used for modeling and simulation of the electromagnetic field in single-phase alternating current meter is the finite element method.

Finite element method is a numerical analysis technique of forces and torques generated by the electromagnetic field.[1]

In the design of electromagnetic devices, the finite element method is applied with simulation programs.[5]

### 3.2 Material properties

Based on the geometrical model, material properties that make up the single-phase alternating current meter are shown in figure 3.

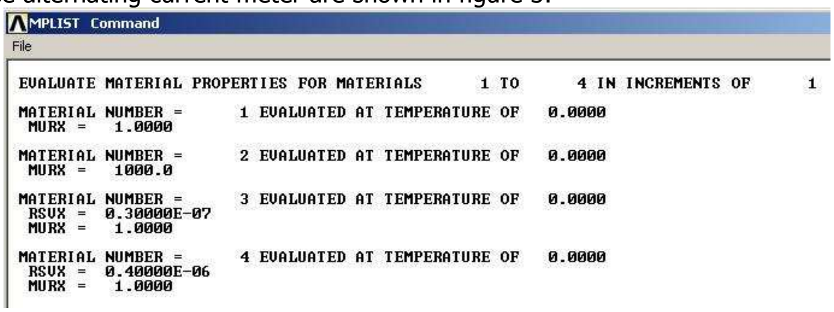



**Figure 3.** Defining the material properties for the single-phase alternating current meter.

Figure 3 shows that single-phase alternating current meter it consists of four materials, namely:

- material no.1 - air gap - represented by air;
- material no.2 – steel - are fixtures of the single-phase alternating current meter;
- material no.3 - copper - is the constituent material of the two coils, voltage, respectively the current coil;
- material no.4 - aluminum - represents the aluminum disc, mobile equipment of the single-phase alternating current meter.

### 3.3 Defining loads

The term loads, in the ANSYS program terminology, includes border conditions and the loads applied inside and outside of the model. For magnetic field, some examples of loads are: magnetic potential, magnetic flux, power supply intensity density, etc. [6]

Loads can be defined on the solid model (key points, lines, areas), and on the finite element model (nodes, elements).

#### 3.3.1 Defining the disc as a component of the single-phase alternating current meter

By following the Utility Menu> Select> Comp / Assembly> Create> Component a component is created, which represents the single-phase alternating current meter mobile equipment, as illustrated in figure 4.

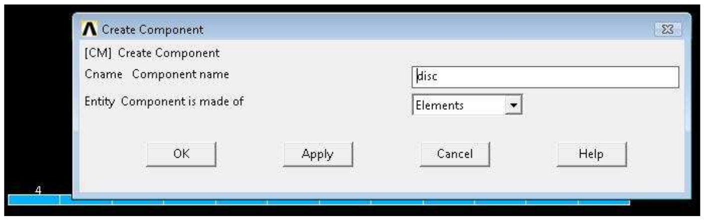



**Figure 4.** Create component for the aluminum disc.

### 3.3.2 Defining the current density

Current density is defined as the load.

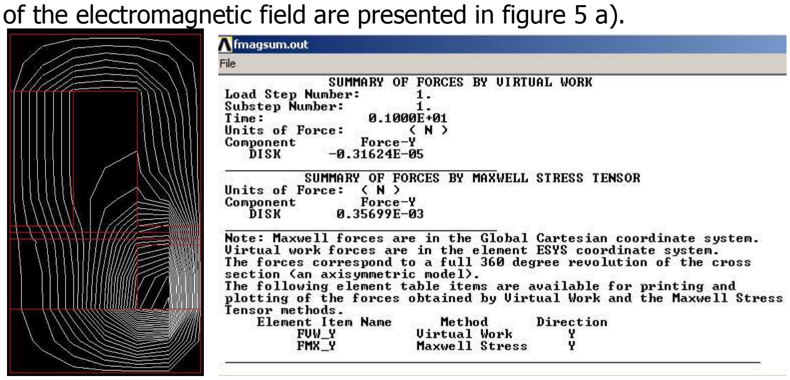
### 3.4. Obtaining the results

Results were obtained from the change of distance between the aluminum disc and fittings, which is going through several steps:

### 3.4.1 First step

In the first step is considered the standard size of a single-phase alternating current meter, where for the distance ha is 5 [mm].

Distribution of magnetic field lines, for this step, the modeling and the simulation of the electromagnetic field are presented in figure 5 a).



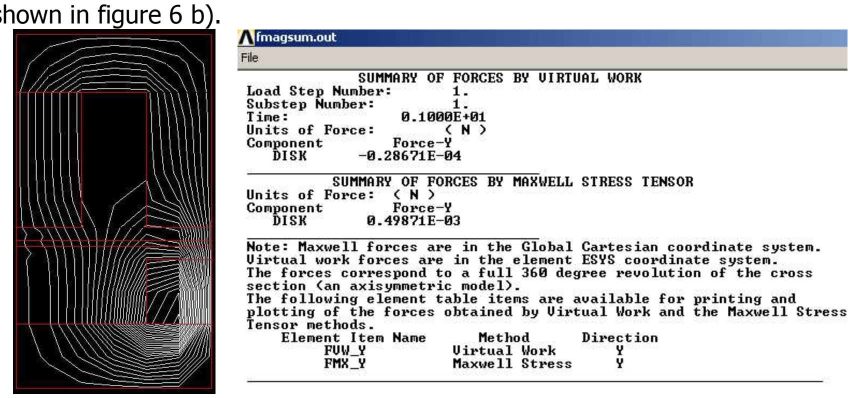

a) b)

**Figure 5**. The results for first step.

### 3.4.2 Second step

In the second step, the distance between the fittings and the electromagnetic equipment, represented by the aluminum disc, is 10 [mm]. This change leads to different field lines curvatures inside the meter, which is shown in figure 6 a).

Also modifications appear among the values of the forces that act on the disc, as shown in figure 6 b).



```
fmagsum.out
File
              SUMMARY OF FORCES BY VIRTUAL WORK
Load Step Number:        1.
Substep Number:          1.
Time:           0.1000E+01
Units of Force:         ( N )
Component          Force-Y
   DISK       -0.28671E-04

           SUMMARY OF FORCES BY MAXWELL STRESS TENSOR
Units of Force:  ( N )
Component          Force-Y
   DISK        0.49871E-03

Note: Maxwell forces are in the Global Cartesian coordinate system.
Virtual work forces are in the element ESYS coordinate system.
The forces correspond to a full 360 degree revolution of the cross
section (an axisymmetric model).
The following element table items are available for printing and
plotting of the forces obtained by Virtual Work and the Maxwell Stress
Tensor methods.
    Element Item Name       Method       Direction
         FVW_Y           Virtual Work        Y
         FMX_Y           Maxwell Stress      Y
```

a) b)

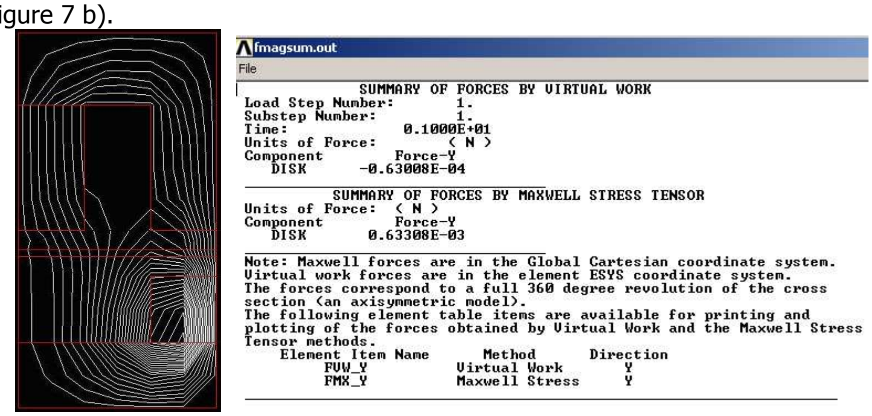
**Figure 6.** The results for the second step.

It can be observed from figure 6 b) the distribution of magnetic field lines has changed, with more pronounced differences around the current coil.

### 3.4.3 Third step

In this step, the distance between the mobile equipment and the fittings is 15 mm. This new value affects the magnetic field lines of single-phase alternating current meter, which is shown in figure 7 a).

The new values obtained from the changes made for this third step are shown in figure 7 b).



```
fmagsum.out
File
              SUMMARY OF FORCES BY VIRTUAL WORK
Load Step Number:        1.
Substep Number:          1.
Time:           0.1000E+01
Units of Force:         ( N )
Component          Force-Y
   DISK       -0.63008E-04

           SUMMARY OF FORCES BY MAXWELL STRESS TENSOR
Units of Force:  ( N )
Component          Force-Y
   DISK        0.63308E-03

Note: Maxwell forces are in the Global Cartesian coordinate system.
Virtual work forces are in the element ESYS coordinate system.
The forces correspond to a full 360 degree revolution of the cross
section (an axisymmetric model).
The following element table items are available for printing and
plotting of the forces obtained by Virtual Work and the Maxwell Stress
Tensor methods.
    Element Item Name       Method       Direction
         FVW_Y           Virtual Work        Y
         FMX_Y           Maxwell Stress      Y
```

a) b)

**Figure 7.** The results for the third step.

## 4. Conclusions and contributions

Through modeling and simulation the electromagnetic field, at the single-phase alternating current meter, values can be provided in areas where it can not be measured.

After modeling and simulation of the electromagnetic field is observed that the single-phase alternating current meter is size correctly designed, because the loads do not lead to destruction, as shown by the values of forces acting on the mobile equipment during operation of the single-phase alternating current meter, values that fit in the standards set for this type of meter.

The distance between the fittings and mobile equipment of the single-phase alternating current meter allows maintaining optimal values of the electromagnetic couples that appear between voltage and current coil.

Finite element method leads to optimization of electromagnetic devices since the design phase.

## 5. References

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