

# Program for stator winding leakage inductance determination by FEA

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**Abstract** – *This paper presents a program designed by the author in order to determine the stator winding parameters. The program is realized in Visual Basic and, in fact, it is for computer aided design of AC machines. Starting from the design data, based on the classical analytical formulas, geometrical parameters of the stator and the parameters of the stator winding are computed. This program works with a finite elements analysis (FEA) software (the one used by the author is MagNet, a product of Infolytica company) and according to data obtained after the design calculation, or according to data specified by user (in case of an existing machine), the stator and stator winding are built 3D (three-dimensional). For the same stator, different types of winding can be chosen. After realizing numerical model, by 3D FEA, leakage inductance is determined.*

**Keywords:** *program, design, AC machine, leakage, inductance.*

## I. INTRODUCTION

AC electrical machine quality and behavior depend on parameters such as resistances and inductances.

The more exact determination of these parameters still remains an important preoccupation of specialists in this field, and that is why many papers approach this problem.

Among these parameters, the calculation of the leakage inductances of AC electrical machines constitutes an important stage in the process of designing these machines. At present, the end winding inductance is probably the parameter that is determined with the highest error [5].

Although the behavior of a machine is given by the total leakage inductance, because the end winding inductance has an important percentage, being able to exceed half of total leakage inductance, the most precise determination of this parameter is very important.

The numeric analysis based on the finite elements method is probably, at present, one of the strongest instruments regarding the precision of the obtained results in determination of these parameters [1] [6].

Moreover, numerical methods allow simulation of conditions encountered in practice, as experimental methods.

The great advantage of numerical methods (FEM, BEM, FDM), compared with some experimental methods, is that they can be already executed in the design/optimization phase.

However, there are two important and often called upon disadvantages of a numerical analysis, especially 3D. One is that it needs important resources regarding the calculation system and time necessary for such analyses. The second refers to the time necessary to build 3D machine (stator and winding).

Unprecedented development of computing technology in recent years leads to elimination of the first disadvantage. Also, because the electric machines are generally symmetric constructions, the domain of analysis can always be reduced, thus the time and respectively the resources necessary for analysis are also being reduced.

To eliminate the second disadvantage is possible using a program to build the machine. That is what we did.

## II. PROGRAM STRUCTURE

At this moment the program is designed to determine stator winding leakage inductance of AC machine. Given this, only geometrical parameters of the stator and stator winding are computed. Therefore only these components will be built 3D. But without too much effort, based on the same algorithm, the program can be adapted to the construction of rotor too.

The program is structured into three main parts: the design calculation, starting from nominal values imposed; stator construction 3D, based on geometrical data computed in the first part, or based on data given by designer; stator winding construction 3D, in correlation with the stator geometry and machine parameters.

The program was developed in Visual Basic because this programming language allows us to realize a friendly and suggestive interface with minimum effort.

The second reason, and also the most important, for us to use Visual Basic is due to the fact that this language is recognized by the used FEA software.

The program interface is presented in figure 1.

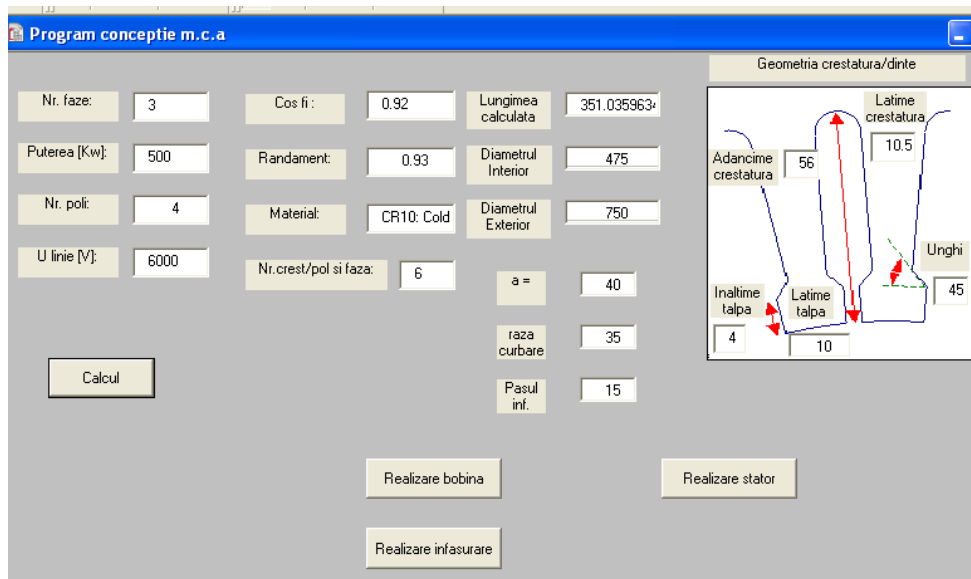


Fig.1. The program interface

### A. Design calculation

Relations used for the calculation of design starting at nominal values imposed - such as: the nominal power, poles number or synchronism speed, nominal voltage - or the choice of a value depending on other previously computed values, so as to achieve optimum geometry, are according to [2], [3], [4], [7], [8].

The efficiency and power factor are set right from the beginning in accordance with the scientific literature previously mentioned. Some values necessary to the design calculation, values that are chosen from certain graphs, are required during the program's running, others are computed with the analytical formulas. The analytical formulas have been obtained with Matlab language, by interpolation of some curves by points defined. Some representative values analytically computed are shown to the designer, and he is able to confirm them, or to change them. Also, some restrictive conditions are included in the program, regarding location in the recommended intervals of the computed parameters. If some values are outside the range, these values are presented to the designer, and he will have to change some values chosen or confirmed during the running program.

Also, in case of selected parameters at a certain initial value, when they are recalculated, if the relative deviation is greater than the maximum permitted, the designer is informed on this. Some aspects during the running program are presented in the following.

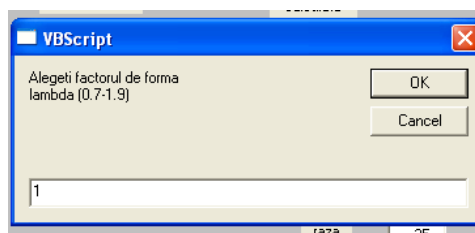


Fig.2. The choice of the factor of shape,  $\lambda$

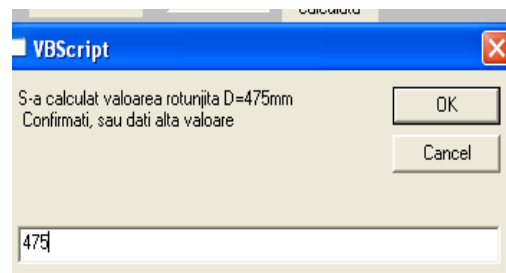


Fig.3. Choosing/confirming the inner diameter, D

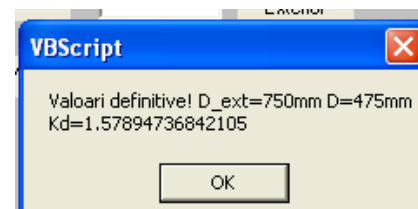


Fig.4. Posting the final values

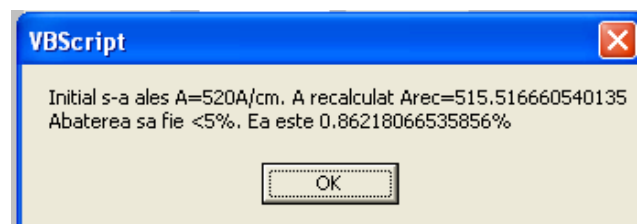


Fig.5. Posting the relative deviation of A

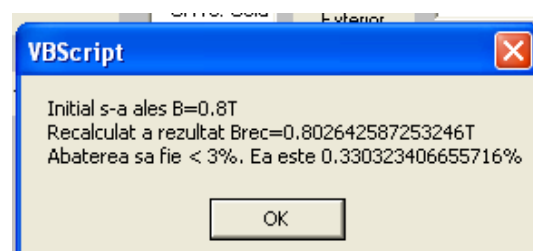


Fig.6. Posting the relative deviation of B

### B. 3D stator construction

3D construction of stator is based on geometry of cross section. The main geometrical dimensions are obtained after the design calculation. Once a representative value has been calculated, it is placed in the corresponding Textbox by form.

In case of an existing machine, these geometrical parameters are specified at beginning in the initial form (fig.1). Moreover, indifferent as it is a newly designed machine, or an existing machine, the needed geometrical dimensions to draw the cross section are taken from corresponding Textbox by initial form.

The geometric parameters needed to the program, in order to construct the stator, are: the inner and outer diameter, stator length, number of slots per pole and phase and respectively the dimensions slot/tooth, conform to figure 7.

The program allows us to achieve the stator with slots or teeth with parallel edges. In case of stator with slots with parallel edges, will be specified the slot width (figure 7), the tooth shape resulting in terms of slot and other dimensions specified. If are chosen teeth with parallel edges, the slot width does not matter, the program will require tooth width (fig.8), and the shape of the slot will be in terms of this width.

Must be specified that the slot type (with or without parallel edges) is in correlation to the type of winding and to the shape of the chosen conductor. In case of shaped conductor, slot with parallel edges is chosen, and the winding in two layers with shortened pitch will be realized.

For a specific value of the pole shoe width, the open slots can be obtained. Thus, for example, in case of slot with parallel edges, if the pole shoe width is equal with the difference between tooth pitch and slot width, the open slot is obtained.

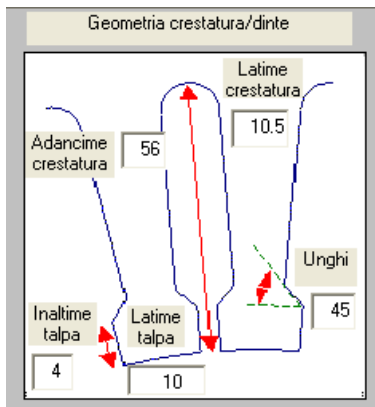


Fig.7. Slot/tooth geometry

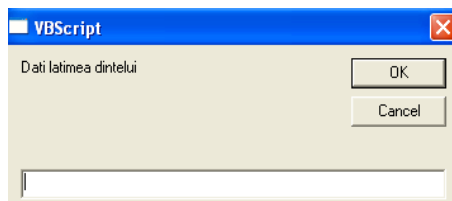


Fig.8. Width tooth specification

This part of program has already worked with the FEA software, thus the slot is drawn by this program and 3D stator construction is performed by this program too.

Also, in this part of the program, specific commands will be introduced to start the numerical analyze program, to open a new document, respectively commands of drawing, selection, copying, constructing components, establishing the stator's material, material that was taken from the corresponding Textbox at the initializing of the stator's constructing program. In order to draw the first lines or arcs, it is first needed to calculate, based on the specified dimensions, the coordinates of the points which define the first tooth. The analytical geometry is the one solving this part.

Once the stator is constructed, only the following properties can be modified: the material and the stator length.

Some sequences from this program will be presented as follows (some of them obtained by blocking the program in different stages).

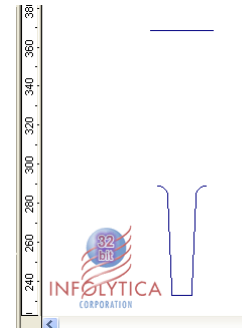


Fig.10. Cross section portion corresponding to one tooth (open slot with parallel edges)

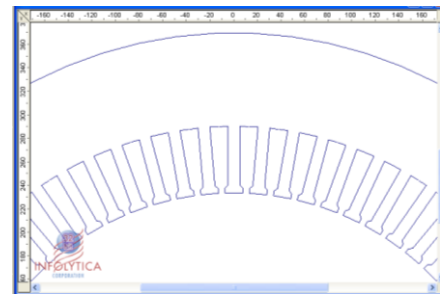


Fig.11. Cross section, teeth with parallel edges

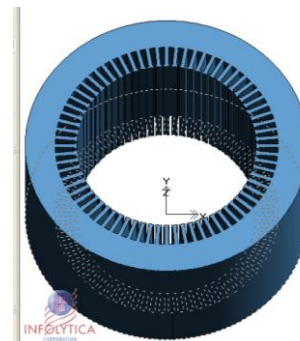


Fig.12. The stator

### C. 3D stator winding construction

Although can be adapted for a number of different phases of three, now, program is designed to carry out only three phase stator winding.

To realize 3D stator winding of AC machine is probably the most difficult stage of the entire numerical model's realization. Considering the fact that at this moment the stator is constructed, the only parameters that are left to be established, although they were chosen in the design phase for a newly designed machine, are: the winding step, the minimal curve radius and the distance 'a' from the stator's yoke to the plan where the formation of frontal ends begins (fig.13).

The following types of stator winding can be chosen in correlation with the type of stator slot: single or two layers winding. The single layer winding can have the end winding in one, two or three plans. Due to the symmetry of electrical machines, only half of the machine will be realized.

Further, several sequences regarding the realization of different winding types, for the stator of AC machine, will be presented.

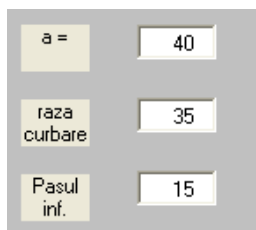


Fig.13. The parameters needed for 3D construction of the stator winding

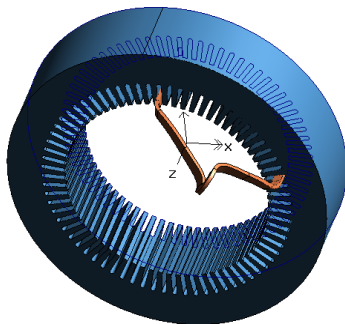


Fig.14. The first coil made,  $y_1=15$

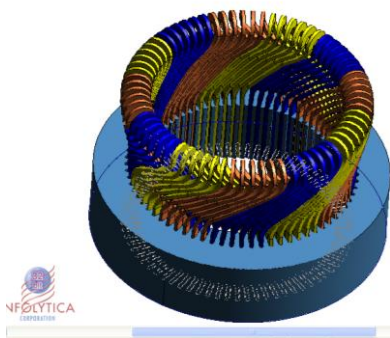


Fig.15. The stator winding of asynchronous three-phase machine with  $q=6$ ,  $p=2$ ,  $y_1=15$

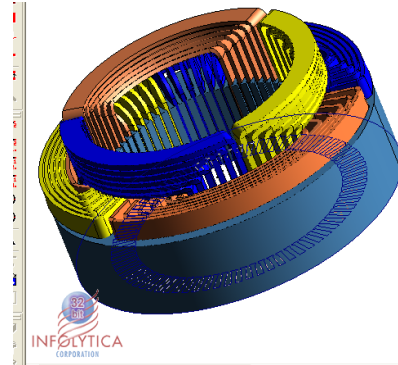


Fig.16 The single layer stator winding, end winding in two plans,  $q=6$ ,  $p=2$ ,  $y_1=18$

### D. Leakage inductance determination

In order to determine the total leakage inductance, a 3D magnetostatic analysis is realized, by winding currents at nominal values being imposed. From the total magnetic energy stored in the whole space is determined the total inductance. From the energy stored in the rotor space, the useful inductance corresponding to the magnetic flux that is closed through the rotor space, is determined. Now, subtracting the useful inductance from the total inductance, the total leakage inductance is obtained. Certainly, end winding inductance or stator leakage inductance can be separately obtained too.

## III. CONCLUSIONS

The utilization of such a program which works together with a numerical analyze software helps a lot the work of design, optimization and determination of parameters for electric machines. The program can be completed with the part of rotor designing / constructing and its developing in such way that it can also be used for the design of DC machines.

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