Simulation of magnetic field of single-phase linear capacitor motor

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Abstract
This article presents the investigation of magnetic field variation at different instants of time in the air gap of a single-phase linear capacitor motor (LCM) as well as outside of the ends of the inductor. Simulation data is presented showing magnetic field dependence current phase time shift differences between operating and capacitance windings. Comparisons are made of magnetic field distribution under the inductor and outside of the inductor's ends, when there is a secondary element in the air gap, when the secondary element is absent, when the secondary element is longer, and when it is shorter than the inductor.

Keywords
Linear induction motor, model, simulation, magnetic field, different instants of time

Introduction
The magnetic field of an LCM is more complex than that of a rotating induction motor. When analyzing the magnetic field of an LCM, one must consider the limited dimensions of the inductor. It is therefore necessary to also investigate the magnetic fields beyond the inductor's limits (edge effect and end effect), and the influence of these fields on the main magnetic field. Because of the phenomenon of end effect, additional factors must be considered: there is a reduction of attraction force, and despite a balanced supply voltage, increased phase impedance and phase differences of leading currents.

Three-phase linear drive is used more often in industry because it is characterized by greater power and efficiency; however, connection requires a three-phase feeding network.

Single-phase drive has less efficiency, but can be utilized where there is a single-phase feeding network. Therefore, single-phase drive is more widely applied for commonly used equipment.

The single-phase linear motor is sparsely discussed in literature sources. Its magnetic field distribution with respect to time outside of inductor limits has not been delineated. Present day technology can be used to facilitate the investigative process into this problem. Using specially programmed software it is possible to simulate the phenomenon being tested, rapidly change conditions during simulation, and obtain simulation results for chosen cross-sections.

The main objective of this investigation is to study, using specialized software, the interdependence of LCM magnetic field within the air gap and outside of the inductor's limits with current phase time shift differences between operating and capacitance windings, and the effects of the presence of a secondary element on this magnetic field distribution.

Simulation model
The capacitor motor was chosen for this experiment because the economic indicators for these motors are more favourable than those for single-phase motors with start-up winding. The motor consists of an inductor, secondary element, and magnetic conductor.

The inductor has eight grooves within which reside two windings generating a magnetic field. Spatial layout between the windings – 90 electric degrees. This construction corresponds to a two-pole motor. The secondary element is copper with specific permeability of 56000000 S/m$^2$, and a thickness of 6 mm. Air gap between the inductor and secondary element is $\delta$ - 0,25 mm. The windings of the inductor are supplied by alternating current with a frequency of 50 Hz; current of the winding density is 5000000 A/m$^2$.

A simple model was chosen for this investigation because the accuracy and continuity of the simulation results depends on the complexity of the model - it depends on the number of mesh nodes where the parameters are calculated. All of the specialized software packages designed for magnetic field studies have limited numbers of mesh nodes to calculate the parameters. Thus when using a complex model the mesh nodes are spread throughout the model and the most relevant areas have low mesh node density.

The model chosen for this study allowed for quite good results without losing essential information. It is possible to choose other simulation models (e.g. double-sided or otherwise constructed LCM's). There can be more grooves or more poles but these changes only reduce the accuracy and continuity of the results without altering the basic nature of the results.
**Simulation of magnetic field**

"Quickfield" software was used to simulate the magnetic field of LCM. This software applies the finite element method to simulate the magnetic field. To calculate the magnetic field the following formula is used:

\[
\frac{\partial}{\partial x} \left( \frac{1}{\mu} \frac{\partial A}{\partial x} \right) + \frac{\partial}{\partial y} \left( \frac{1}{\mu} \frac{\partial A}{\partial y} \right) - \gamma \frac{\partial A}{\partial t} = -j_0 + \left( \frac{\partial H_z}{\partial x} - \frac{\partial H_y}{\partial y} \right).
\]

Magnetic field at different instants of time is realized by giving actual current density to windings in the grooves (windings are supplied permanent voltage, that are equal to momentary voltages, for 100 s). Simulating magnetic field with different current density and analyzing results in desirable cuts the characteristics family of magnetic field at different instants of time are made. Current densities in windings are chose to simulate, the rotation of supply voltages start by 360°.

Using the above-described methods, distribution of magnetic flux lines outside the inductor at different instants of time was investigated. For purposes of comparison, magnetic flux parameters were computed in the cross-section outside of the inductor next to the air gap between the inductor and the secondary element at both ends of inductor.

Also investigated: magnetic field (outside of the inductor ends) dependence on current phase time shift differences between operating and capacitance windings. In this test, one moment in time was selected, and while changing the current phase time shift difference in the windings, magnetic flux density outside the inductor limits was measured. A characteristic grouping is formed showing the magnetic flux density's dependence on current phase time shift changes in the windings.

Experiments were conducted altering the dimensions of the secondary element: secondary element length corresponding to the length of the inductor, secondary element longer or shorter than the inductor, and finally no secondary element in the air gap. These variations were tested to ascertain the influence of the secondary element on the magnetic flux density distribution outside the inductor ends. Characteristic groupings were formulated.

**Results of simulation**

Simulation of magnetic field shows that the magnetic field distribution outside of the inductor at different instances of time is changing (Fig. 1-2).

**Fig. 1.** Magnetic flux density distribution under the inductor when there is different current phase time shifts in the windings at 0.83 ms from starting time.

**Fig. 2.** Magnetic flux density distribution under the inductor when there is different current phase time shifts in the windings at 5.83 ms from starting time.

It is also evident that in the presence of different current phase time shifts in the windings, the amplitudes of the magnetic flux density fluctuations differ.

It is noteworthy that the magnetic flux density towards the right end of the inductor is slightly less than at the left end of the inductor (fig. 3). These are pulsating fields alternating in the same frequency but their phases differ.

**Fig. 3.** The distribution of magnetic flux density outside of the inductor ends with different current phases time shifts in windings at 0.83 ms from starting time.
Comparing figures 3 and 4, it can be seen that when the current phase time shift difference in the windings is greater, the magnetic field’s (outside the inductor ends) amplitude is smaller. That is, when decreasing the current phase time shift difference, the maximal value of magnetic flux density increases with varying time, while the minimal - declines. When decreasing the current phase time shift difference, the magnetic flux density outside the inductor ends pulsates more.

Investigating the model without the secondary element within the air gap (fig. 5) showed magnetic flux density (outside inductor ends) to be stronger than when the secondary element was included in the air gap.

Upon investigation of cases where the length of the secondary element does not coincide with inductor length, it can be seen that magnetic flux density's (outside inductor ends) phases differ. See figures 6 and 7.

When the secondary element in the air gap is longer than the inductor, magnetic flux density is larger towards the right end of the inductor. When the secondary element is shorter, magnetic flux density is stronger towards the left end of the inductor.
Conclusions

1. The distribution of the primary magnetic field outside of the inductor at different instants of time was investigated and the results graphically presented.

2. The distance at which magnetic flux density outside inductor ends is equal to zero depends on the instantaneous value of magnetic flux density in the ending tooth of the inductor.

3. As the current phase time shift differences change, the amplitude of the magnetic flux density (outside the inductor ends) changes dependent on the instant in time.

4. The secondary element influences the amplitude and phase of the magnetic flux density distribution outside of the ends of the inductor.

References


