PHENOMENA OF FORWARD AND BACKWARD ROTATION FIELDS IN RESPECT OF LOCALIZED FLUX DISTRIBUTION AND CORE LOSSES IN A SINGLE-PHASE INDUCTION MOTOR

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ABSTRACT

Since the iron core losses are directly related to the localized flux distribution, so having knowledge of distribution of the localized flux density in a magnetic core, can lead to optimization of the electrical steels and the design of the motor cores.

With high and increasing capitalized values of core losses in electrical motors, manufacturers strive continuously to improve the cost/performance characteristics of their products with particular attention being focused on core design.

It was found that backward and forward rotational field changes the magnetic performance in electric motors, particularly in single-phase motors. Up to present time, as far as the authors are aware no report on optimization or deterioration in terms of forward and backward rotation of electric motors has been made. This paper attempts to fill void by making direct comparison of the localized flux distribution and power loss, in the stator core of a single-phase induction motor, being magnetized under forward and backward rotation [1].

KEY WORDS
Backward rotational field, forward rotational field, flux distribution, search coil, iron losses

1. INTRODUCTION

Core losses in laminated magnetic cores consume over 3% of all electricity generated [2]; consequently, producers of electrical steels and the manufacturers of electrical machines are attempting to cut these losses by developing new magnetic materials and using them more effectively. The core losses in electrical machines may be regarded as taking place as a result of two main mechanisms. The first is when flux changes cyclically in magnitude and direction in the plane of a lamination, but does not vary in angular direction. This gives rise to alternating power loss. The second occurs when the magnetic field and flux rotate in the plane of a lamination and give rise to rotational losses. It is well known that, at most magnetization levels, the loss due to rotational flux is much higher than that due to alternating flux.

Rotational flux occurs behind the teeth of ac rotating machine stator cores. The magnetization in these regions is very complex and is completely different from the condition under which electrical steel laminations are tested for quality control or grading. The well-known Epstein test is used to measure the loss of 30- by 3-cm strips of electric steel magnetized under pure sine wave magnetization conditions. The steel is graded and sold on the basis of the results of this test, and machine performance and efficiency calculation are often based on these data. Rotational magnetization that might occur in the final application is not taken into consideration. It is now becoming increasing important to know to what extent the performance of a magnetic material under rotational flux conditions will affect the efficiency of a motor.

There are many single-phase motor applications in the world. Most of these motors have efficiency less than 65%. However core loss in a single motor is low, but for huge amount of using, there are very large losses for all. One of the most important criterions for the manufacturer and the user is the efficiency of the machine. Induction motors are used in large numbers, therefore any reduction in power loss however small can lead to the reduction of energy losses. Further more the maximum working temperature of a machine depends on the thermal quality of its insulating materials. As a result of the growth in the use of induction motors and due to the cost of the total losses a need has arisen to reduce the power losses.

One such loss is that of the stator core, which is generated in stator core laminations. The stator lamination of small induction motors, are usually made from non grain-oriented electrical steels.

In order to understand the effect of core frame geometry, direction of rotation and magnetic properties in each direction of rotation as well as using the materials to the best effect, better understanding of localized flux distribution behavior within specific regions of a stator
core can lead to optimization of core design and magnetic
efficiency.
This paper presents the analysis of experimental
measurement of the localized flux density and power loss
in a stator core of an induction motor being magnetized
under forward and backward rotation [1, 3, 4].

2. MEASURING TECHNIQUES AND RESULTS

The special flux distribution was determined from an array
of search coils and their signals were amplified and
processed by the purpose built microprocessor controlled
system [3].
Figures 1 and 2 show the pictures of experimental
measuring set up and the four-pole single-phase induction
motor with test layer on, respectively.

![Figure 1: The Experimental Measuring Set up](image1)

![Figure 2: The Single-Phase Induction Motor with the Search Coil
Layer on](image2)

Now consider a four-pole single-phase motor which was
manufactured by Belal Electric Motor Industry Company,
with the specifications of: Power rating = 1.2hp, Rotor
speed = 1450rpm, Power factor = 0.9, Rated current
2.81A and Supply voltage = 220V. It is interesting to note
that however, the localized flux density measurement in
the stator cores was performed when the motors were
running under actual conditions.

In order to detect the localized induced emf in any point in
the stator core, search coils were constructed. Basically,
these search coils act as localized secondary windings on
any specified regions in a magnetic core, to detect the
magnitude and phase angle of the emf induced in the
search coils due to flux variation with time. In this
investigation, about 50 orthogonal search coils were used,
in specific areas to measure the flux components in the
radius (r) and the tangential (t) directions of the stator
core. The search coil holes, 5mm apart, in the coreback
and 4mm apart in the teeth area, were made. Figure 2
shows the stator core geometry and the positions of the
search coils and their wires.
The magnitude and direction of the instantaneous
localized flux density can be calculated mathematically,
by measuring the fundamental and harmonics of induced
emfs and phase angles of two orthogonal search coils.
However it can be stated from Faraday's law:

$$E_{rms}(t) = 4.44 n f N A b_n$$

(1)

Consider a crossing point of the orthogonal search coils r
and t, and the instantaneous flux density at any instant of a
magnetic cycle being represented by a vector b at an angle
$\alpha$ with respect to a reference direction. In induced emfs in
search coils r and t are given by:

$$e_{nr}(t) = E_{mnr} \sin(n(\alpha t + \theta_{nr}))$$

(2)

$$e_{nt}(t) = E_{mnt} \sin(n(\alpha t + \theta_{nt}))$$

(3)

Where:

- $n =$ harmonic number $1^m, 3^m, 5^m, \ldots, n^m$.
- $f =$ frequency.
- $b_n =$ flux density passing through any search coil.
- $E_{mnr} =$ maximum value of the nth harmonic
component induced emf in search coil in radius and
tangential directions respectively.
- $\theta_{nr} =$ phase difference in time of the nth
harmonic component of $e_{nr}(t)$ and $e_{nt}(t)$ from a reference
vector respectively.

By introducing equations (2) and (3) into equation (1),
after some rearrangements, the magnitude of instantaneous
harmonic flux density in each search coil can be obtained by:

$$b_{nr}(t) = \frac{E_{rms}(nt) \cos(n(\alpha t + \theta_{nr}))}{4.44 N f A n_{mnr}}$$

(4)

$$b_{nt}(t) = \frac{E_{rms}(nt) \cos(n(\alpha t + \theta_{nt}))}{4.44 N f A n}$$

(5)

Where:
E_{rms}(n) and E_{rms}(nt) = the rms induced voltages of the nth harmonic components in search coils r and t directions respectively.

Using the co-ordinate system, the instantaneous magnitude (\(b_T(t)\)) and direction (\(\alpha_T(t)\)) of the total components (1\(^r\), 3\(^r\), and 5\(^r\)) of r and t of the flux density can be computed.

\[
b_T(t) = \sqrt{b_{nr}^2(t) + b_{nt}^2(t)} \tag{6}
\]

\[
\alpha_T(t) = \tan^{-1}\left(\frac{b_{nt}(t)}{b_{nr}(t)}\right) \tag{7}
\]

The above equations were developed and calculated through Delphi program [3]. Therefore the signal in each search coil was detected and saved in a specified file and the corresponding flux density being crossing through the search coil was obtained.

The measuring circuit setup used in this work is shown in Figure 3. For gradual and smooth regulation of the excitation, the supply voltage was connected via a connector to single-phase auto-transformers (0-220V). During the experiment, the excitation current was readjusted in order to maintain a constant coreback flux density. This change in excitation current occurs due to the change of the excitation winding resistance caused by the variation of the winding temperature.

The supply voltage was stepped down to the required voltage by means of an auto-transformer. The output of the auto-transformer was connected to the single-phase excitation winding of the motor.

According to the calculations for the maximum voltage of 79.44 (V) was required to produce flux density of 1 Tesla under the pole. However, the winding of the motor was in such a way that to produce strong coupling so as to rotate the rotor under the nominal speed (1450 rpm). However, the stator core was magnetized at 1.0T and the flux measurements for backward and forward rotations were carried out under the same conditions.

Figure 3: A Single Layer of Stator Core Geometry with the Orthogonal Search Coils on

In order to monitor the flux distribution variations in forward and backward rotation phenomena 6 prominent points in the stator core were chosen.

The induced emf waveforms for forward and backward rotation conditions in search coils 'a', 'b', 'c', 'd', and 'e' are shown in Figures 4, 5, 6, 7, and 8 respectively.

![Forward rotation](image1)

![Backward rotation](image2)

Figure 4: The Induced EMF Waveforms in Orthogonal Search Coils 'a' in r and t Directions with Forward and Backward Rotations
Since a loci area of a localized flux density is directly proportional to the corresponding localized power loss in a specific point therefore, it indicates the extent of a local flux distortion being due to the local magnetic saturation.
of the core materials. However, Figure 9 shows the comparison of the loci of the localized flux densities in various points in the core, under forward and backward rotation conditions. It is clearly evident that, under forward rotational field the loci areas are comparatively bigger than the corresponding points in the backward rotational field. This implies that the core loss is higher under forward rotation than that of backward one.

In order to justify the above statements, the core losses were measured when the stator core was magnetized at different core flux densities (0.6T up to 1.0T). Figure 10 shows the variation of the core losses with the stator core flux density in forward and backward rotational fields at the frequencies of 50Hz and 60Hz. It is evident from the curves (a) that under 0.66T the core losses are lower in forward rotation than backward one. However, from 0.66T up to 0.77T no change in losses are observed, but after that the losses in forward rotation becomes slightly higher. Now consider the loss variation in curves (b) at 60Hz, up to 0.76T the loss variation is almost the same as 50 Hz condition. However, after that the losses are increased in backward conditions.

![Forward rotation](image1.png)

Figure 9: The Loci of the Localized Flux Densities under Forward and Backward Rotational Fields

![Backward rotation](image2.png)

![Power loss vs Flux density](chart1.png)

Figure 10: Variation of Core Loss with Core Flux Density in Forward and Backward Rotational Fields (a): 50Hz and (b): 60Hz
3. DISCUSSION

Since all the easy magnetic direction axis of the crystal structure in the non-oriented electrical steels are not aligned along the same axis. Therefore, the difference between the forward and backward rotational fields can be justified by slight alignment of the easy magnetic direction axis of the core material along the magnetization direction.

4. CONCLUSION

In this paper it was shown that the localized flux densities and consequently localized losses are different for the forward and backward rotational fields in the non-oriented electrical steels. Although, this difference depends on the levels of core excitation
For better understanding about the forward and backward rotation phenomena higher power rating motors needs to be investigated.

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