Effects of Moderate DC-magnetization on 3-D Loss Distributions of a 3-phase Model Transformer Core

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Abstract – Unbalanced DC bias of 3-phase transformers may cause very strong increases of excitation currents and thus of stray fields. We investigated whether influx of the latter into the core yields planar eddy currents (PECs) as a source of planar eddy current losses. By use of the rise-of-temperature method, local distributions of total losses P were determined at 128 regions of the surface of a 3-phase/3-limb model core. Moderate bias in the middle limb yielded increases of P up to 100%, especially in limbs, while T-joint regions of rotational magnetization prove to be less affected. Local determinations of planar, classical eddy current losses P_{PEC} by means of a field vector sensor revealed local increases up to a factor of 10. Finally, interior PECs were analyzed by means of thin silver layer sensors. As a result, the intensity of P_{PEC} decreases exponentially towards the centre of the core.

1 Introduction

As well known, unbalanced DC-bias of 3-phase transformers may cause very strong increases of excitation currents and thus of the corresponding stray field. According to experience, the latter may interact with magnetic components of the core like clamps and - in special - the tank. However, parts of the stray flux may also pass through the soft magnetic machine core. We investigated whether such influx may yield planar eddy currents (PECs). PECs may widely spread out since not being restricted by the thickness of lamination. Thus they represent a potential source of PEC-losses. So far, the literature has not reported the involved mechanisms.

2 Methodologies

Experiments were performed on a 1m x 1m 3-phase/3-limb model transformer core exhibiting 56 layers of GO SiFe (300µm, M-5). The core was magnetized with 1.7 T by means of excitation coils of short length, thus offering free access to the ends of limbs, e.g. for stray flux investigation generated from windings and joint regions. Unbalanced DC-bias was simulated by DC-current impress into a secondary coil on the middle limb. Equivalent to a DC/AC excitation ratio $r_{DC} \approx 1$, the DC current intensity was close to the AC-current intensity for mere AC-magnetization (r_{DC}=0).

The following tests were made for the DC/AC-case in comparison to mere AC:

(a) At the core surface, in a fully-automatic thermistor scanning chamber [1] applying the rise-of temperature method, the distribution of total losses $P(x,y,z=0)$ was investigated.

(b) At the surface, by means of a multi-parametrical 4-needle-contact field sensor, the local distribution of classical eddy current losses $P_{EC,C}$ $(x,y,z=0)$ was determined.

(c) Interior analyses of $P_{EC,C}$ (x,y,z) were based on a thin-film technique [2]. Tests were based on approx. 15 µm thick silver paste strips, which were applied both on the top and bottom sides of a "sensor-laminate". It detects eddy field components between lamination surface points of a "sensor" lamination which is arranged in different regions of the core package. Thus it allows an effective separation of planar eddy currents (PECs) and regular eddy currents (RECs). Measurements were taken for 23 layers L1...L23, i.e. considering almost one half of the stack.

3 Results

Out of a high number of established analytical profiles, the examples of Fig.1 show local distributions of total losses *P*. For mere AC magnetization (Fig.1a), the limbs show values close to 1 W/kg, while the T-joints show 2 W/kg as a clear indication of rotational magnetization. DC-bias (Fig.1b) resulted in a roughly 50% loss increase in the limbs. With about 35%, T-joints were affected in a weaker way. That is, bias tends to yield some homogenization.

The core surface showed maximum planar EC losses P_{PEC} of about 0.2 W/kg close to the ends of all windings. Bias yielded strong increases of almost one order. This indicates enhanced stray flux into the core interior.

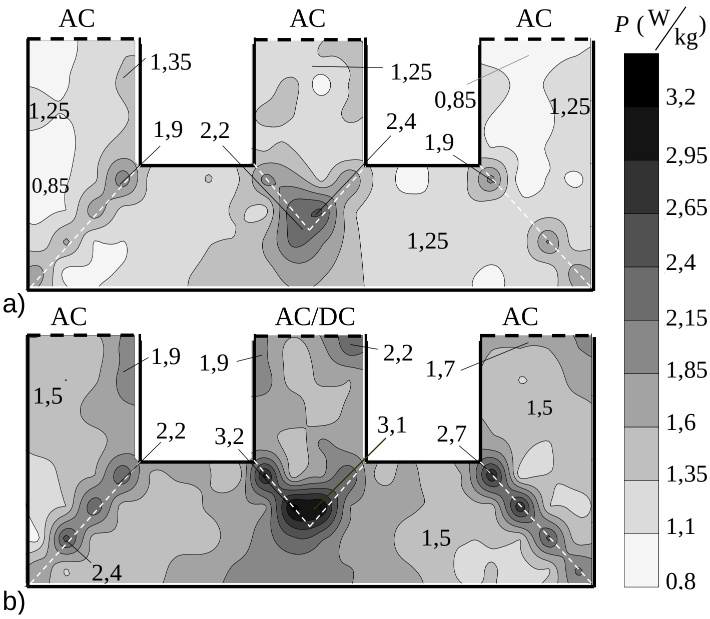

Fig. 1. Local distribution of the total losses *P*(x,y,z=0). (a) Mere AC-magnetization for 1.7 T. (b) DC-bias in middle S-limb (r_{DC}=1.1).

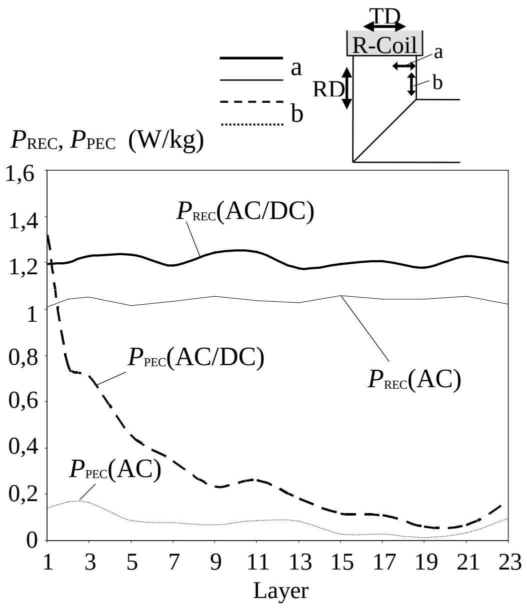

Fig. 2. Results from thin film sensors. Evakuated regular eddy current losses P_{REC} and planar eddy current losses P_{PEC} for the 13 uppermost layers of the R-limb, for mere AC and AC/DC respectively.

Fig.2 shows results for the core interior. Without bias, all layers of the limb show regular EC losses close to P_{REC} = 1 W/kg. It should be stressed that this value arises at the lamination surfaces. Bias yielded 20% increase, which lacks clarification. Planar EC losses P_{PEC} show an exponential decrease from 0.2 W/kg at the surface down to zero in the centre of the stack - as to be expected. In an analogous way, an exponential decrease from 1.3 W/kg down to almost zero resulted for the case of bias.

As a conclusion, the present study confirms results from z-flux measurements which indicated that stray flux flows into the core primarily at the coil ends. It generates planar eddy current fields and corresponding increases of losses. The exponential drop-off means that effects are dominant for peripheral core regions. With respect to model core experiments, the study indicates that the core surface is not representative for the dominant inner core mass.

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