New concept of active control of transformer noise, part 1 : The active envelope

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1. INTRODUCTION

In the past few years, active control systems for transformer noise have been developed, and some systems are currently available. However, noise specialists have to be involved in each application to evaluate the radiation pattern of the transformer. Moreover, the error microphones are located in the field far from the transformer, which requires cable installation. Those systems are thus complex and expensive to use. To overcome those limitations, a new concept called the *active envelope* is investigated.

The first part of the paper presents the principle of the active envelope. The second part presents a theoretical model and an experimental setup realized to evaluate the potential and efficiency of this principle.

2. General concept of the acoustic envelope

The classical objective of an acoustical ANC system is to drive the output of an actuator (ex. a speaker) so that the sound pressure at the error sensor (ex. a microphone) is minimized. Minimizing the pressure at the error microphone creates a '*zone of quiet*' around the error microphone[1,2]. The objective of the acoustic envelope is to create a quiet *skin* over the transformer using an appropriate arrangement of control units.

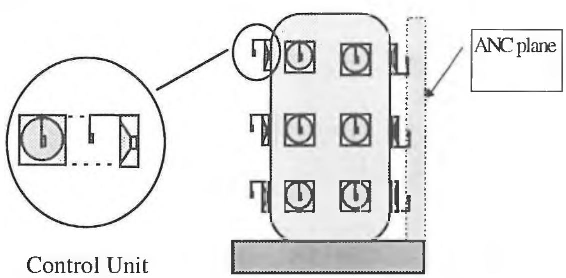

Figure 1 Schema of the active envelope over a transformer.

Also, for its simplicity and cost-effectiveness, it was decided to develop independent control units instead of a real multi-channel (MIMO) controller. However, this may cause instability of the overall system. A theoretical model was developed and an experimental setup was realized to evaluate not only the efficiency of the principle of the active envelope, but also its stability.

3. Theoretical model

A theoretical model has been developed in order to analyze the effect of the distance between the control units (L) and the effect of the distance between the actuator and the sensors (d) on the overall noise reduction.

In this model, the transformer is considered as a vibrating structure of N subsurfaces S which generate a sound field in a semi-infinite space according to the Raleigh integral :

$$P(M) = -\rho_0 w^2 \int_S \frac{W(P)\exp(jkr)}{2\pi r}\, dP$$

W(P): amplitude of the vibration at point P on the vibration structure
P(M):Sound pressure at a distance r of the plate

This formulation is used to calculate the primary sound field generated in front of the transformer and, among others, at the error sensor of each control unit. The sound field generated by the actuator of each control unit being:

$$P(M) = -y_j \frac{\exp(jkr)}{2\pi r}$$

where y_j is the optimal amplitude and phase needed at the actuator to minimize the sound field due to the transformer. The optimal command for the actuator is calculated with :

$$y_{opt}(\omega_n) = -C^{-1}(\omega_n)\, d(\omega_n)$$

Figure 2 gives a typical example of the radiated sound field in front of the transformer with ANC and noise reduction obtained for various configurations of the active noise control units.

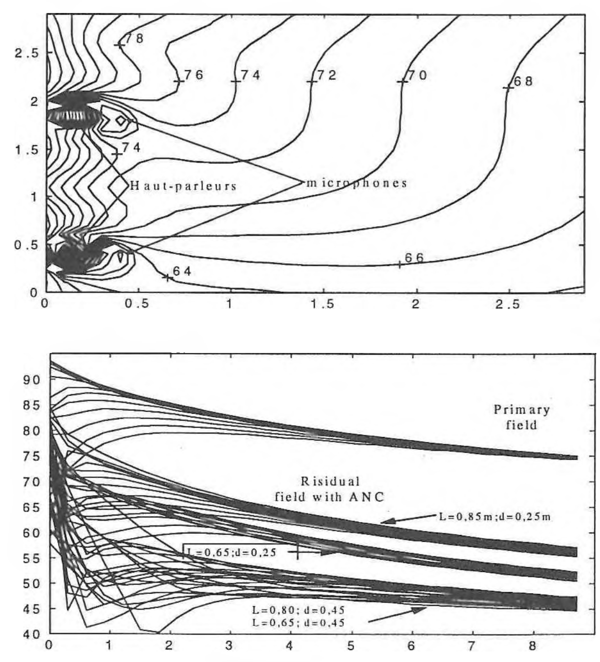

Figure 2 A) Sound field in front of the transformer with ANC; B) Noise reduction with ANC.

From those results, it was found that distances L= 0,70m between each control unit and d=0,30 m between the actuator and the sensors can provide 15 to 20 dB of global attenuation at 120 Hz.

In an application, the secondary sound field generated by a given control unit generates a residual sound field at the error sensor of the adjacent units. Those adjacent units will then adapt their response to minimize the noise at their error sensors and obviously generate a residual sound field to the error microphone of adjacent control units, and so on. This phenomenon can thus generate instability, since each control unit is independent in the proposed system. To analyze these effects, an experimental setup was necessary.

4. Experimental setup

A system of 24 control units was developed to verify the efficiency and stability of the system. Each control unit is composed of an error microphone, a DSP (TMS320C50) an amplifier and a speaker. A feedback control algorithm (see 2nd paper on this subject) is loaded on each DSP using a serial link with a PC[3]. Once the control is turned on, each control unit works to reduce the noise at is own error microphone.

After a set of tests in laboratory, it was found that the stability of the system is dependent, among others, on the distance between the error sensors and the speakers. For a distance of *L*=0,70 m between the control units, a distance of *d*=0,20 m allows an efficient noise reduction and a suitable stability.

Using those results, an experiment was then conducted on a real transformer (figure 3) on the first harmonic. A noise reduction of 10 dB was obtained (figure 4). In terms of perception, this reduction appears to be very significant for a person who is on the site.

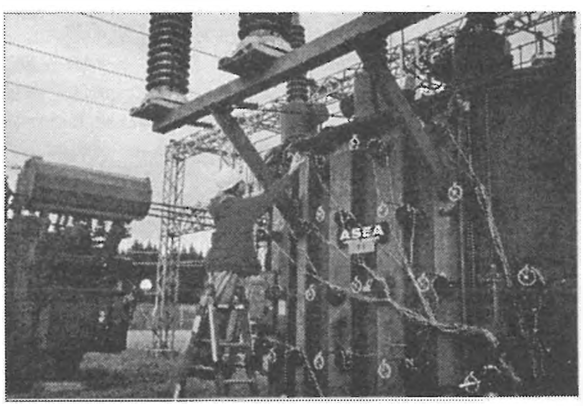

Figure 3 Experimental setup on a real transformer. Distance between the control units is 0,70 m.

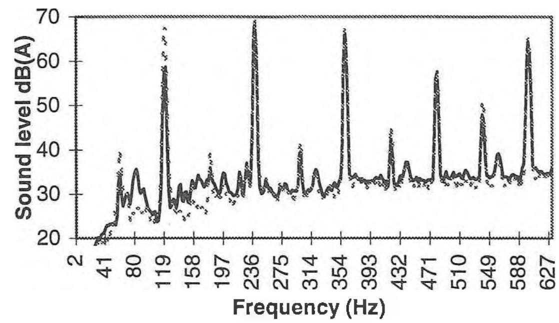

Figure 4 Sound spectra measured with and without control.

5. Conclusion

A new concept of active noise control for transformers has been proposed. This concept uses a set of independent control units distributed on the transformer surface.

A theoretical model has been developed to determine the optimum distribution of the control unit on a transformer surface. An experimental setup composed of 24 control units has also been realized. This system allowed to determine that a distance of about 0,20 m between the error sensor and the speaker of each control unit ensures a good stability of the system.

An experiment realized on a real transformer gave a noise reduction of 10 dB of the first harmonics.

The system is actually under development to obtain a noise reduction of the first 2 harmonics (120 Hz and 240 Hz).

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