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Publisher’s version / Version de l'éditeur:

Noise Control, 3, 2, pp. 37-39, 86, 1957-02-01

NATIONAL RESEARCH COUNCIL

CANADA

THE ACOUSTICAL DESIGN OF ENCLOSURES FOR POWER TRANSFORMERS

by

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REPRINTED FROM NOISE CONTROL

VOL. 3, NO. 2, MARCH 1957

RESEARCH PAPER NO. 31

OF THE

DIVISION OF BUILDING RESEARCH

Ottawa

NRC 4215

FEBRUARY 1957

Price 25 cents

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The Acoustical Design of Enclosures

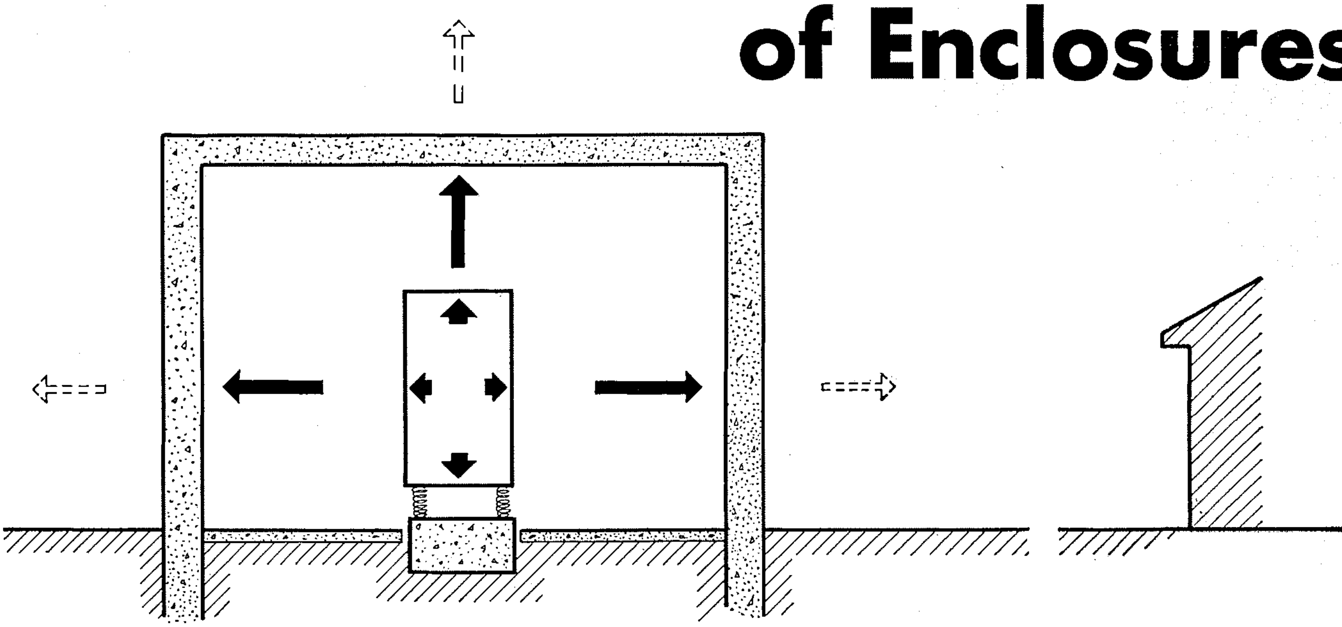


FIG. 1. Schematic diagram of transformer enclosure.

for Power Transformers*

T. D. NORTHWOOD, L. B. SMITH,† AND E. J. STEVENS

NATIONAL RESEARCH COUNCIL OF CANADA

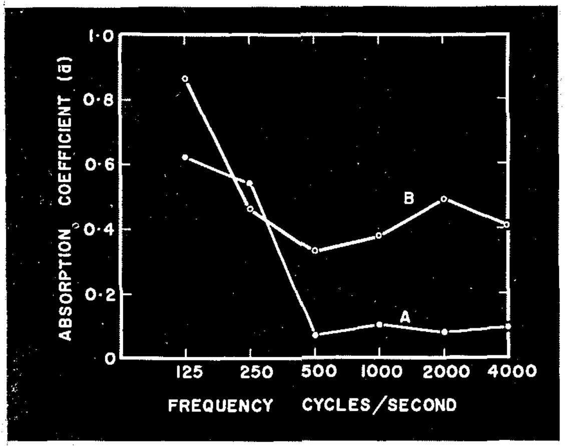
This paper discusses the design of enclosures for controlling the noise from large power transformers. The design of ventilating ducts and resonant absorbers for lining enclosures is described.

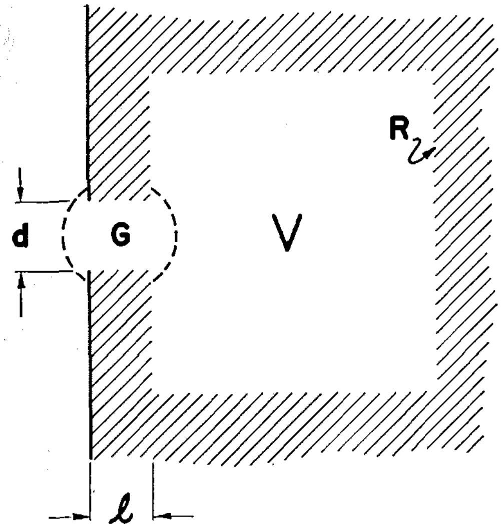
TRANSFORMER noise is not a new problem. The literature goes back about thirty years, and the history of complaints probably began with the first transformer substation. During these years power companies have usually managed to placate the neighbors by various means. In the last ten years, however, several factors have combined to make the problem much more difficult. One such factor is the postwar increase in the use of electric power, requiring new substations and a doubling or tripling of the capacities of substations that formerly were on the borderline of being too noisy. The transformer manufacturers now have an awakened interest in the problem because noise has become the limiting factor in transformer design, preventing them from taking full advantage of recent developments in magnetic materials. The most important factor of all, perhaps, is the fact that people are acquiring the idea that obnoxious noise can and should be eliminated.

The early work in the field was done mainly by power companies and consisted of experiments with partial or full enclosures, resilient mountings, and other methods of confining noise and vibration. More recently the transformer manufacturers have been attempting, with some success, to reduce noise at the source. Eventually the latter studies may substantially reduce the problem for new equipment, but there are many noisy transformers already in service whose noise must be dealt with by external means. This paper describes some developments toward this end undertaken by the Division of Building Research in collaboration with the Hydro-Electric Power Commission of Ontario.

* An address before the seventh annual National Noise Abatement Symposium in Chicago, October 11, 1956.

† Now with Canadair Limited.





$$Z = \frac{p}{v} = R + \frac{j\omega\rho_0}{G} + \frac{\gamma P_0}{j\omega V}$$

$$G = \frac{s}{\ell + 0{\cdot}8\,d}$$

Fig. 2. Sound absorption of two low-frequency absorbers. Curve A—absorption of 2 ft × 4 ft × 1/4-in. plywood and glass-fiber backing. Curve B—absorption of 8 × 8 × 16-in. cinder blocks, one 3/8-in. perforation per cell.

Fig. 3. Diagram of Helmholtz Resonator; *s* is the cross-sectional area of the hole whose diameter is *d*.

We might begin with a brief survey of the main features of transformer noise. The problem arises because for efficient power distribution it is necessary to space transformer stations throughout a community, including residential areas. The nearby residents are never very pleased to have one of these installations in their midst, even when it is hidden behind a residential-looking facade. The noise is frequently the "last straw."

The noise consists mainly of the hum produced by a magnetostriction effect in the iron laminations of the transformer. A transformer operating at a line frequency of 60 cycles per second produces a fundamental hum frequency of 120 cps and a series of harmonics at 240, 360, and so on. The fundamental is generally the loudest component, but the first two or three harmonics may also be important. Thus, it is mainly a low-frequency noise. It happens that low-frequency noises are particularly difficult to deal with: the conventional procedures for absorbing or confining or directing sound tend to become inefficient at low frequencies. But the noise has the additional feature that it consists of a small number of discrete frequencies. In fact, the problem is solved if one can dispose of the components at 120, 240, and 360 cps, usually in that order of importance.

There is often difficulty in deciding what is an acceptable noise level. The decision is complicated by various legal, economic, and psychological factors which will not be discussed in this paper. Common practice is to ensure that a transformer does not measurably increase the ambient level in the vicinity of the nearest neighbor. The ambient level may be quite low in the quiet hours just before dawn, and this is also the period when noise, interfering with sleep, is particularly objectionable. Since this problem is concerned with relatively low sound levels, it is necessary to take account of the low-frequency character of transformer noise compared with most other ambient noises. In the past it has been usual in transformer noise studies to use weighting network "A" on the sound-level meter, which gives an approximation to loudness levels for noises in the vicinity of 40 decibels.

Consider, then, the design of an enclosure that will reduce the noise from a given transformer to a given level at the nearest neighboring house. Figure 1 illustrates the various factors which must be considered. In addition to the direct radiation of airborne noise, the transformer produces vibration which may be communicated to the ground and later reradiated as noise in an adjacent building unless prevented by suitable vibration isolators. This involves a consideration of the mountings, the supporting slab, and the soil. The objective is to produce the greatest possible impedance mismatch between the transformer and the soil. The vibration problem will be discussed in a forthcoming paper by A. T. Edwards; * in the present paper we will concentrate on airborne noise.

* Submitted for presentation at the AIEE winter general meeting in New York, January 1957.

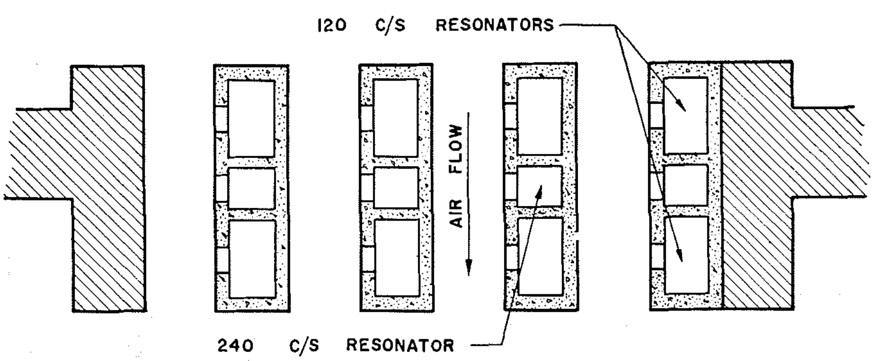


Fig. 4. Horizontal section of transformer enclosure ventilator stack.

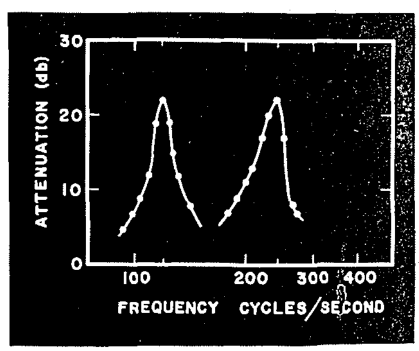


Fig. 5. Sound attenuation in transformer enclosure ventilator stack of Fig. 4.

The airborne noise from the transformer may either be absorbed within the enclosure or transmitted through the walls. It is worth noting that if none of the sound were absorbed, the level would build up inside the enclosure until the sound would all be transmitted just as if the enclosure were not there. Hence, the resultant level outside depends on both the absorption inside the enclosure and the transmission loss through the walls. An economical design involves the judicious consideration of both parameters. Since transformers dissipate a substantial amount of heat, an enclosure design is usually complicated by ventilation requirements. These constitute a third acoustical problem.

The wall transmission problem is generally taken care of by local building bylaws. If any kind of enclosure is built, most bylaws require something of the order of a 13-in. masonry wall, and this is about as far as one wants to go from the point of view of sound transmission. Even at this point very careful design of doors and other details is required to realize the full value of a 13-in. wall.

The absorption of low-frequency sound is best achieved by means of a resonant system tuned to the required frequency range. One approach is to tune sharply to the individual frequencies: 120, 240, and 360 cps, for example. Another is to use broadly tuned elements that are moderately efficient over the whole range. The latter approach has been found particularly useful in the design of absorbent linings for enclosures.

Several resonant systems might be considered. For example, a thin panel clamped only at the edges may have suitable low-frequency resonance properties. Suitable damping may be obtained by filling the back space. The absorption properties of one such panel are shown in Fig. 2 (Curve A).

Another useful system is the Helmholtz Resonator, illustrated in Fig. 3. The resistive element in this system may be provided by a flow-resistant material in the orifice or in the cavity, or by porosity in the walls of the cavity. The acoustical design is fairly straightforward; the problem is mainly to devise a simple, inexpensive way of constructing the elements. For roofless enclosures there is the additional restriction that the elements must withstand the effects of weather. Several Helmholtz Resonator systems were devised to meet these requirements. The simplest one, suggested by Mr. A. T. Edwards of the Ontario Hydro, was made by drilling a hole of suitable size into each cavity of an ordinary hollow cinder block. The absorption properties of this system are shown in Fig. 2 (Curve B). Similar results were obtained with building blocks made of other porous aggregates such as expanded slag and expanded mica. In all cases good absorption was obtained over at least two octaves. In order to achieve maximum sound absorption it is necessary to prevent communication between cells over more than 2 or 3 ft. One way to accomplish this is to use a course of brick or solid blocks for every three or four courses of resonator blocks. An example of this construction is shown in Fig. 8. The holes could possibly be formed by a modification of the standard block-making process, but it costs only a few cents to drill them. For new construction the perforated blocks form the inner part of a standard wall. Thus, the acoustical treatment for the enclosure may be obtained for the cost of drilling the holes: a few cents per square foot.

Turning now to the matter of ventilation, the low-frequency characteristic of the noise again presents a problem. Conventional noise-attenuating stacks that provide attenuations of the order of 20 db at 120 cps are large and costly. Again the

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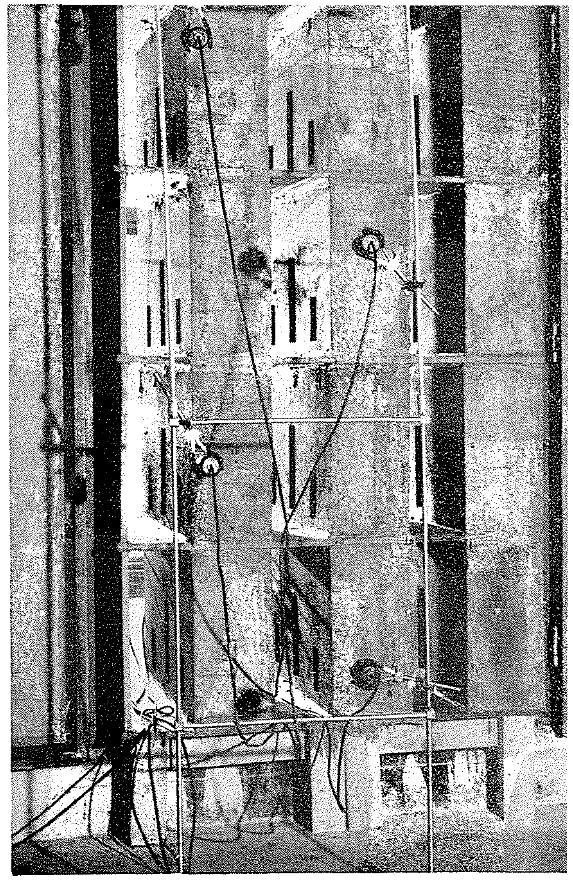

Fig. 6. Test array of ventilator stack elements.

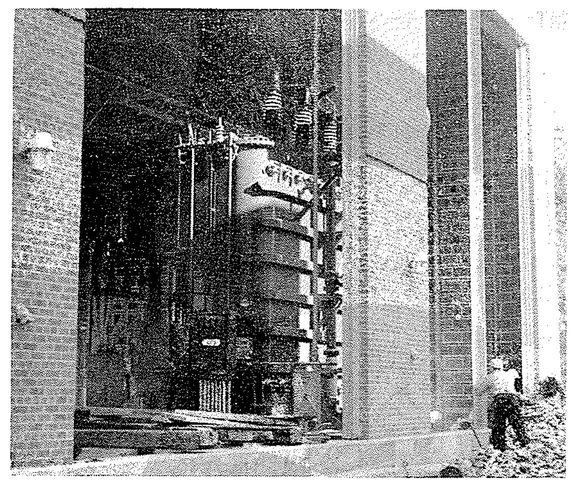

Fig. 7. View of transformer enclosure during construction.

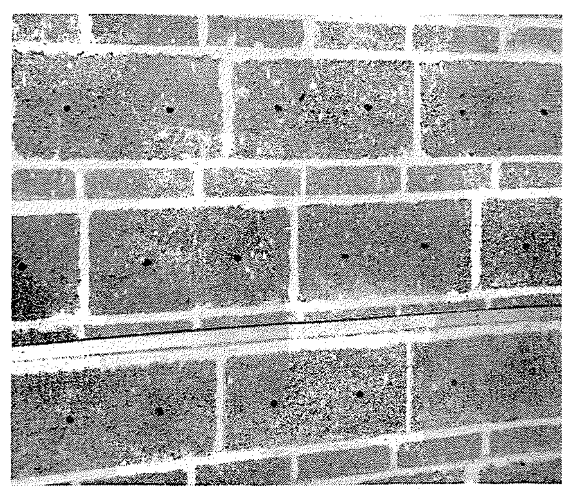

Fig. 8. Close-up of perforated block absorbing wall.

Enclosures for Power Transformers

(*Continued from page 39*)

Helmholtz Resonator principle is a useful solution. One might use something like the perforated cinder blocks, broadly tuned to be absorbent over the range of frequencies. One can do better, however, by concentrating on the discrete frequencies and by locating each tuned element strategically in the length of the duct. Figure 4 illustrates some preliminary experiments with a very short duct designed to attenuate 120 and 240 cps. The duct is about a quarter-wavelength long at 120 cps. A simple duct of this length provides some attenuation by virtue of the impedance mismatch at the two ends. An attenuation of about 10 db was obtained for a simple duct of this type. The attenuation was increased to the design value of 20 db by introducing 120-cps absorbers near the two ends. The 240-cps component falls in a transmission band for a simple duct of this length, but a 240-cps absorber at the mid-point attenuates this frequency most effectively. Results obtained with an array of these units are shown in Fig. 5. Figure 6 shows the array under test. It is envisaged that an assembly of these units would be incorporated in the lower part of enclosure walls to form an air inlet. In small stations a roof might not be needed. Otherwise, a similar outlet stack at roof height could be used. Experiments aimed at obtaining slightly higher attenuation are currently under way with variants of this design.

Another approach to the ventilation problem is to separate the cooling coils from the transformer and enclose only the transformer. Figure 7 shows such a station now under construction. The station is lined with perforated blocks of the type described earlier, a close-up of which is shown in Fig. 8. Two 33 000-kva transformers are being installed now, with provision for a third at a later date. The large openings, required only for installing transformers, will be blocked off with preformed concrete slabs. A few measurements have been made on the unfinished station, and present indications are that the noise levels will be comfortably below the design values.

This paper is intended not so much as a solution to the transformer noise problem as an illustration of the special techniques that are useful in dealing with noises of this special class. Transformer noise is perhaps the best example, but there are other noises of this type, consisting mainly of a few low-frequency components, in which the fruitful line of attack is to consider one frequency at a time.

No attempt has been made here to cover the whole field of transformer noise research. For readers of NOISE CONTROL it should suffice to draw attention to several recent papers in that magazine. Particular reference should be made, though, to the excellent bibliography on transformer noise sponsored by the AIEE and reprinted in the November 1955 issue of NOISE CONTROL.

This paper is a contribution from the Division of Building Research, National Research Council of Canada and is published with the approval of the Director.

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