# TRANSFORMER NOISE, ITS CAUSES AND LIMITATIONS

By

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(Note:- Detailed contents are given at the beginning of chapter 2.3.4 and 5 ).

# SUMMARY

With the installation of an ever increasing number of transformer sub-stations in built up areas, the noise emitted by the transformer has become a problem of growing concern. In this dissertation, an a attempt is made to review the present day knowledge on the subject of transformer noise. Though all the major sources of noise are listed, particular attention is given to the magnetostriction properties of the core material, since magnetostriction is known to be the chief source of double frequency "hum" emitted by the transformer. Theoretical and design considerations affecting the level of transformer noise are discussed in some detail and the characteristics of noise with particular reference to the human ear are examined critically. Various methods of limitation and reduction of transformer noise are described and it is shown that economic considerations do not usually permit the use of very low noise levels in commercial transformers.

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## LIST OF PRINCIPAL SYMBOLS.

$A$= Attenuation in decibels.

$B$= Build up effect in decibels.

$B_o$= Reference flux density in lines/sqcm.

$B_{max}$= Maximum flux density in lines/sqcm.

$C$= Velocity of sound in Air=331.6 m/sec.

$D_2$= Density of leg $l_2$

E.L.= Effective loudness.

$E_2$= Modulus of elasticity of the core material.

hi= Harmonic-Index.

$I$= Intensity of sound at a point under consideration
in watts/sqcm.

$I_o$= Reference intensity of sound and equal to $10^{-16}$ watts/sqcm.

$I_2$= Moment of Inertia of the cross section of the core.

$K_2$= Ratio of the lengths of two legs.

$L$= Length of the core in cms.

$m_2$= Mass per unit length.

$P$= Sound pressure at a point under consideration in dynes/sqcm.

$P_o$= The reference sound pressure in dynes/sqcm. and is
equal to 0.000204 dynes/sqcm.

$S$ = Percent increase in the core length due to magnetostriction

$S_o$ = Percent increase in the core length for a reference
level of induction $B_o$

$TR = \text{Transmissibility} = \frac{\text{Transmitted force}}{\text{Disturbing force}}$

$W$ = Weight of the core.

$W_2$ = Width of the leg $\ell_2$

$\rho$ = Density of Air.

$\lambda$ - Wave length of the sound wave for the frequency f c/s.

# INTRODUCTION

In most countries of the world, the last decade has witnessed a phenomenal increase in the domestic consumption of electric power. To meet this evergrowing demand of power, it has become necessary for the power utility concerns to install an increasing number of transformer sub-stations in residential districts. Such installations have always brought forth complaints from the inhabitants of the locality, based mainly on the grounds of the objectionalbe "hum" emitted by the transformers. Trasformer noise has thus become a problem of considerable concern both for the manufacturers of transformers and for the users. In the advanced countries of the West noise-levels are specified at the design stage and the supply companies undertake the responsibility of restricting the noise emitted by their sub-stations to values which are not objectionalbe.

The demand for "silent" transformers has led to an extensive study of mechanism of transformer noise. The first significant contribution was due to Rober B.George(1) of the U.S.A. and E.T. Norris(29), B.G.Churcher and A.J. King[27] in U.K. In 1940, B.G.Churcher and A.J.King published a classical paper on transformer noise(Limitation of Transformer Noise) which deals with the chief sources of transformer noise and methods of reducing noise levels. In U.S.A. in the year 1941 **W.C.** Sealy[5] and H. Fahnoe[6] published papers in which the effect of physical dimensions of the transformer and operating flux-density were discussed and theoretical results were confirmed by measurements of noise levels on actual transformers.

In the year 1950 there were six papers[9,10,11,12,13,1 published in the Transactions of the A.I.E.E. Some of the papers dealt with the noise problem as faced by the Electric supply companies,[11,13] some dealt with the acoustical measurements on trasformer[10,12] and some dealing with theoretical and design considerations[9,14]. Briggs Gettys and W.B. Conover made investigations on Acoustic Models of transformers and there from developed a method of calculating transformer noise levels, based on a study of small scale models of the transformers.

William B Conover and R.J.Ringlee[19] have given a method by which noise of particular frequency can be cancelled in a particular direction by the use of loudspeakers which generate a noise at a frequency equal to the one which is to be cancelled. The principle of operation is the interference-phenomenon which the sound waves undergo. E.T.Edward[21] published a paper in 1957 on the use of Vibration-Isolators and their importance in reducing the noise levels. For getting low sound levels in large power-transformers "Preassembled Enclosures" are becoming very popular in the U.S.A.

In short the published literature on transformer noise is very much diversified and there is not a single paper which deals with all the aspects of transformer noise. In this dissertation, an attempt has been made to examine all the aspects of transformer noise problem, and, to suggest methods of limiting and reducing the noise.

Any study of an acoustical problem involves a detailed examination of (1) the source of noise and the mechanism of its production,(2) the transmission of noise and its attenuation and(3) the reception of noise with particular reference to the characteristics of the hearer.

Audio noise is produced when vibrations associated with noise are within the frequency range of 20c/s to 20000c/s. Though there are various sources of such vibrations in the transformer, the chief source of noise is the vibrations set up in the core due to magnetostriction property of the core material.[1,5,8,9,27] The transmission of this noise and its attenuation depend on the acoustical properties of the medium, and the length and nature of the path taken by the sound waves from the source to the hearer.

Once a transformer has been manufactured, the level of noise generated in the transformer under operating conditions is fixed and any reduction of noise level can be attempted only through external means. It is therefore, desirable that a thorough examination of the feasibility of limiting the generated noise be undertaken at the design stage and the problem kept under constant review at all the manufacturing stages, since faulty manufacture may add considerably to the inherent electromagnetic noise of the apparatus.

Every engineering problem requires a solution which is not only technically practicable but also economically justifiable. Noise limitation or reduction is an expensive business and economics plays a very important part in deciding the permissible noise levels of the transformers.

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# CHAPTER -2

## SOURCES OF TRANSFORMER NOISE.

(2.1) Vibrations due to magnetostriction

  (2.1.1) Magnetostriction characteristics.

  (2.1.2) Influence of supply voltage wave form.

(2.2) Vibrations produced at the gaps and joints.

(2.3) Vibrations due to interaction between the core and the coils.

(2.4) Resonant parts and structures.

(2.5) Noise produced by auxiliary equipment associated with the transformer.

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# CHAPTER - 2

## SOURCES OF TRANSFORMER NOISE.

Since noise is emitted through mechanical vibrations in the audio-frequency range, all sources of noise are primarily sources of audio-frequency oscillations. In transformers such oscillations are present in nearly every part of the structure, and hence the noise level is fairly high. For analytical purposes, the vibrations can be classified under the following general headings:-

(a) Vibrations due to magnetostriction.

(b) Vibrations produced at the gaps and joints.

(c) Vibrations due to interaction between core & coil.

(d) Resonant parts and structures.

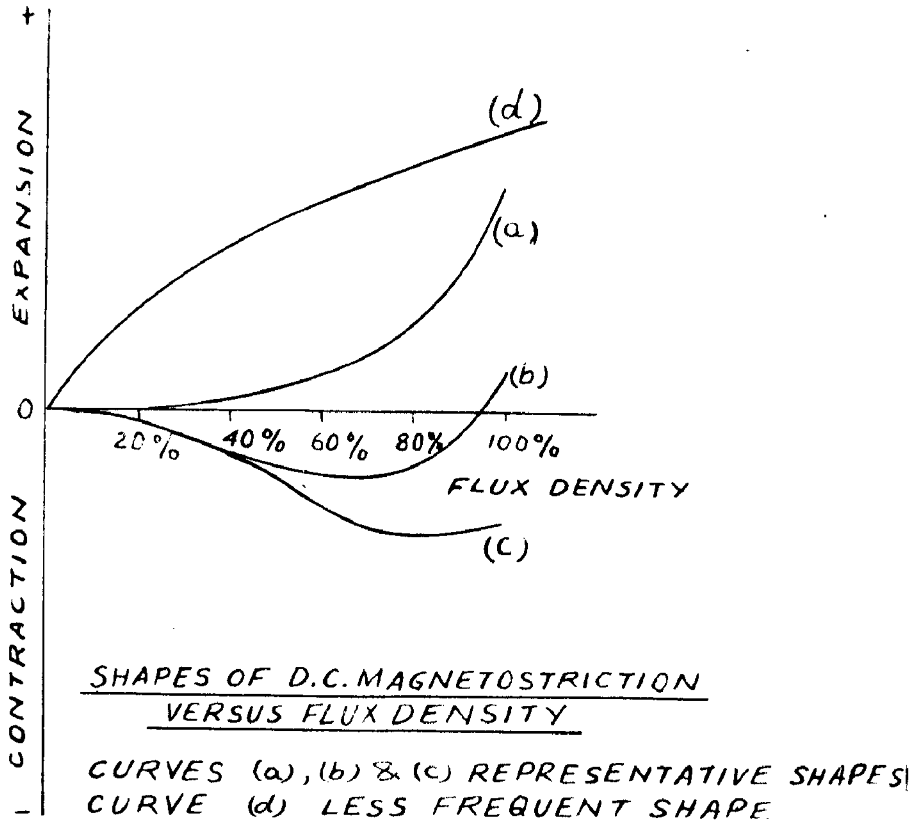
(e) Noise produced by auxiliary equipment associated with the transformer.

### (2.1) Vibrations due to Magnetostriction:-

#### (2.1.1) Magnetostriction characteristics:

Magnetostriction may be defined as the change in dimensions of a magnetic material under magnetic stimulus, when the field is varied. Volume and transverse changes also occur but are not of great importance. Magnetostriction is a property of the material and a true evaluation of this property may be obtained by using D.C. stimulus. When D.C.magnetostriction measurements are made the results are similar to D.C.fluxdensity and field intensity data and a single valued relation between magnetostriction and fluxdensity is obtained on initial magnetisation of the material. A loop is obtained when the flux density is increased and then decreased. The change in demensions partly or wholly disappears when the magnetizing force is removed; and is independent of the direction of magnetization. Magnetostriction characteristics depend on the following:

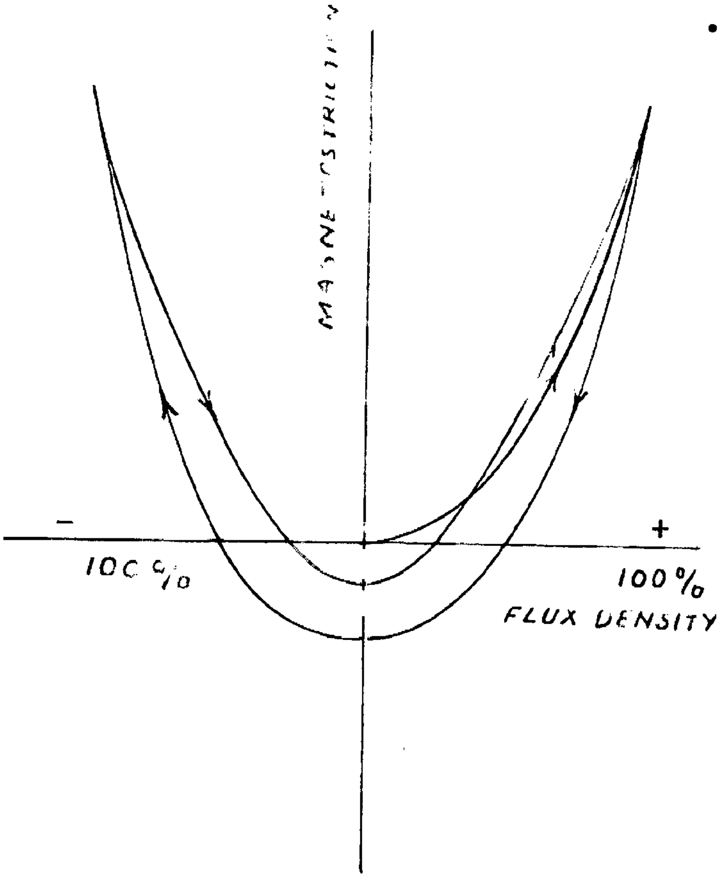
(a) Surface condition of the sample.
(b) The strain in the sample.
(c) Heat treatment of the sample.
(d) Chemical composition of the sample material.



SHAPES OF D.C. MAGNETOSTRICTION VERSUS FLUX DENSITY

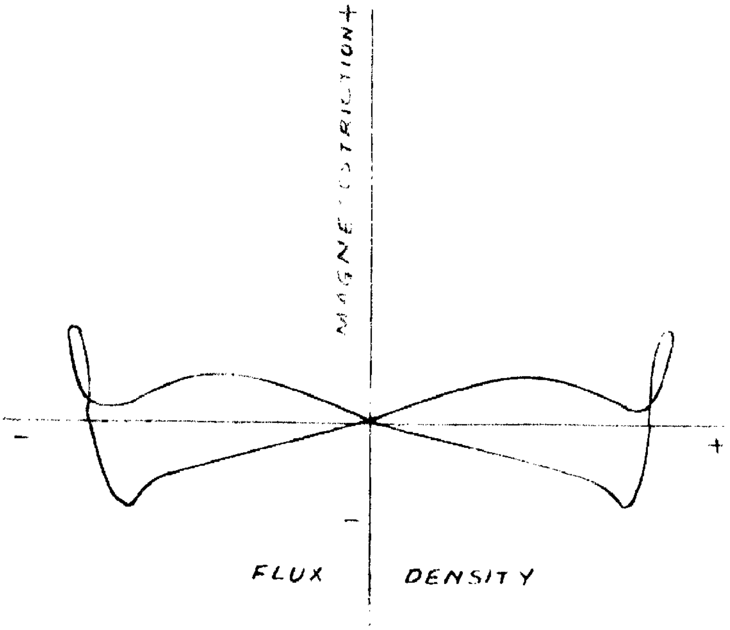
CURVES (a), (b) & (c) REPRESENTATIVE SHAPES
CURVE (d) LESS FREQUENT SHAPE

FIG. 2.1



REPRESENTATIVE D.C. MAGNETOSTRICTION LOOP OF A TRANSFORMER CORE STEEL

FIG. 2.2



A.C. MAGNETOSTRICTION LOOP OF TRANSFORMER CORE SHEET AT HIGH SATURATION FLUX DENSITIES

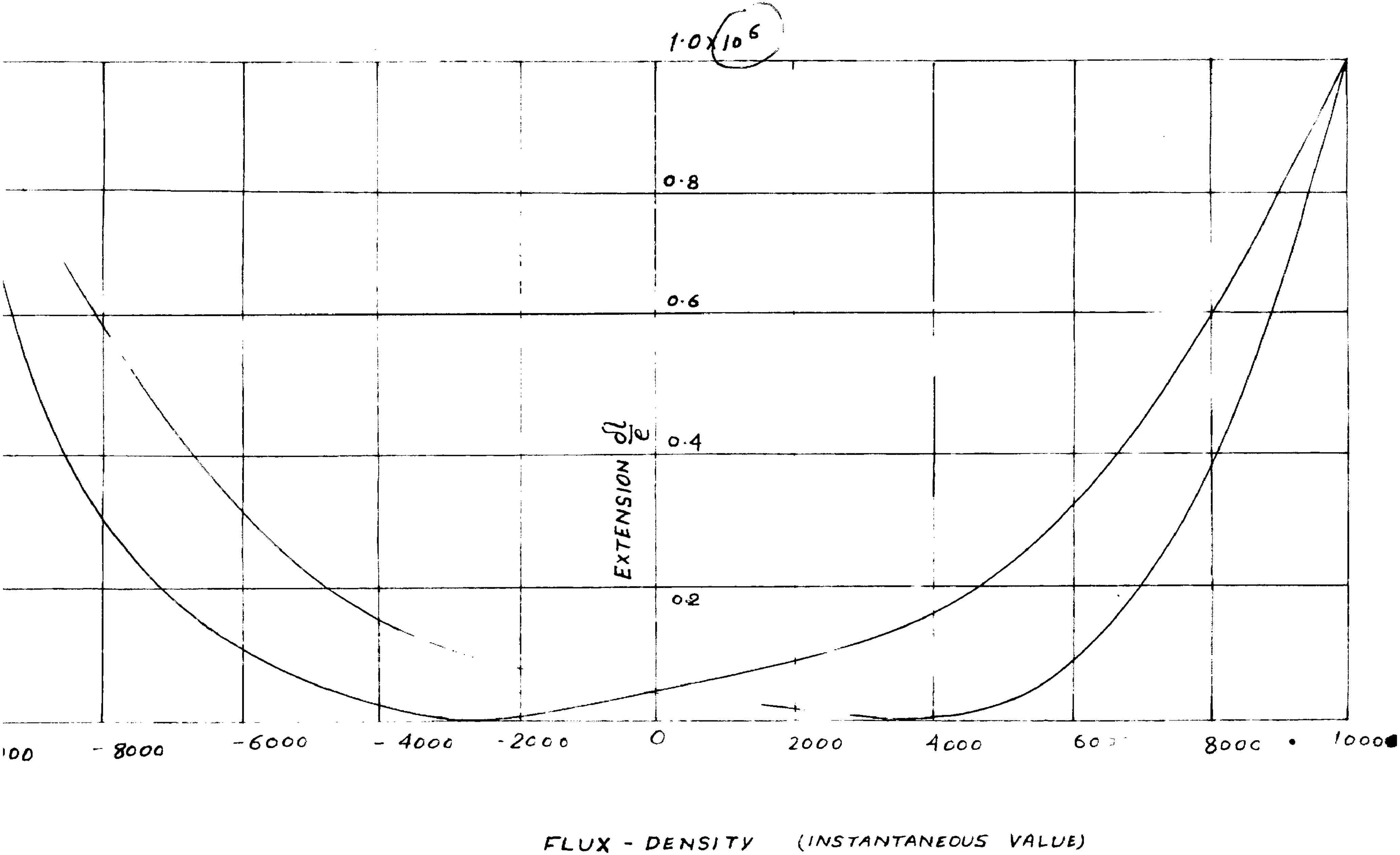
The vibration of D.C. magnetostriction of transformer core-steel with flux density is given, in general, by a concave shaped of type(a)(b) or (c) of Fig.2.1. Ocassionally a convex-shaped curve similar to curve(d) in this Fig. is also encountered. The curves of Fig.(2.1) are for initial excitation of the sample. If the flux density is varied through a complete cycle of positive and negative values, starting with an initially un-magnetized sample, the magnetostriction characteristic is no longer given by a single valued curve but a loop similar to the one whoen in Fig.(2.2) is obtained.

All magnetostriction curves show a nonlinear relationship between magnetostriction and flux-density. This nonlinearity indicates the presence of harmonics in the magnetostriction, if the flux-density varies sinusoidally.

The magnetostriction characteristics of ferromagnetic materials under a.c.excitation are represented by loops similar to d.c. loop of Fig.(2.2) This is however, true when the peak flux-density is not very high. If the peak a.c. flux-density be increased to saturation value, the a.c. loop becomes very much distorted as shown in Fig(2.3) giving rise to vibration harmonics.

Since the magnetostriction effect occurs in the same direction for a given material irrespective of the external field, a sine wave source supplying the transformer winding will produce a dimensional change in the core at twice the exciting frequency.

In Fig.(2.4) is shown the order of magnitude of magnetostriction effect in 4% silicon-steel for one complete cycle of magnetization. It is seen that the extension per unit length $\frac{\delta l}{l}$ is exceedingly small, being of the order of $10^{-6}$ inch/inch length($10^{-6}$ cm/cm length) of the core for a maximum flux-density of 10000 gauss(1.0 $wb/m^2$) . Neverthless, the length of the core of transofrmer of a few hundred KVA is sufficient to cause an undesirably loud noise, owing to the very small amplitude required to produce an appreciable sound. This point may be illustrated by a simple example; that is a surface of area 100 sq.cm. vibrating sinusoidally and uniformly with an amplitude of 0.0001" at 300 c/s then the Effective-loudness at 1 meter distance will be 70 phons[27].



RELATION BETWEEN FLUX DENSITY AND EXTENSION FOR 4% SILICON STEEL

The loudness spectrum from the simplest possible form of core, a single ring puching, magnetized by a conductor located at centre is given in the table (2.1) below. 27

Table (2.1)

Loudness spectrum of a core of single ring puching.

| Frequency of Component. | Equivalent loudness of components at distance of 1 metre in Phons | |
|---|---|---|
| | Bmax = 10500 gauss. | Bmax = 14800 gauss. |
| 100 c/s | 0.5 | 9.5 |
| 200 " | 6.0 | 16.0 |
| 300 " | 36.5 | 50.5 |
| 400 " | 28.0 | 40.5 |
| 500 " | 26.5 | 52.5 |
| 600 " | 14.5 | 32.0 |
| 700 " | 19.5 | 33.0 |
| 800 " | 18.5 | 32.0 |
| 900 " | 16.5 | 22.0 |
| 1000 " | 13.0 | 19.5 |
| 1100 " | 18.0 | 25.5 |
| 1200 " | - | 24.0 |
| 1300 " | - | 18.5 |
| 1400 " | - | 21.5 |

From the above table it is easily seen that components of appreciable magnitude exist upto1100 c/s at Bmax=10500 gauss(1.05wb/m and extending to 1400 c/s for Bmax=14800 gauss(1.48 $wb/m^2$). Each component contributes to the noise experienced by a hearer but not in the direct proportion of the E.L.Values. The largest component is see to occur at 300 c/s at the lower flux density and at 500 c/s at the

### (2.1.2) Influence of the supply voltage wave form

We have seen that even with a sinusoidal fl wave form, the wave form of the magnetostrickion extension and hence of the sound pressure wave contains harmonics. In general the distortion of the flux wave, due to the application of a distorted voltage wave to the transformer is to be expected to lead to a further generation of harmonics in the sound wave, and an increase in the effective loudness.

It is to be stressed that not only is the magnitude of the magnetortriction important, but so also is the shape of its characteristic curve, because of the harmonic phenomenon involved. One core material may have less magnetostriction magnitude than a second material, but under operating condition of distorted voltage, the first may produce more effective noise as compared to the second, which is operating on sinusoidal voltage supply. This is due to a number of harmonic frequency components of sound waves generated by the first.

## (2.2) Vibrations at the Gaps and Joints.

Cores of power transformers are usually built by stacking many thin laminations into a structure. These laminations have junctions, joints and gaps of one type or another through which flux must pass. Most of these joints have over lapping regions in which the flux is devided between the parallel iron and air paths. The division of flux between the paths varies through-out the cycle, because the permeability of iron is varying. Secondly the flux distribution in the corner sections of the plate type cores is not uniform.

Hence, across these gaps of joints in the core exists a force, which at each instant during the cycle, and it varies as the square of the instantaneous flux-density. These forces tend to vibrate the leg and yoke sections of the core, thus becoming a source of noise.

If these regions had only fundamental flux in them, only a vibration and noise of frequency twice the core exciting frequency would be obtained.[9] That is, if only 50 cycle sinusoidal flux were in the joint region, then only 100 cycle vibration would exist. But due to distortion of flux and variable permeability in the joint regions, harmonics of vibration will be generated and they will be emitted from the transformer.

### (2.3) Vibrations due to Interaction between core and coil.

When a current flows in a transformer winding, forces are exerted on the conductors and the winding supports. An exaggerated case of such forces is one when a short circuit occurs in a transformer. However at normal current densities which are used in the design of power transformers, the noise emitted by the coils due to their load currents is not very appreciable. If the transformer is to be designed for very low noise levels, the noise due to the coils may become sufficiently appreciable and can not be neglected. Similar to the coil noise, the noise, caused by vibrations due to forces between the coil and the core and clamps is negligibly small in normal designs.

### (2.4) Resonating parts or structures.

Mostly all materials, which are built in to a transformer, either themselves or together as a structure have mass and spring characteristics. This is true for the core, tank, radiator tubes, junction-boxes and so forth. To a certain extent there is associated

Depending on its geometrical shape, mass, elasticity and material, the structure or part under consideration may have natural frequencies of vibration which are the same or nearly the same at which the core vibrates due to magnetostriction effect. If the resonance occurs, the amplitude of vibration set up is increased many times and the noise produced due to resonating frequency component may reach a high value which will contribute to a considerable amount of noise.

Although most of the resonating parts do not in themselves contain sources such as magnetostriction, they may if not properly designed, be driven by other sources and amplify certain frequencies that would otherwise be undetectable.

Some resonant frequencies for mechanical vibrations can be calculated with sufficient accuracy. One of these is the natural frequency oftransformer core as a closed-frame type structure. The frequency of this type of structure is not only a function of the width of leg devided by the length squared , but also a function of other parameters as well.[9] The natural frequency of a rectangular frame with legs of length $\ell_1$, and $\ell_2$ can be expressed as

$$f = \frac{K_2^{2}}{2\pi \ell_2^{2}} \sqrt{\frac{E_2 I_2}{m_2}} \quad \ldots\ldots\ldots\ldots(2.1)$$

Where:

$K_2$= Ratio of two lengths of the two legs.

$E_2$= Modulus of elasticity of the core material.

$I_2$ = Moment of Inertia of the cross section of the core

$m_2$ = Mass per unit length

for the leg length $l_2$

In a transformer, the distributed parameters (E, I and m) of the two legs are equal or bear a constant ratio. $K_2$ is a function of the ratio of the length of two legs and this can be designated as 'r' . If we assume that the legs are of rectangular section(shell type) or approximately circular section(core-form), then the equation (2.1) reduces to

$$f = C. \; F(r) \frac{W_2}{\ell_2^2} \sqrt{\frac{E_2}{D_2}} \quad \ldots\ldots\ldots \; (2.2)$$

Where:

C is a constant having different values for core type and shell type construction.

F(r)-: represents a function of the ratio of leg lengths

$W_2$= width of leg $\ell_2$

$D_2$= Density of leg $\ell_2$

The equation (2.2) indicates that for a specific type of core and core materials, the natural frequency is a function of(i) the ratio of leg lengths and (ii) ratio of leg width to the length squared.

The possibility of parts of the structure resonating must be kept in view during the design of the transformer and the natural frequencies in the close neighbourhood of the audio-frequencies generated due to magnetostriction must be avoided.

## (2.5) Noise produced by Auxiliary equipment associated with the transformer( such as fans and pumps)

**Another** source of noise which is not related to the transformer proper is that due to external cooling equipment. This equipment may include fans, pumps or unit coolers. Usually this equipment is mounted on radiator tubes or headers and therefore is a source of noise from one to several feet from the transformer tank.

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# CHAPTER - 3

## SOME THEORETICAL AND DESIGN CONSIDERATIONS AFFECTING NOISE-LEVELS OF TRANSFORMERS.

(3.1) Effect of the physical dimensions of the transformer.

(3.2) Effect of the operating flux density.

(3.3) Effect of the magnitude and Power Factor of the load.

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# CHAPTER - 3.

## SOME THEORETICAL AND DESIGN CONSIDERATIONS AFFECTING THE NOISE LEVELS OF TRANSFORMERS.

Power transformer noise-level is dependant not only upon the transformer itself but also upon conditions imposed on the transformer. The following factors affect the Noise level of the transformer.

(a) Physical dimensions of the transformer.

(b) The operating flux density.

(c) Magnitude and P.F. of the load.

### (3.1) Effect of the Physical dimentions of the transformer.

It is general experience that the noise of a transformer varies with its size and that larger transformers are more noisy than small transformers.

According to the American standards Association regulations for measurement of transformer noise; the sound intensity is measured one foot away from the major sound producing surface. Consequently the sound intensity measured is practically the sound intensity at the surface of the sound transmitting member.[5]

For transformers of similar proportions, the core weight W isproportional to the length of the core L raised to the third power.[5] Thus

$$W = K_1 L^3 \quad \ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where $K_1$ is a constant

$$L = \left(\frac{W}{K_1}\right)^{\frac{1}{3}} \quad \ldots\ldots\ldots\ldots \quad (3.2)$$

Further it is assumed that the transformers under consideration operated at the same flux-density in the core and are of the same core material.

With the above assumption, the noise intensity I at the outside of the transformer is proportional to the square of the core length. This is due to the fact that the noise intensity is proportional to the square of the amplitude of vibration and because the change in dimensions due to magnetostriction is proportional to the core length.

Hence we have

$$I = K_2 L^2 \ldots\ldots\ldots\ldots \quad (3.3)$$

Where $K_2$ is a constant.

But $L = \left(\frac{W}{K_1}\right)^{\frac{1}{3}}$

Substituting the value of L in equation (3.3) we have

$$I = \frac{K_2}{(K_1)^{\frac{2}{3}}} (W)^{\frac{2}{3}} = K_3 W^{\frac{2}{3}} \ldots\ldots \quad (3.4)$$

Where $K_3 = \frac{K_2}{(K_1)^{\frac{2}{3}}}$

Hence we find that the noise intensity is proportional to the weight of the core raised to the two-thirds power when the induction is constant.

By definition the sound level in decibels is given by:

$$db = 10 \log_{10} \frac{I}{I_o}$$

$$db = 10 \log_{10} \frac{K_3 W^{\frac{2}{3}}}{I_o}$$

or $db = 10 \log_{10} \frac{K_3}{I_o} + \frac{20}{3} \log_{10} (W)$

or $db = K_4 + 20$ $(W)$ (3.5)

Where $K_4$ = constant when the reference intensity $I_o$ is constant

$$= 10 \log_{10} \left( \frac{K_3}{I_o} \right) \quad .$$

Therefore we find that the noise level in decibels is equal to a constant + 6.67 times $\log_{10} W$. From the above relation, it is evident that changing the reference intensity level does not change the slope of the curve but merely the value of $K_4$ is altered.

## (3.2) Effect of operating flux density.

It is well known that the noise of a given transformer increases as the applied voltage is increased.[5] That is, the sound level of a transformer increases as the induction in the iron is increased.

The curve of change in length due to magnetization is obtained from tests on small samples of iron tested one sheet at a time in a device for determining the change in length due to magnetization of steel.

If " S " is the percentage increase in length due to magnetostriction and K is a suitable factor, the sound intensity as for a given transformer steel is given by

$$I = KS^2$$

If the relative proportions of the different harmonics of the sound to each other remain the same with variation in S, then K will be constant. Hence the following derivation will be applicable to all cases in which K is constant under conditions specified above.

If "$S_o$" is the percentage increase in length for reference level of induction $B_o$; then the sound intensity

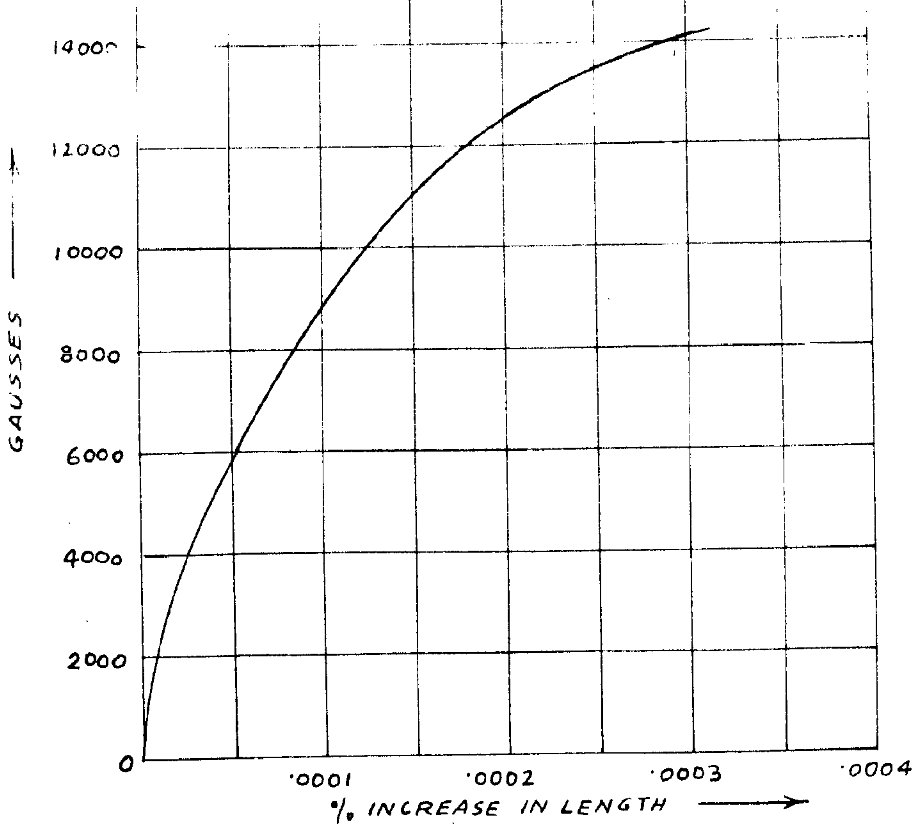
$I_0 = KS_0^2$

Hence the sound level in decibels

$$db = 10 \log_{10} \frac{I}{I_0} = 10 \log_{10} \left(\frac{S}{S_0}\right) = 20 \log_{10} \left(\frac{S}{S_0}\right)$$

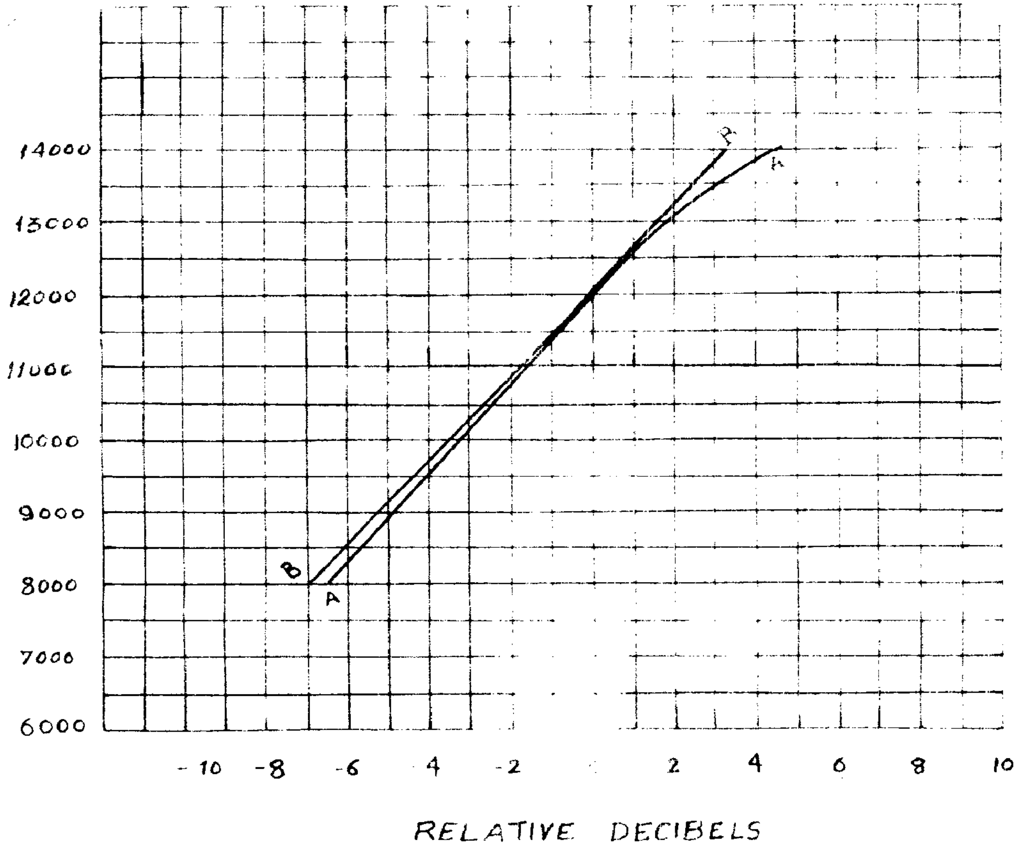
Choosing the reference intensity as 12000 gauss (1.2 $wb/m^2$) $S_0 = 0.000177\%$ and $db = 20 \log_{10} \frac{S}{0.000177}$

By substituting the values of S from Fig.(3.1), the values for plotting curve A of Fig.(3.2) are obtained. Curve A of Fig(3.2) shows the change in sound level in decibels due to the magnetostriction when the maximum induction in the iron-changes.



TYPICAL MAGNETOSTRICTION CURVE OF HIGH-SILICON TRANSFORMER STEEL.

FIG 3.1



CURVE A - FROM MAGNETORISTRICTION TESTS ON STEEL

CURVE B - FROM SOUND LEVEL TESTS ON COMPLETE TRANSFORMER

FIG No 3.2

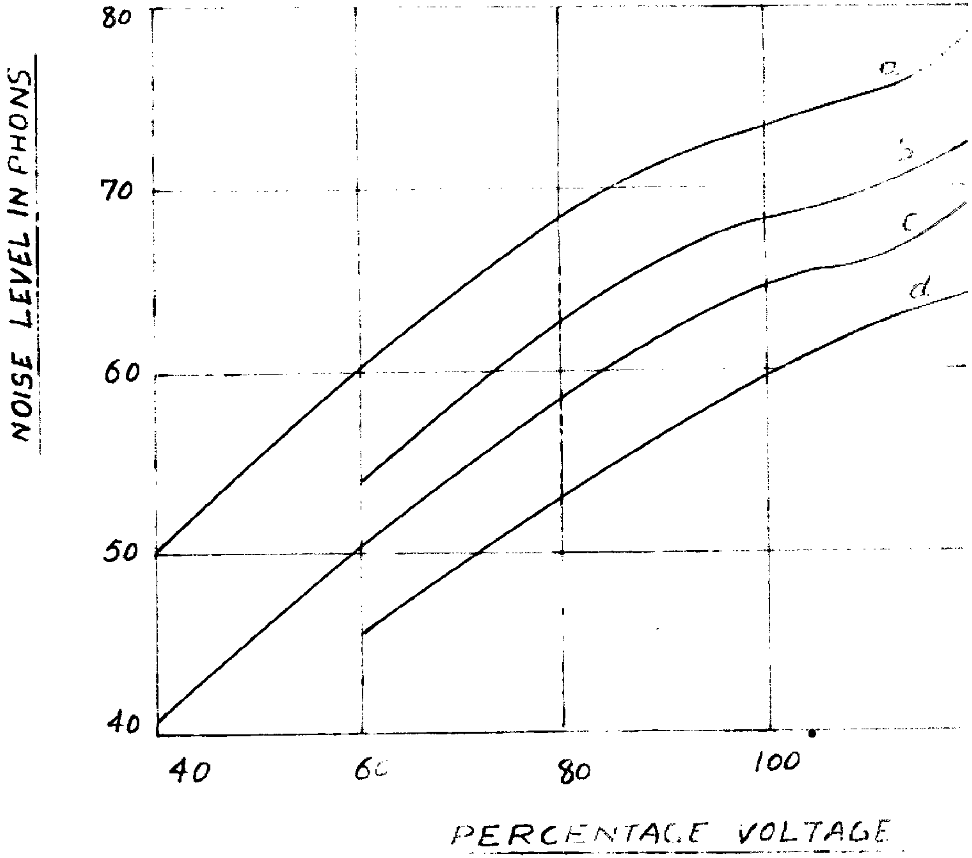


FIG 3.3

Under no load conditions, the variation of sound level with excitation voltage is dependent on the type of core as well as the operating flux density for which the transformer is designed. Given a design with a certain core material the change in sund level per percent change in excitation voltage will vary as the excitation voltage is varried. This is shown in Fig(3.3) curves(a) and (b) are for one type of core using different types of steels. Whereas curves(c) and (d) are for two different types of core for the same steel as for curve (b)

### (3.3) Effect of the magnitude and P.F. of the load.

The present American standard Associations' Audio-Noise standards for transformer specify that noise test be made at 100% excitation voltage with no load on the transformer. In actual operation of the transformer the problem still remains to determine what noise level the transformer will have under load if the no load noise level of the unit is known.

The extent to which the load changes thenoise level is mostly dependent on the way in which the flux in the core is affected by load. Naturally the type of core, the type of windings and the winding arrangement affect the flux in the core on loading. In many cases the noise level of the transformer is determined by the highest fluxdensity in the core, since as much as half the total core steel operates at this fluxdensity. The problem then reduces to one of determining the variation of core flux density with load.

From the basic transformer theory we know that the induced voltage of a winding varies with the magnitude and power-factor of the load. Confining our attention to the core type concentric winding designs it is seen that -

(i) Practically all the leakage flux returns through the core because of the high permeability of the core material as compared with the parallel air paths.

(ii) The addition of the leakage flux with the main flux will be vectorial, the resultant flux in the core will be a function of the load magnitude and power-factor.

(iii) Variation of resultant flux in the core will depend upon which winding is being excited and which winding is connected to the load; that is, whether the inside or outside winding is primary or secondary.

(iv) The resultant flux will depend upon whether the input or output voltage is maintained constant.

It will be seen that the variation ofnoise level with load is closely related to the transformer design, as is the regulation and must be considered as another characteristic dependent on other specified characteristics.

Magnitude of noise level change may be as high as that corresponding to the core flux density being increased by the full load leakage flux. For example if the inside winding is excited and constant output voltage is maintained, a load of 0.1 power-factor lagging be supplied and the leakage reactance of the transformer be 10%, then the change in noise level would be between 2 to 3 decibels. This would be an extreme case and for higher power -factor loads with the inside winding as secondary, no change in noise level would be detected.

# CHAPTER -4

## CHARACTERISTICS OF TRANSFORMER NOISE AND MEASUREMENT OF NOISE.

(4.1) General.

(4.2) Criterion for objectionability of Transformer Noise.

(4.3) Response characteristics of the Human-Ear.

(4.4) Measurement of Noise.

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# CHAPTER-4

## CHARACTERISTICS OF TRANSFORMER NOISE AND MEASUREMENT OF NOISE.

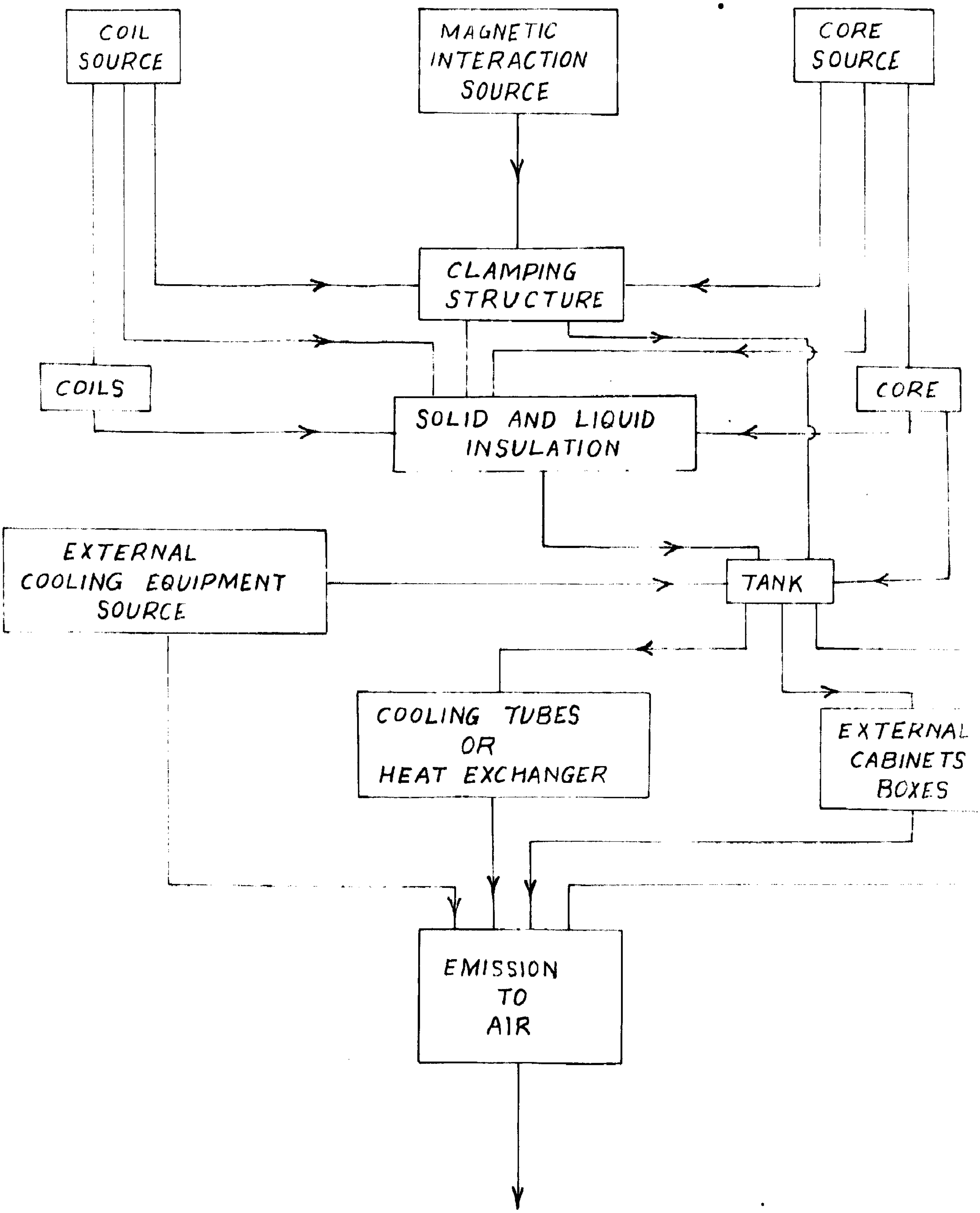
### (4.1) General:-

The transformer noise is due to the audio frequency vibrations, of the core and coils which in the case of dry type units radiate sound waves of corresponding frequency and amplitude. In the case of oil immersed transformers the vibrations are transmitted through the oil to the tank walls before being radiated as sound waves. The ~~oil to the tank walls~~ Vibrations originate mainly in the core and this is due to magnetostriction property of the core material. The fundamental frequency of core vibrations will be double the exciting current frequency, that is 100 c/s in the case of 50 c/s transformer. As discussed in Sec(3.3) the noise of the transformer may vary with load, but tests confirm that the variation is usually small.

It is also possible for a heavy current lead in close proximity of the tank side to set up, audible vibrations. This can be avoided by increasing the spacing between the tank side and the current lead. The amount of noise emitted and its frequency depend on induction density, magnetostriction and the composition of steel and the weight and linear dimensions of the core. In the Fig.4.1 is shown the block diagram of transformer noise circuit.

### (4.2) Criterion for objectionability of transformer Noise.

The problem of determining whether a noise is objectionable is a very complex one. Generally speaking the



BLOCK DIAGRAM OF TRANSFORMER NOISE CIRCUIT loudness of a noise is the best measure of its undesirability. Acoustically there is a basic difference between loudness and nuisance value of noise. Objection to noise of any kind arises bacause the loudness is sufficient to cause interference with the hearing of the desired sounds.

With transformer noise the loudest component rarely exceeds 400 c/s and the components of higher frequencies than 500 c/s are usually unimportant because of the negligibly samll amplitude of vibration.

In general unpitched noises, that is noises which do not have any particular frequency components are not objectionable if from 15 to 20 decibels below the total noise at the location under consideration.[5] Masking of these noises by existing ambient noise may make them unnoticeable pitched noises,(those having a single outstanding frequency) are extremely objectionalbe and it may be necessary for them to be more than 20 decibels below the ambient noise level in order not to be objectionable.

(a) Noises of the higher frequencies are more objectionable than equally loud low frequency noises.

(b) Noise which is varying continually in intensity or frequency is particularly objectionable.

There are no definite ranges of sound levels and frequencies to define an objectionable noise. In general, it can be safely said that the noise emitted from a transformer is objectionable.

## (4.3) Response characteristics of the human-ear.

Before any equipment can be designed for the measurement of noise, we must have some knowledge of the characteristics of the human ear. It is the ear which indicates whether a sound is objectionable or not.[8]

Most important aids in understanding the characteristics of the human ear are given in the specifications of the American standards Association Fig.(4.2) and (4.3) are reproductions from the A.S.A.

In Fig.(4.2) are shown equal loudness contours for pure tones. The ordinates of the curves is the intensity level, a measure of the amount of noise emitted. Decibel is the unit for these curves. An inspection of the contours shows that the response of the ear depends on both intensity level and frequency of the tone. All pure tones having intensity levels and frequencies on the same contour are equally loud. A 300 cycle note having an intensity of 57 decibels is just as loud as a 100 cycle note having an intensity of level of 71 decibels both of them being on 50 phon contour. Both of these tones have a loudness level of 50 phons.

The loudness level of a sound in phons is equal to the intensity level in decibels of equally loud 1000 c/s tone. For these contours various tones were compared with the equally loud 1000 cycle tone used as a reference.

Fig(4.3) shows the loudness as a function of loudness level. The loudness scale is such that the ratio of any two loudness values indicates the relative loudness between two tones. For example a tone having a loudness of 8000 loudness units is twice as loud as one having 4000 loudness units.

The use of these two curves enables us to determine how much louder one noise is than the other. Having determined the intensity level and frequencies of both noises, one can get their loudness levels from Fig(4.2) and their relative loudness from Fig(4.3)

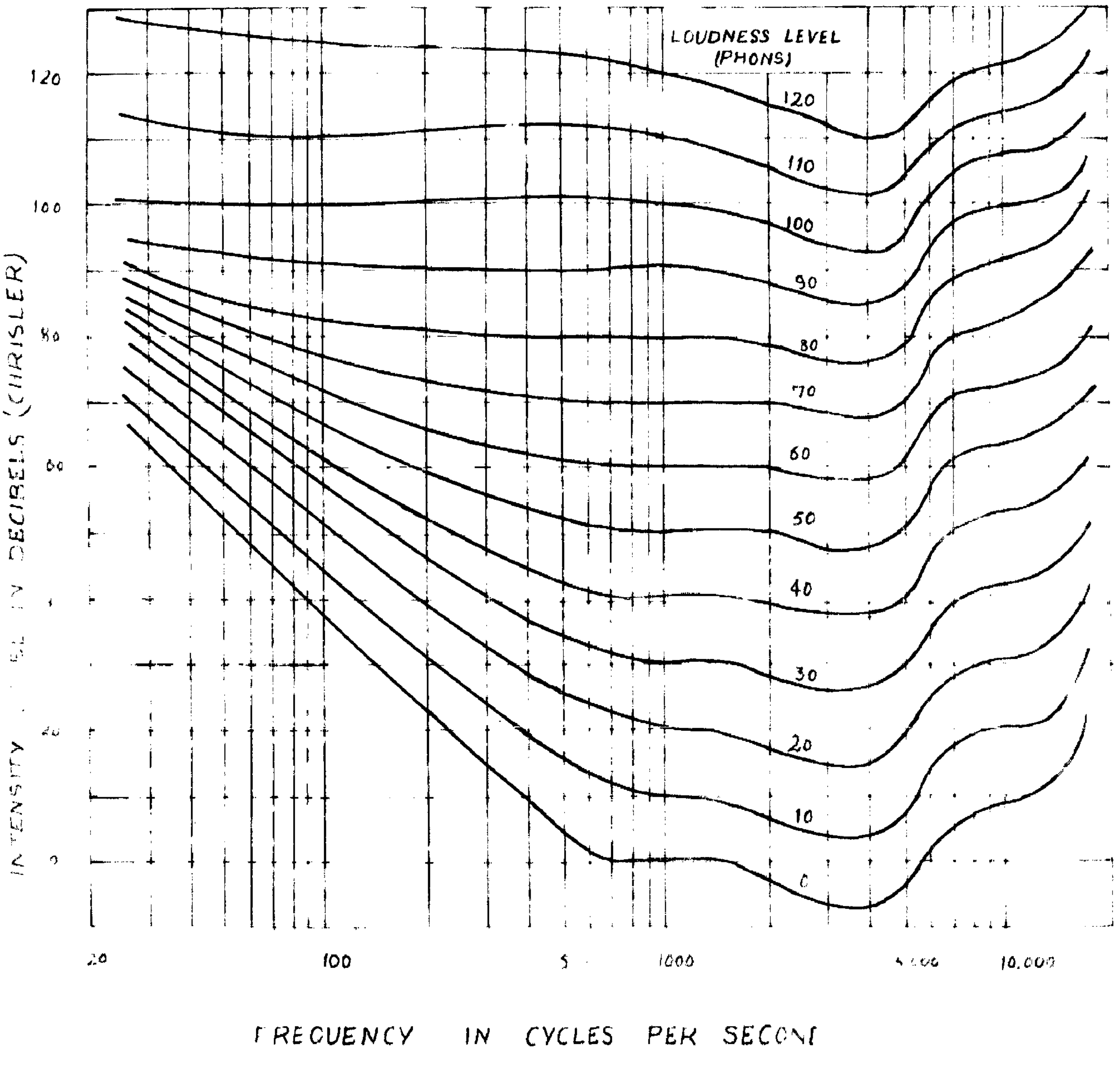
Figs. (4.2) and (4.3) are based on pure tones and are obtained under conditions where the back groudn noise or ambient noise is so small as not to interfere with the pure tones heard by the members who used their ears in the determinations of the curves. The presence of other tones will alter the curves, since the other tones might mask the tone under study.

## (4.4) Measurement of Noise.

A method of predetermining the noise of transformer from its design is the first step in designing a quiet transformer.[5] Satisfactory methods of measuring noise and convenient units of expressing the amount of noise are also required.

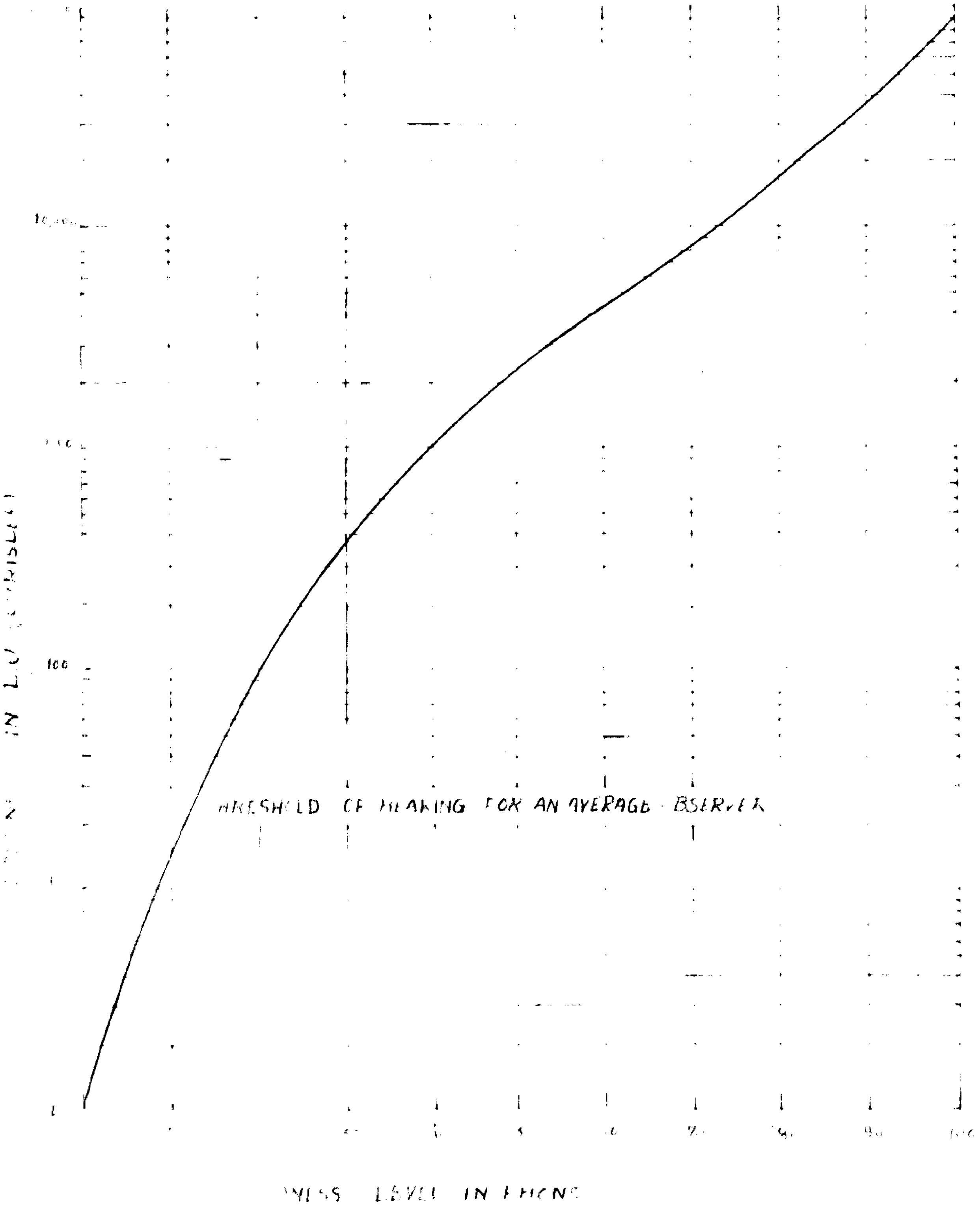
Noise can be expressed in a wide variety of ways. Recurrent sound may be expressed as the sum of its various harmonics each expressed in terms of maximum amplitude. Such an analysis is very useful for sound analysis and is generally used for the purpose of noise reduction measurements. It may be obtained by recording the curve of intensity versus time and analysing it into its harmonics or by more usual mehtod of obtaining each harmonic separately by a harmonic analyser.

To take account of the variation in response of the ear to the various frequencies, the measurements must give



LOUDNESS CONTOURS

Fig. No 4·2



[illegible] LOUDNESS AND LOUDNESS LEVEL

[illegible] 4.3

weighted values of the intensities of various frequencies. Standard curves for such weightings have been established. Using such curves as a base, the overall noise is expressed in decibels.

Really speaking decibel is the measure of the ratio of two amounts of power. Since the human ear responds to an extremely wide range of sound intensities, the decibel offers a convenient means of expressing sound intensities. The ear respondsto intensities from minute values to values $10^{12}$ times as much.

The decibel is so expressed mathematically that the sound intensity increases 10 times for each 10 decibel increase in sound level. Mathematically the sound level in db

$$db = 10 \log_{10} \left(\frac{I}{I_o}\right) \ldots\ldots\ldots\ldots \quad (4.1)$$

Where $I_o$= The reference intensity for the scale in watts/sqcm.

$I$ = The measured intensity in the same units.

The referene level $I_o = 10^{-16}$ watts/sqcm.

This corresponds to a pressure of 0.000204 dynes/sqcm. at a temperature of $20^{o}$c. and a pressure of 760 mm of mercury for plane and spherical waves.

When expressed in terms of pressure, the sound level in decibel

$$db = 20 \log_{10} \left(\frac{P}{P_o}\right) \ldots\ldots\ldots \quad (4.2)$$

Where $P_o$= The reference sound pressure in dynes/sqcm.

and $P$= The measured sound pressure in dynes/sqcm.

..

### (4.4.1) General:-

The objective principle of Noise measurement is generally employed in transformer noise measurements in the United States.[5] The sound level meter operates on this principle of measurement.

An ideal noise measuring instrument is one in which a single meter can indicate the loudness of a noise of any type in terms of primary standards. In order to design this meter, the response of the ear must be known; not only for pure tones but also for any complex sound, such as that emitted by transformer. The evaluation of the response of the ear to complex sounds is still in the experimental stage.

### (4.4.2) Subjective Method.

The subjective method of measuring noise consists of comparing the noise under measurement with an equally loud reference tone either pure or complex. For example the noise under study may be listened with one ear, and the reference tone listened with the other. The reference tone is adjusted until it is equally loud to the noise under study. In this way the relative loudness can be determined for any sound not matter how complex it may be. It is also to be noted that human element would play an important part in the values obtained.

### (4.4.3) Objective method.

The objective principle consists on having a meter with a response based on the equal loudness contours given in Fig.(4.2). When a pure tone of any frequency is being measured, and assuming that the meter is equipped with means to follow all equal loudness contours of the ear, the meter will indicate the equivalent 1000 c/s value. This type of meter equipped with all the equal loudness contours given in Fig (4.2) can be used to obtain loudness of a pure tone. When a complex sound is to be measured the meter sums up the energy in the equivalent 1000 c/s values and indicates this energy sum in a decibel value.

The above principle of energy summation assumes that a given pure tone of the complex sound will be just as loud regardless of the presence of other tones. Measurements show that the ear is not responsive to an equivalent energy summation.

Since in the subjective-method of noise measurement human element is involved, the objective-method is always used in practice for the measurement of transformer noise.

### (4.4.4) Sound Level Method.

The sound level meters are divided into three categories depending upon the principle of measurement on which they operate.

(a) A or 40 db net work.
(b) B or 70 db network.
(c) C or Flat network.

On **A** or 40 db network of the sound level meter, the frequencies lower than 1000 c/s are attenuated with increasing attenuation as the frequency is lowered. Frequencies above 1000 c/s are attenuated with decreasing attenuation.

On C or Flat network , the meter measures the R.M.S. sound pressure at the microphone. The instantaneous sound pressure is the difference between the instantaneous total pressure and the static pressure at the point of measurement. The meter respect to a given reference pressure.

$$\text{db } F = 20 \log_{10} \frac{P}{0.0002} \text{------------} \qquad (4.3)$$

Where P= R.M.S. sound pressure in dynes/sqcm.

On the B or 70 db network, the response characteristic is between the A and C networks.

On all the networks the readings are the same at 1000 c/s. On these networks the meter reads in decibels the r.m.s. of the weighted pressures of the various component frequencies. The reading of a sound level meter is called the sound level for the particular sound.

For complex sounds, the sound level meter will generally read low as regards loudness level. For exceptional cases of complex sounds, covering a wide range of frequencies, it may be possible for the loudness level to be 5 to 15 phons numerically higher than the sound level.

Nevertheless, the sound level meter is the simplest device made for the purpose of measuring sound. Transformer sound levels are being measured on the 40 db weighting network of the sound level meter. The main reason for this is that the sound from the transformer gets attenuated to about 40 db level at the location of greatest interest.

### (4.4.5) Loudness level Method.

This is a method in which the noise is specified by its loudness level. The octave band analyzer is the most practical method of determining the loudness of a broad band noise. The octave band analyzer has eight bands in the audis range.

There is another method of calculating the loudness of complex sounds consisting of a number of dêfinite frequencies. This method is based on the principle that a sound in the presence other sounds does not sound as loud. The method requires the calculation of effective loudness of each component in the presence of all other components. The total loudness is the sum of these component effective loudness. The method requires a frequency analysis of the sound and the calculation of loudness. The method is very labourious and not practical method for determining loudness.

When using the octave band analyzer, the 75-150 c/s and 150-300 c/s bands will each contain only one frequency 120 cps. and 240 cps respectively for 60 c/s transformers. This will result in wide difference between the maximum and minimum readings about the transformer in each of these two bands, because with a single frequency it is quite possible to have complete cancellation at a point. In such cases it may be necessary to resort to logrithmic average.

### (4.4.6) Audibility Method.

-:Audibility in presence of Background Noise:-

The level at which a transformer becomes just audible above the ambient noise can be determined. The ear behaves as though it were an analyzer. Composed of a group of narrow filter bands called the ear-critical bands, Asingle frequency tone is barely audible in a " White Noise " background if the energy of the single frequency tone equals the total energy contained within the ear critical band.

Hence, when a pure tone is sounded in the presence of a random noise, only the noise within such a critical band centered upon the tone serves to mask it. And by definition the width of one of these bands(in db) is equal to the degree in db to which the pure tone must be elevated above the spectrum level of a random noise to make it just audible. The width of these ear-critical bands is tabulated in Table No.(4.1) for those centre frequencies which are of importance to transformer noise.

Table No. (4.1)

Width of ear-critical Bands, two ear listening.

| Cps. | 120 | 240 | 360 | 480 | 600 | 720 | 840 | 960 | 1080 | 1200 |
|---|---|---|---|---|---|---|---|---|---|---|
| db. | 17.5 | 15 | 15.5 | 15.5 | 16 | 16 | 16 | 16 | 16.5 | 17 |

$$db = 10 \log_{10} \frac{\Delta f}{1 \text{ cps.}}$$ width of the ear critical band in cps.

The average width of these bands is about 16 db or 40 cps. Hence each of the single frequency components present in the transformer noise spectrum falls into one of these critical bands. Then, according to the foregoing definition, a single frequency tone is just audible if its sound pressure level is higher by the number of db given in table (4.1) than the spectrum sound level pressure of the ambient noise at the particul frequency of the single tone.

## Determination of the level at the Residence.

This concept can be used to determine when a transformer becomes just audible at a neighbouring residence.

The background noise at the location of the residence must be known. Measurement of background noise in residential areas can be easily made. The curve of ambient noise for a particular locality is plotted as curve A of Fig(4.4)

A transformer noise is audible if any one of its components is above the levels indicated in Fig(4.4) curves B and C. These points are obtained by adding the width of critical bands( in db) to the values of the ambient noise, at the corresponding frequencies. These values are given in the table below.

Table No.(4.2)

Minimum Level of Audible-tones above Background Noise.

Noise of curve B, Fig(4.4)

(Flat Response and 40-db Network of sound level Meter)

| Cps. | 120 | 240 | 360 | 480 | 600 | 720 | 840 | 960 | 1080 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|
| Db Flat. | 49 | 39 | 33.5 | 30 | 29 | 28 | 27.5 | 26 | 26 | 2 |
| Db-40 | 32 | 30 | 27.5 | 26 | 26.5 | 26.5 | 27 | 26 | 26.5 | 2 |

(4.47) Harmonic Index.

Definition:- The harmonic index, hi, is defined as the difference between the noise level measured by the flat response and the noise level measured by the 40 decibel response curve[10].

$$hi = db_{(flat)} - db_{40} \ldots\ldots\ldots\ldots\ldots(4.4)$$

Since the noise level measured by the "flat" response is equal to the physical noise present and the noise level measured by 40 decibel response is equal to the noise

## SPECTRUM LEVEL FOR NOISE IN RESIDENTIAL AREAS AND INTENSITY LEVEL OF SINGLE FREQUENCY TONES JUST AUDIBLE ABOVE BACK GROUND NOISE

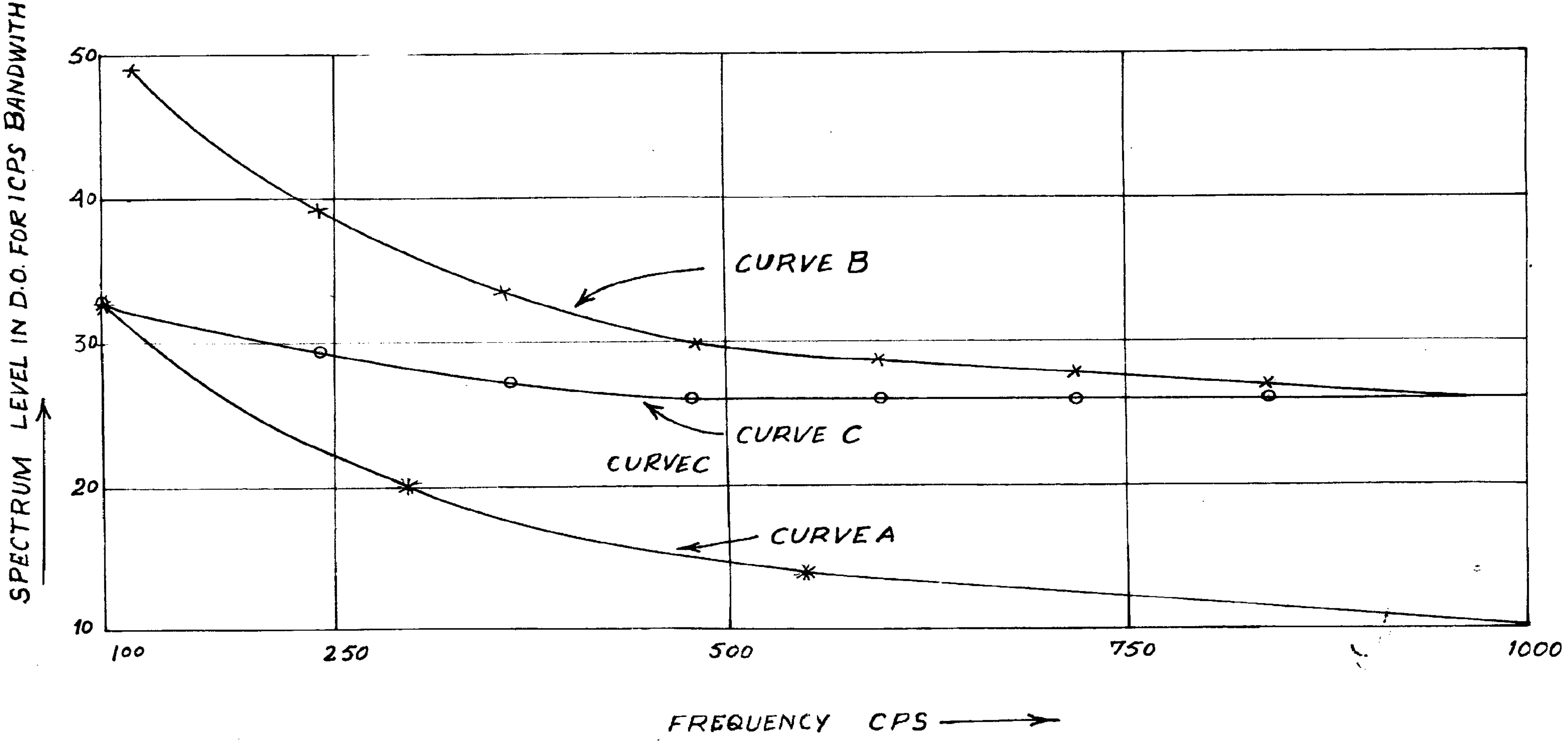


FIG. 4.4

as determined by the ear, the harmomic index is actually a measure of attenuation of the physical noise by the ear.

Attenuation of the ear is a function of the frequency at which the noise is generated. This is best explained by considering two pure tones, one of 120 cycles and one of 480 cycles and both having a physical noise intensity of 55 decibel The sensation experienced by the ear for the 120 cycle pure tone is approximately 39 decibels and the harmonic index for this is

$$hi_{(120\ c/s)} = 55-39 = 16 \text{ db.}$$

With a pure-tone of 480 cycles, the attenuation of the ear is less and the ear would experience a sensation equivalent to 51.5 decibel. The harmonic index for this particular tone is

$$hi_{(480\ c/s)} = 55-51.5 = 3.5 \text{ db}$$

Obviously the energy, as detected by the ear, equivalent to a physical noise level of 55 db is less objectionalbe when generated at 120 cycles than it would be at 480 cycles.

<u>Application:-</u>

The above principle is very useful in the analysis of transformer noise. This principle can be used to give an indication of the quality of a complex sound, such as generated in a transformer. Noise having a high harmonic index indicates a predominance of low harmonics, while noise having a low harmonic index indicates a predominance of high harmonics.

Extreme variations in harmonic index as exhibited for pure tones, donot take place in a transformer because of the complex nature of the noise;however thes significant factor in the application of the harmonic index is the manner in which it changes.

## Transformer Noise level determination by the application of harmonic Index.

For a given size transformer core, the sound energy will be a function of the harmonic content and the maximum amplitude of the magnetostriction in the steel used. Using the amplitude of each frequency obtained from a harmonic a analysis of the magnetostriction versus time characteristic, it is possible to determine the average harmonic index and the physical noise level for the core.

If the core has been designed to avoid resonance, the harmonic index and the physical noise level of the transformer should equal to the calculated values. Factors such as damping pressure, core impregnation, size and influence the noise level of the core. Here the harmonic index may be used to study the effects of each of these factors.

If the physical noise level is increased above the calculated value, the range of resonant frequencies can be determined. Thus it is possible to determine what structural changes can be made in the core assembly for maximum noise attenuation.

When the transformer is tanked most of the vibrations are transmitted from the core and coil assembly through the oil, The magnitude of these vibrations is decreased by the damping force of the oil. Other vibrations are transmitted directly to the tank wall by the structural members which support the core and coil in the tank with very little damping.

By comparing both the physical noise level and the harmonic index before and after tanking, the extent of resonance can be determined. If the harmonic index has decreased it indicates that high harmonic resonance may exist; and the change in physical noise level will show to what extent it exists.

Table No. (4.3) has been prepared to show the several different changes that can take place and their most probable cause.

Table No.(4.3)

Variation of Physical Noise level and Harmonic Index between Untanked transformer and tanked Transformer.

| | Variation of. | | Causes of Variation. | | |
|---|---|---|---|---|---|
| Item No. | Physical Noise | Harmonic Index. | High Frequency Resonance. | Low frequency Resonance | Poor Dampi |
| 1. | + | + | --- | X X | --- |
| 2. | + | 0 | X | X | X X |
| 3. | + | - | XX | --- | --- |
| 4. | 0 | + | --- | X | --- |
| 5. | 0 | 0 | --- | --- | X |
| 6. | 0 | - | X | --- | --- |
| 7. | - | + | --- | X | --- |
| 8. | - | 0 | --- | --- | --- |
| 9. | - | - | X | --- | --- |

\+ Increase - Decrease 0 No change
X Probable cause X X Most probable cause.

Item 8 represents the ideal case in which physical noise level is decreased, while the harmonic index remains practically constant.

After resonance has been eliminated and if the harmonic index remains practically constant before & after tanking, then the change in physical noise level is an indication of the damping properties of the oil and the core and coil assembly supports etc.

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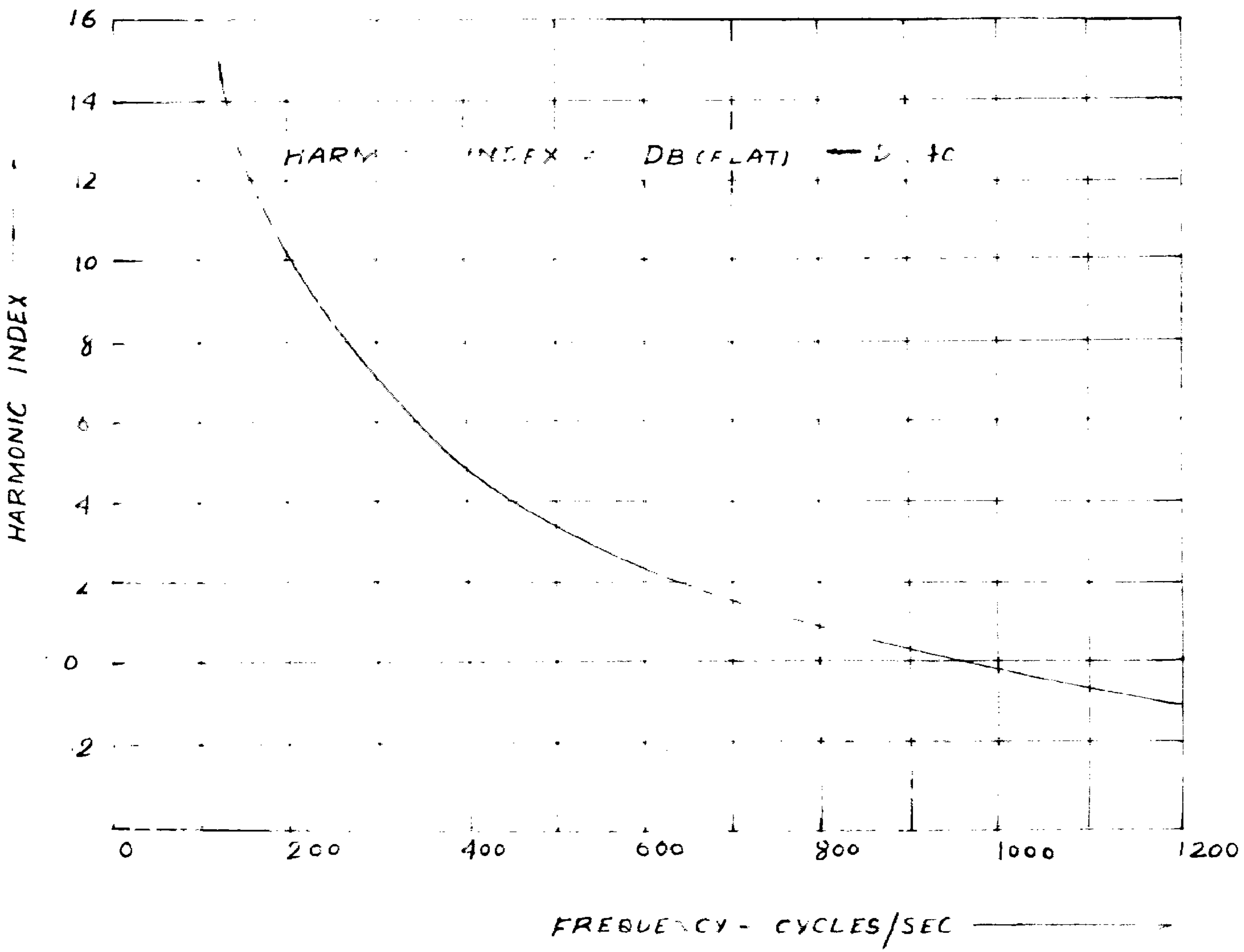
HARMONIC INDEX OF NOISE COMPONENTS FOR PURE TONES



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# CHAPTER-5

## LIMITATION AND REDUCTION OF TRANSFORMER NOISE.

(5.1) Internal Methods.

- (5.1.1.) Choice of core Material.
- (5.1.2.) Core construction.
- (5.1.3.) Reduction of flux density.
- (5.1.4.) Interception of vibrations transmitted from core to tank.
- (5.1.5.) Tank construction.

(5.2) External Methods.

- (5.2.1.) Reduction of Noise with distance.
- (5.2.2.) Use of vibration-isolators.
- (5.2.3.) Use of Barriers.
- (5.2.4.) Use of enclosures.
    - (5.2.4.1) Essential requirements of an enclosure.
    - (5.2.4.2) Acoustical aspects.
    - (5.2.4.3) Impairing effect of openings in an enclosu
    - (5.2.4.4) Build-up effect.
    - (5.2.4.5) Preassembled enclosures.

(5.2.5) Sound Cancellation Method.

(5.2.6) Penetration of noise into buildings.

(5.2.7) Psychological-Factors.

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# CHAPTER -5

## LIMITATION AND REDUCTION OF TRANSFORMER NOISE.

The methods of noise reduction in transformers can be divided in to two categories:

(a) Internal Methods:- Methods by which noise is limited by the design of the transformer or by incorporating noise suppressing devices inside the transformer or devices which form part of the transformer as a unit.

(b) External Methods:- Those in which the noise is limited or reduced by devices external to and separate from the transformer.

### (5.1) Internal Methods.

(5.1.1) CHOICE OF CORE MATERIAL:- This is a direct and fundamental method of limiting transformer noise 5,9,27. If a magnetic material of low magnetostriction effect is chosen, the noise level of the transformer will be low. 6 to 6.5% silicon-steel has a very low magnetostriction effect, hence the core vibrat in a transformer whose core is made of this type of steel will be negligible. However, theuse of this type of steel is impracticable since it is very brittle.

Estimation of the noise levels for different types of steels involves some what lengthy calculations. Determining the magnetostriction curves for different types of steel having ring shaped cores is quite simple. From these curves the relative amplitudes of harmonics produced can be analyzed when the core is excited at a given flux density and frequency.

Table No.(5.1) *

Magnetostriction-Effect with different Grades of sheet-steel.

| Grade of steel % silicon | $\delta l/l \times 10^6$ | |
|---|---|---|
| | $B_{max}$= 10000 gauss. = (1.0 $wb/m^2$) | $B_{max}$= 13000 gauss. = (1.3 $wb/m^2$) |
| 0.2 | 0.9 | 1.4 |
| 1.5 | 0.75 | 2.5 |
| 4.0(transformer steel) | 1.3 | 2.8 |

Some noise tests on these three core materials using ring cores gave the following results.[27] The noise produced is entirely due to magnetostriction.

Table No.(5.2) *

**Effect of Grade of Steel on Noise-Levels.**

| Grade of steel % silicon | Noise level in Phons at a distance of 1 meter. |
|---|---|
| 0.2 | 39 |
| 1.5 | 36 |
| 4.0 | 36 |

### (5.1.2) Core Construction.

Power transformers are mostly of the core type. From the view point of reducing the noise, it has been established by experience that [5, 9, 27]

... .. .. .. .. ... .. .. .....

* Reference 27.

(i)The core must be carefully interleaved.

(ii)The clamping pressure should be adequately distributed.

The use of exceptionally large clamping pressures does not reduce the noise.[27] This is to be expected, since the noise is due to magnetostriction; the legs and the yoke of the core will extend as a whole with each alteration of the flux. Hence lateral pressure will not appreciably affect the extension. This theore ical pre-position is confirmed by results obtained on a transformer by B.G. Churcher & A.J.King.

TABLE NO. 5.3 *

Effect of Tightening Core-Bolts on Noise

Transformer specifications      100 KVA, 3 phase,core ty

Bmax = 10500 gauss (1.05 wb/$m^2$)

f = 50 c/s

| Clamping condition | Phones |
|---|---|
| 1. Core bolts thumb tight | 51 |
| 2. Core well clamped by 3 turns of the nuts. | 52 |
| 3. Core very tightly clamped | 50 |

TABLE NO. 5.4 *

Effect of consolidating the core with a strongly adhesive materi

| Core | Condition | Noise level in phones |
|---|---|---|
| 10 KVA,1 phase core | Before oil Immersion | 48 |
| | After " " | 37 |
| | Cemented & " " | 26 |
| 60 KVA,3-phase core | After oil Immersion | 65 |
| | Cemented & oil immersed. .... .... | 64 |

* Reference 27.

From the above table we find that there is no appreciabl reduction in noise for large size 3-phase transformer on cementing of the core. The interleaving of the core andproper joints reduce the noise and results in low noise level transformer. Increase in clamping pressure has no effect on noise reduction.

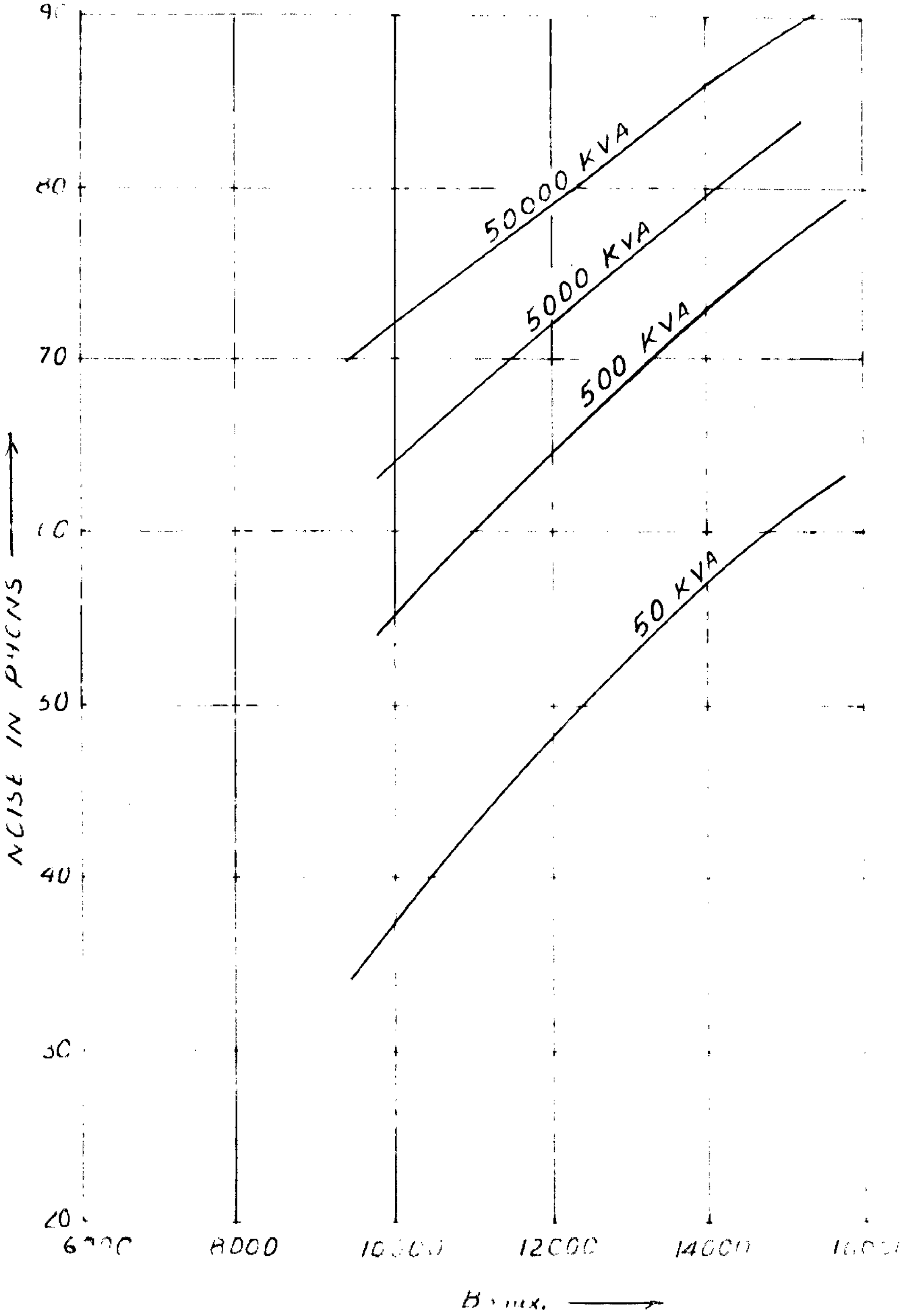
### (5.1.3)Reduction of operating flux density.

Some times it is suggested that the transformer be designed for a flux density lower than what would normally be used. This simple solution to reduce the noise-level, is dependent on the circumstances, particularly the size of the unit and the level to which it is desired to reduce the noise.

Fig. 5.1 consists of a family of curves giving approximate noise levels for transformers of different ratings and at different flux densities. The noise levels are in no way definite and apply only to particular conditions. They are quite sufficient for the purpose of comparison. For these transformers the normal flux density is 13000 gauss(1.3 $wb/m^2$). By making suitable assumptions we can always assess the effect of reduction in flux-density.

Assuming a 10% reduction in flux density , and also that the core section, winding depth and the conductor size remains unaltered. We find that in order to regain the lost voltage, the number of turns and hence the length of the winding must be increased by 10%. This means that the length of the leg is increased by 10%. If the iron and copper losses were to be equal, then this change in flux density will create a large disproportion in the two losses.

Secondly an increase in dimensions of the transformer would give rise to a small increase in noise level to overtake



RELATION BETWEEN EQUIVALENT LOUDNESS AND FLUX DENSITY FOR [illegible] TRANSFORMERS be needed.

Thirdly, other factors such as leakage reactance etc. may be affected by the change in dimensions.

Fourthly, a reduction of 10% in the flux density would involve an increase in active material of the same order with a corresponding increase in tank Size and the quantity of oil.

Under these circumstances, the increased cost of the transformer for a given reduction in noise level must be compared with the cost involved for the same reduction in noise level by other methods. By comparison we can find which method is cheaper.

We therefore, find that it is technically possible to effect a substantial reduction in noise level by reducing the flux density, but for specially large transformer this method is quite impracticable due to economic considerations.

## (5.14) Interception of Vibrations transmitted from core to tank.

In a normal transformer transmission of sound energy takes place by two paths.

(i) By direct contact of the core with the bottom of the tank and thence to the sides.

(ii) By direct transmission through the oil or air(in dry type transformer)

Some vibrations may be transmitted through leads from the core to tank, but unless the leads are unusually stiff, the amount of vibration transmitted in this ways is quite negligible.

The effect of noise reduction by mounting the core on resilient supports having a large attenuation constant is shown in table No.(5.5) [27].

## Table No. (5.5)*

## Effect of mounting oil immersed core on resilient supports

## 60 KVA, 3 phase Transformer 50 c/s

(Flux density remaining constant)

| Condition | Phons |
|---|---|
| Without resilient supports | 56 |
| With "" | 52 |

The use of resilient supports alone does not reduce the noise to substantial amount; but the supports are of great importance, if a considerable amount of attention is to be introduced in the oil path.

Experiments were made by B.G.Churcher and A.J.King in England in 1939-40 by using an absorber which readily yields to pressure pulsations in the oild. The arrangement used is shown in Fig. 5.2 and the results of noise level with absorber in position and without absorber in position are shown graphically in Fig. 5.3.

From the above curves we conclude that reductions in transformer noise of the order of 25 to 30 phons are possible by the use of absorbers in the tank at normal working flux densities. This reduction is sufficient to remove the cause of complaint.

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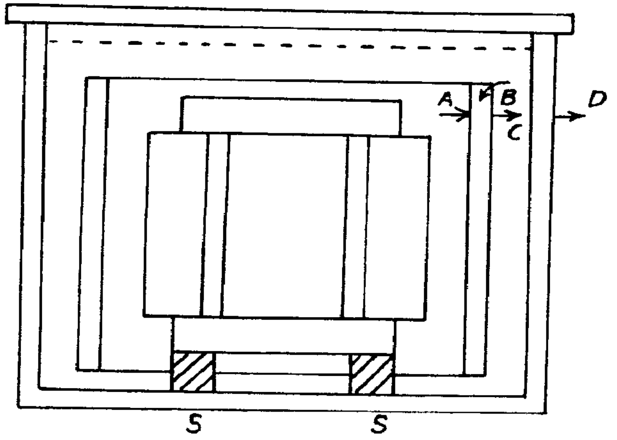
* Reference 27.



A = LARGE LOW PRESSURE PULSATIONS IN OIL (INCOMPRESSIBLE) DUE TO CORE VIBRATIONS

B = ABSORBER YIELDING READILY TO PRESSURE PULSATIONS

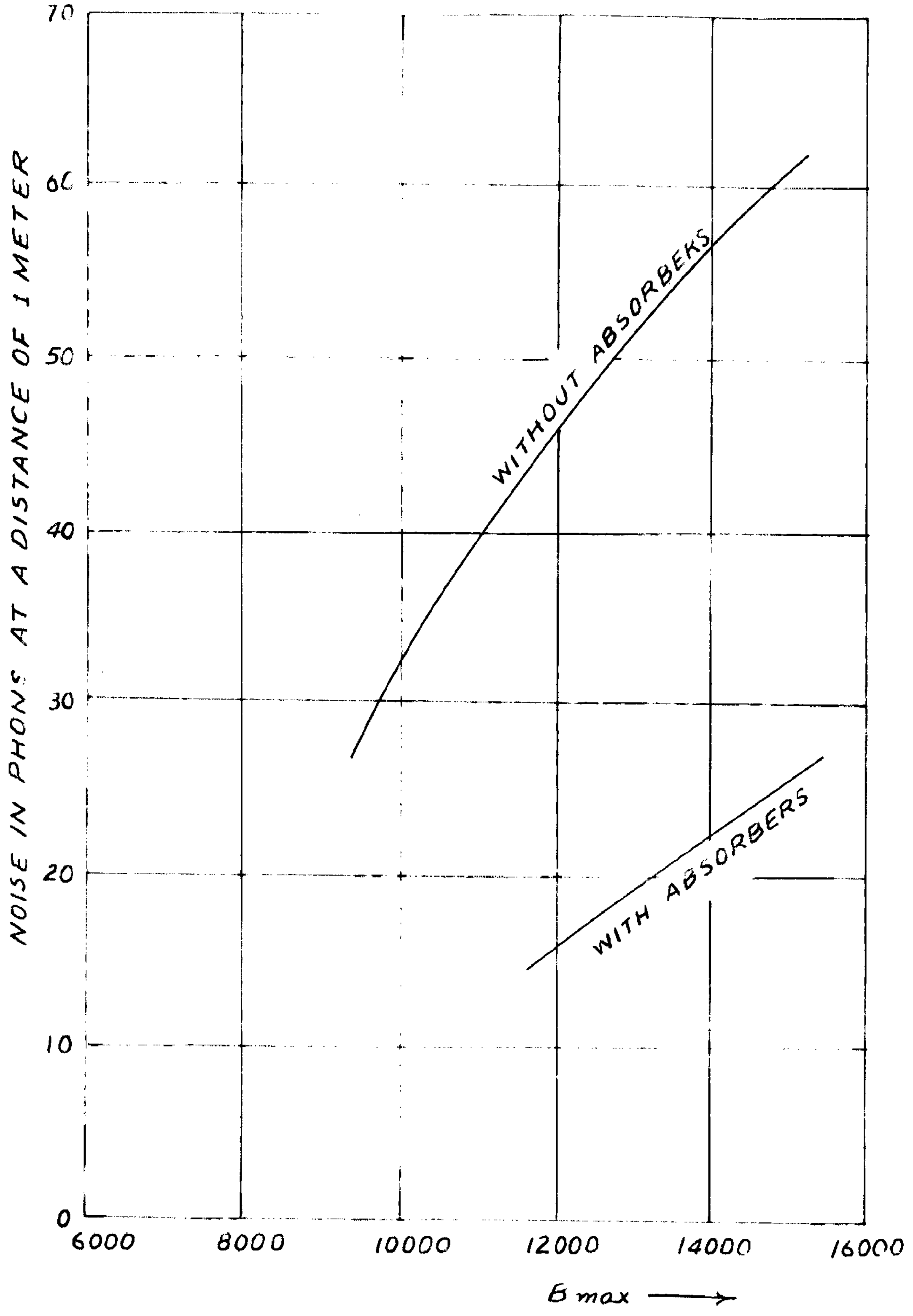
C = REDUCED PRESSURE PULSATIONS, TRANSMITTED BY ABSORBERS TO OUTER LAYER OF OIL TANK SIDE

D = REDUCED SOUND PRESSURE. RADIATED BY TANK SIDE

S = RESILIENT SUPPORTS

DIGRAMATIC ILLUSTRATION OF RESILIENT ABSORBERS AND MOUNTING IN A 3 $\phi$ TRANSFORMER

FIG. 5.2



REDUCTION OF NOISE BY THE USE OF VIBRATION ABSORBERS FOR 60 KVA, 3 PHASE 50 C/s.

FIG. 5.3

## (5.1.5) Tank Construction.

This section deals with the constructional modifications and the attachments which may be incorporated in the tanks of oil immersed transformers for the purpose of noise reduction.

Generally speaking a normal transformer tank has many modes of vibration, the corresponding natural frequencies extend over a wide range of audible frequencies. As we have seen the impressed vibratory frequencies for a transformer core extend from 100 to 1400 c/s in steps of 100 cycles for 50 cycle excited transformer. Estimation of the natural frequencies of a tank is a very complex and uncertain matter.

The addition of mass to the walls of the tank or stiffening the tank may simply shift the natural frequencies of vibration, and thereby either increase or decrease the contribution of particular components without greatly affecting the total noise.

It is possible to reduce the radiation of noise from transformer tanks by providing false sides resiliently mounted on the tank[27]. In this case it will be necessary to effect cooling by a separate radiator piped to the tank or by some other means. To obtain a sufficient reduction the following two conditions should be fulfilled.

(a) The amplitude of vibration of the false sides should be reduced to the order of 1/10th that of normal tank sides. This requires very effective resilient mounting of the false sides.

(b) The tank should be completely covered by the false sides so that the acoustic energy emitted is reduced to 1/100 of that emitted without false sides.

The last point requires a serious consideration due to the following nature of sound waves.

" The propagation of sound waves of a few hundred cycles per second does not follow the usual optical laws, i.e. such low frequency sound waves are not directional but spread out readily in all directions." Hence sound will not be emitted from the top of a tank purely vertically but would be heard even if none were emitted from sides.

"Forrest" in his investigation with false sides had reported a reduction of 10 phons for a 20,000 KVA unit.

Useful noise reduction can be obtained by "lagging thetransformer tank with sound absorbing material."

## (5.2) External Methods.

This section deals with the methods by which the effective loudness of the noise reaching the hearer can be controlled. In practice some attenuation is often provided by the circumstances which are due to other considerations than noise. It is useful to utilize such attenuation supplementing it wherever necessary be attenuation obtained by artificial means.

### (5.2.1) Reduction of noise with distance.

The distance between the source and the hearer itself generally makes some contribution towards the limitations of transformer noise. The rate at which the effective loudness falls with increase in distance depemds on a number of factors.

### Calculation of sound intensity for a point source.

If a point source emitting a single tone of 1000 c/s is imagined, then spherical radiations will result. Neglecting the energy absorption in the atmosphere, which is negligible for this frequency andmoderate distances, the total energy radiated will be constant at all radii. Hence the energy per unit area varies inversely as the square of the radius and the acoustic pressure inversely as the first power of radius.

Hence,

if the intensity level at radius R $= 20 \log_{10} \dfrac{P}{0.0002}$

then the intensity level at radius 2 R $= 20 \log_{10} \dfrac{P}{0.0004}$

and there is a difference of 6 db between the intensity level at the two points.

Since at 1000 c/s the intensity level is equal to the E.L.(Effective loudness), the effective loudness at a radius 2R will be 6 phons less than at R. In other words, each time the distance from the source is doubled, the E.L. falls by 6 phons until the threshold intensity level corresponding to a pressure of 0.0002 dynes/cm$^2$ is reached after which the sound becomes inaudible.

## Evaluation of sound level for large distances considering the transformer as a spherical source.

One of the factors entering into the resultant sound level at large distances, which is normally over looked is the physical size of the transformer. Although the actual sound levels in the vicinity of a transformer are complex, it is possible to draw some general conclusions by considering the transformer as a special source[21].

$I_t$ = Sound intensity measured one foot from the transformer

$I_d$ = Sound intensity in decibel at a distance "d"

R = Radius of theequivalent sphere(Representing transformer)

v = Velocity amplitude of pulsation.

$\lambda$ = Wave length for frequency 'f' c/s

$\rho$ = Density of air

c = Velocity of sound in air.

For spherical waves

$$I_d = \frac{\rho c v^2}{2} \frac{R^2}{d^2} \left[ \frac{\left(\frac{2\pi R}{\lambda}\right)^2}{1 + \left(\frac{2\pi R}{\lambda}\right)^2} \right] \quad \text{.........} \quad (5.1)$$

In order to express $I_d$ in terms of $I_t$ we assume the sound wave to be spherical.

$$I_t = \frac{\rho c v^2}{R}\left(\frac{R}{R_1}\right)^2\left[\frac{\left(\frac{2\pi R}{\lambda}\right)^2}{1+\left(\frac{2\pi R}{\lambda}\right)^2}\right] \quad \text{------} \quad (5\cdot 2)$$

Where $R_1 = (R + 1)$ ft.

Substituting equation (5.2) in (5.1) we get

$$I_d = \left(\frac{R_1}{d}\right)^2 \times I_t \quad \text{---} \quad \text{----} \quad \text{---} \quad \text{---} \quad \text{---}(5.3)$$

If the wave at one foot distance is assumed as a plane wave then,

$$I_t = \frac{\rho c v^2}{2} \quad \text{-----} \quad \text{----} \quad \text{----} \quad \text{----}(5.4)$$

Now the equation (5.1) may be written as

$$I_d = \frac{R^2}{d^2}\left[\frac{\left(\frac{2\pi R}{\lambda}\right)^2}{1+\left(\frac{2\pi R}{\lambda}\right)^2}\right] I_t \qquad (5.5)$$

For frequencies whose wave lengths in air are small compared with $2\pi R$ both equation(5.5) and (5.3) indicate a variation in intensity approximately as the square of the radius.

For wave lengths that are of the same order of magnitude as $2\pi R$ equation(5.5) indicates a higher rate of variation which approaches 4th power of the radius for wave lengths large compared with $2\pi R$.

At a frequency of 100 c/s the wave length in air is approximately 12 ft. so that if equation(5.5) is valid it may be possible to observe a 4th power variation for small transformers. For large power transformers the rate of variation will be close the second power of linear dimension.

Based on the above reasoning, we would expect the relative size of the two transformers to produce at a remote point, a difference in level given by

$$\text{Decibel diff.} = 10 \log_{10} \left(\frac{L_1}{L_2}\right)^{n}$$

where $L_1 / L_2$ = the ratio of linear dimensions of the two transformers.

$n$ = An index, may vary from 2 to 4

If for example one transformer has twice the linear dimension of another, then even though they have indentical levels measured at 1 foot, the small transformer may still be 6 to 12 decibels lower than the larger transformer say at 200 ft. distance.

Because of the simiplifying assumptions made in the derivation, the exact effect of size on the resultant level must be established by field tests. The above analysis is only for the purpose of showing the influence of transformer size.

From field tests it has been found that there is a reduction of 4.5 decibels for every doubling of distance from the source [21,27]. The average of 4.5 is quite reliable for preliminary estimation.

### (5.2.2) Use of Vibration Isolators

It has been observed that when a large transformer is located within 50 ft. of dwellings, the hum level in these residences is generally caused by the combined effects of

(i)Air-borne sound

(ii)Ground transmitted vibrations

Normally it is necessary to reduce both the ground-borne and air-borne sound to minimise the hum level inside the nearby house. The transformer must be isolated from its enclosing structure to present the ground or structure borne vibrations fro exciting the walls and thereby reducing the acoustic effectiveness of the enclosure if any.

To obtain effective vibration isolation it is first of all necessary to satisfy the following conditions[21].

(a) The ratio of the exciting frequency to the natural frequency of the system must be greater than 3.

(b) The stiffness of the isolator must be very much lower than that of the supporting structure.

(c) The damping should be kept to a minimum.

The ground is a complex medium and very little is known of how it behaves in a vibrating system. It may be considered as a complicated spring - mass system, or in electrical terms as a non uniformly distributed inductance and capacitance having some resultant impedence. The isolator may be considered as an impedence, arranged to provide a mis-match between the source (transformer) and the foundation.

To illustrate the importance of the elasticity of the foundation, the ground may be greatly simplified and represented as a spring of constant K. The transformer may be represented by a mass M and the spring constant for the isolator $K_1$ as shown in Fig. 5.4

According to the standard vibration theory

$$\text{TR(Transmissibility)} = \frac{\text{Transmitted Force}}{\text{Disturbing force}} = \frac{1}{\left(\frac{\omega}{\omega_n}\right)^2 - 1} \qquad (5.6)$$

Where

$w$ = $2\pi$X Exciting frequency

$w_n$ = $2\pi$X Natural frequency of the system.

$w_n$ = $\sqrt{\frac{K}{M}}$

K = Spring constant

M = Mass

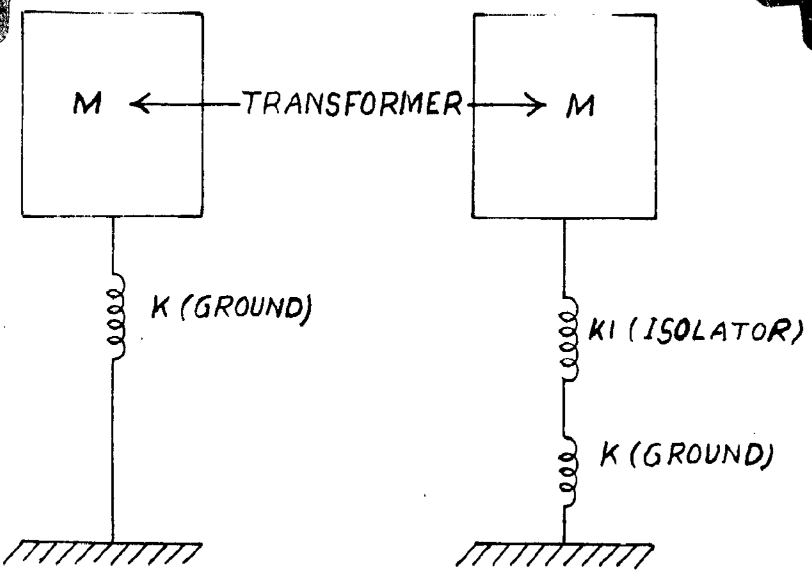


FIG. No. 5.4

If the natural frequency of the transformer and its foundation is say 20 c/s. Then fundamental exciting frequency being 120 c/s.

TR = 0.0286

Interposing a vibration isolator with a spring constant $K_1$ comparable with K. Then the spring constant of the system will be

$$K_2 = \frac{K\,K_1}{K+K_1} = \left(\frac{K}{2}\right) \ldots\ldots\ldots \qquad (5.7)$$

And consequently

Now the resultant TR= 0.014

$$\text{Decibel reduction} = 20 \log_{10} \frac{\text{Original (TR)}}{\text{New (TR)}} \ldots\ldots\ldots (5.8)$$

$$= 6 \text{ db.}$$

From the above relation of Equation (5.8) we find that decibel reduction will be low if the spring contant of the isolator is greater than that of the foundation. Hence proper choice of isolator material is very essential.

### (5.2.3.) Use of Barriers.

Another method of obtaining external attenuation is to use a barrier(i.e. a brick wall) between the transformer and the location at which it is desired to limit the noise. Unless the barrier is of infinite height and width the attenuation that it would afford will never approach the value that it would produce if it formed one of the sides of a complete enclosure. At the frequencies of transformer noise there is a considerable amount of defraction of sound round a barrier of finite dimensions. The attenuation obtainable by this method depends on a number of factors, the most important being the following:

(i) The effective height of the barrier above a line joining the source to the hearer.

(ii) The nearness of the source and hearer to the barrier.

Taking the case of a transformer of mean height 5 ft, situated 24ft. from a two storey residence. The attenuation with distance without a barrier would be 15db. The table No. 5.6 below shows the estimated effect of interposing barriers of 10ft and 15ft height at a distance of 4ft from the transformer.[27] The various values are calculated for the upper and lower floors of the house and for 100 and 300 c/s, the frequencies with which we are most concerned .

Table No.(5.6)

Attenuation obtained from different height barriers.

| Height of the Barrier | Floor | Frequency c/s | Attenuation in db |
|---|---|---|---|
| 10 ft. | Ground | 100 | 10 |
| 10 ft. | Ground | 300 | 5 |
| 10 ft. | Upper | 100 | 7 |
| 10 ft. | Upper | 300 | 10.5 |
| 15 ft. | Ground | 100 | 14 |
| 15 ft. | Ground | 300 | 18.5 |
| 15 ft. | Upper | 100 | 11.5 |
| 15 ft. | Upper | 300 | 16.0 |

The attenuation values shown in the table (5.6) are additional to that due to distance; and may be just sufficient to bring the effective loudness below 40 phons.

From the table it can be noted that:

(a) The attenuation to the upper floors is less than that due to the lower floor

(b) That 50 % increase in the height of the barrier increases the attenuation only by 4 db.

## (5.2.4) Use of Enclosures.

The need for the enclosure of a transformer for the purpose of noise limitation is in general confined to outdoor type of transformers. It would seem that the only case where enclosure for an indoor type of transformer would be needed is where quietness is required in the room in which the transformer is located. This is an unusual requirement. There are two types of enclosures.

(i) Completely enclosing the transformers by a roofed building and sometimes with enclosures without a roof.

(ii) Pre-assembled enclosures. These are very useful for large transformers and very popular in U.S.A.

## (5.2.4.1) Essential requirements of an enclosure:

(a) The enclosure must be weather proof.

(b) The oil gauge and the temperature indicator must be visible.

(c) Emptying valve and the filter valves must be accessible.

(d) Lowest possible " Build-up Effect"

(e) It should not impair the cooling of the transformer.

## (5.2.4.2) Acoustical Aspects.

Now we can consider some accoustical aspects of the enclosure. Normally, the attenuation is measured by inserting a partition of the material into an opening between two rooms, entirely isolated from one another. A source of sound of the desired frequency is operated in one of the rooms. The acoustic pressure on either side of the partition is measured by calibrated microphones and the attenuation in decibel is given by:

$$\text{Attenuation in db} = 20 \log_{10} \left(\frac{P1}{P}\right)$$

The most important conclusions arrived at from such investigations[27] are

(i) The attenuation is a function of the mass/ unit area.

(ii) The attenuation is proportional to the frequency, i.e. if the frequency is doubled; the attenuation will be increased by 6db.

Thus at 200 or 300 c/s, the frequencies with which we are most concerned, the attenuation varies from 12db for partition weighing 0.5 lb/sq ft. to approximately 49db for one weighing 50 bls/sq.ft.[27] This is true for materials such as building-board, plate glass, wood and brickwork.

From the above theory we will expect that if attenuation varies only as inertia, (Mass/unitarea). The attenuation of a partition for doubling the thickness would be increased by 6db. Experiments also show that this figure holds good approximately. Thus if a $4\frac{1}{2}$" brick wall has an attenuation of 47db at 200 or 300 c/s a 9" wall will have a value approximately 53 db.

Instead of doubling the wall thickness, if we use two independent walls of the same thickness or a double wall, the attenuations will be additive if the following conditions are fulfilled.

(a) There shall be negligible mechanical coupling between the two walls by ties or other solid connection.

(b) The air space be large to make the air coupling negligble.

Thus the attenuations of the order of 100 db are theoretically possible. Although such high values of attenuati are rarely required in practice, but the other sound leakage paths will normally reduce the effect of double walls.

(5.2.4.3) <u>Impairing effect of openings in an enclosure</u>:

This can be illustrated by an example. Consider a partition giving an attenuation of 40 db. The energy density on incident side is 10000 times that on the emergent side. If now holes are made in the partition, having a total area equivalent to 1% of the area of the partition. Then the average energy density on the emergent side will be increased 100 times. Thus the attenuation will be reduced from 40 db to 20 db. This effect has a very important bearing on the enclosures of naturally cooled transformers.

(5.2.4.4) <u>Build-up Effect:</u>

Another acoustical effect which arises when a transformer is placed in an enclosure is what may be termed as "Build-up Effect". The absorption coefficients of brick, concrete and metal surfaces are very low, of the order of few percent. Thus with the usual brick or concrete walls 97% or more of the sound energy radiated by the transformer tank is reflected from the enclosure surfaces, and multiple reflections take place. The sound energy is conserved rather than dissipated, so that the average intensity level at a given short distance from the transformer is greater with enclosure present than without it. This "Build-up Effect" which can be expressed in decibels off sets the attenuation effected by the enclosure. This is illustrated diagrammatically in Fig.(5.5)

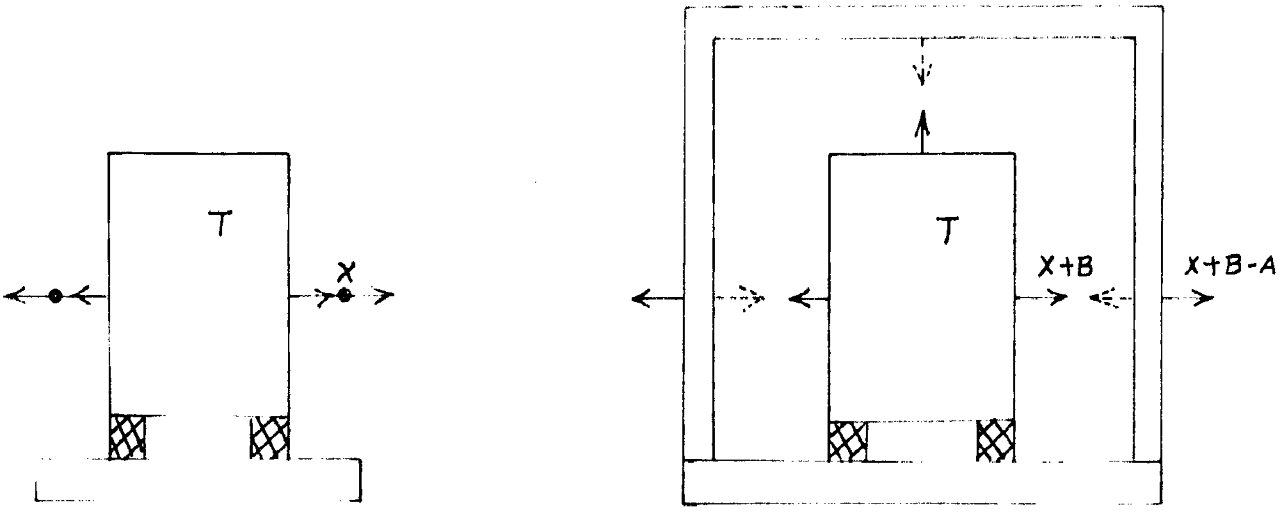
In diagram(a) a transformer T ismounted on resilient supports on a substantial foundation, when the transformer is excited, sound waves are radiated from the sides and the top. Suppose the intensity level in decibels of a particular component near the tank side is X. When the enclosure is placed in position, the internal intensity level will increase to (X+B), where B is the build up effect. The intensity level immediately outside the enclosure will be (X+B-A), where A is the attenuation of the enclosure for the frequency.

The build up effect in practical cases may reach considerable values. If it is desired to utilize A, more fully build up effect must be reduced by increasing the total absorption inside the enclosure, by making use of suitable sound absorbing material.

Fig(5.6) illustrates a transformer in an enclosure with an external radiator.

(5.2.4.5) <u>Pre-assembled Enclosures:-</u>

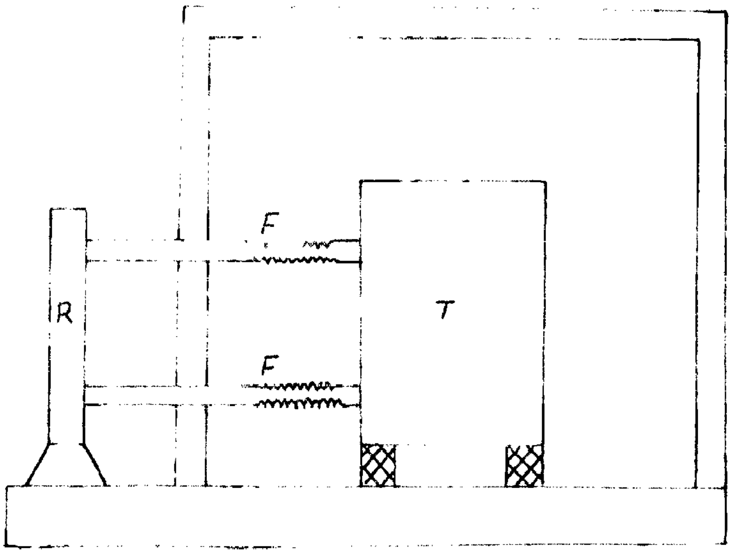
The preassembled sound enclosures are being extensively used for large transformers in the U.S.A. This is buildt around a transformer of conventional design. When completely assembled the outer tank or enclosure surrounds



(a) (b)

DIGRAMMATIC ILLUSTRATION OF THE EFFECT OF ENCLOSING A TRANSFORM

FIG. No. 5.5



T = TRANSFORMER, RESILIENTLY MOUNTED
R - RADIATOR
F = FLEXIBLE PIPE CONNECTIONS

DIAGRAMMATIC ILLUSTRATION OF A TRANSFORMER IN AN ENCLOSURE WITH EXTERNAL RADIATOR

FIG. No 5.6

the main tank.[22] The standard accessories (oil level indicator, thermometers and valves) are readily accessible from the outside of the enclosure. A sound absorbing material is placed in the dead air-space between the two tanks to reduce the build up effect of sound within the enclosure. All connections from the main to the outer tank are flexible to prevent the direct transmission of vibrations. Although both the tanks rest on the same foundation, resilient pads are placed under the base of the main tank to minimize coupling through the foundation. The enclosure has a separable channel bars which is removed for shipment.

### Advantages of the Preassembled Sound Enclosures:

(i) Large reductions in sound level can be obtained.

(ii) It is a lower cost method of obtaining large reductions in sound level.

(iii) Radiation of noise in all directions is attenuated because it completely encloses the main sound radiating surface.

(iv) The efficiency of the enclosing system is not decreased as it would be with a masonry enclosure around the complete transformer, because the cooling surface is located external to the enclosure.

(v) The installation is simpler than for other types of enclosures. It requires a slightly more time for installing than that required for a standard transformer. This is due to the fact that the enclosure is preassembled at the factory.

(vi) It is less bulky for shipment than a separately assembled metal enclosure.

(vii) **No** special overhead clearance is required at the installation site for assembly of the enclosure.

(viii) Substitution of a larger unit at the same site is not limited by the size of the enclosure, since the enclosure is an integral part of the unit and moves with it.

Complete enclosures of all types have the advantage of producing very large reductions of sound level in all directions. The factory built (Preassembled) enclosures can provide reductions of the order of 15 to 20 db at a lower cost than other methods. The preassembled enclosures provide the most desired simplicity for installing and erecting.

(5.2.5) Sound Cancellation Method.

Recent tests have demonstrated the practicability of projecting a "Beam of silence" through the complex sound field which surrounds a transformer.[19] At the present stage of development the beam is limited to a width of 30°. This is sufficient to reduce complaints in some installations. The equipment consists of from one to four loudspeakers, a source of a fraction of a watt of electric power, and a means of adjusting the phase and amplitude of each harmonic. The cost of this equipment is a few percent of the cost of conventional sound barriers.

Theory of operation.

To understand as to how sound cancellation can be obtained, the transformer may be considered as a point source, which is true for large distances when measurements are made along a fixed radial line. It is well known that the placement of a second point source in the vicinity of the first one will give rise to intereference patterns, which result in large variation in sound pressure with angular position. The forms of these patterns depend upon the number of wavelengths of separation between the sources and the phase angle between their pressure variations.

Fig(5.7) shows some typical polar plots of sound pressure around a pair of point sources of equal strength. A study of these curves indicates the effect of separation and phase angle of the sound pressure field at large distances from the source. It is also apparent that by proper adjustment of the phase angle of the second source(i.e. a loud speaker), the sound from the first can be cancelled in a desired direction.

For the first few harmonics of the transformer noise a 12inch loud speaker in a closed baffle is a fairly accurate model of a point source.

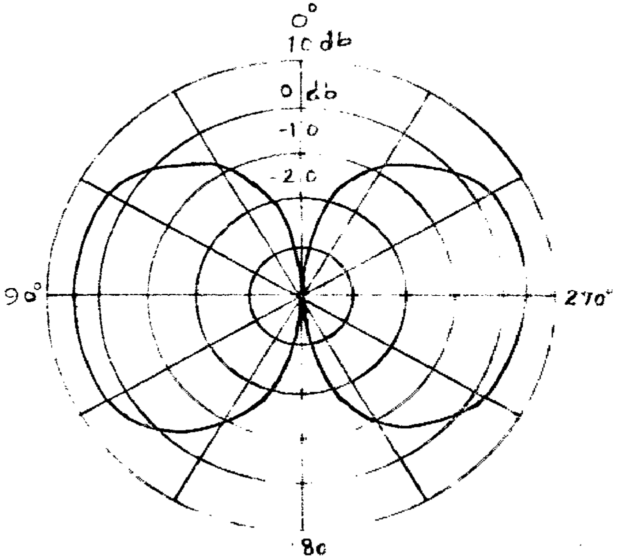
In Fig(5.8) a block diagram of sound cancellation equipment is given.

### (5.2.6) Penetration of Noise into Buildings:

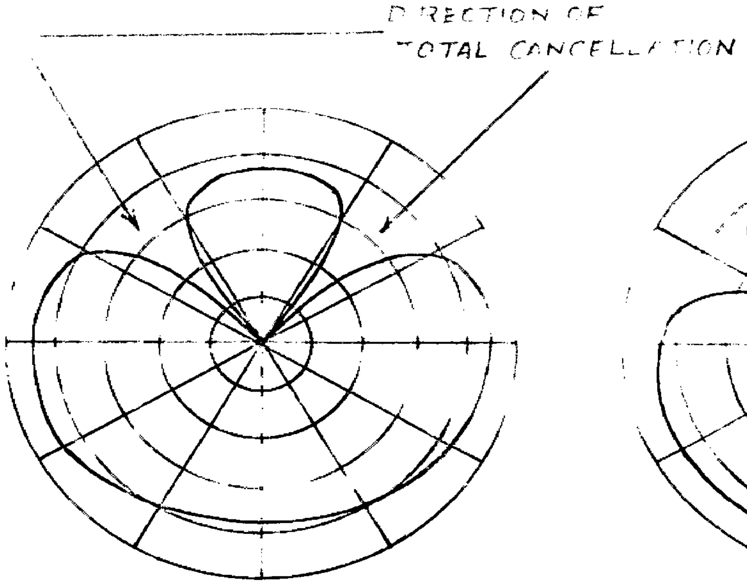
The final attenuating factor in the sequence from the source of noise to hearer in transformer noise problem in residential district is the attenuation provided by the house. The difference between the intensity incident upon the outside of a house and that within a room depends upon the following factors.

(i) The area of the openingof the window.

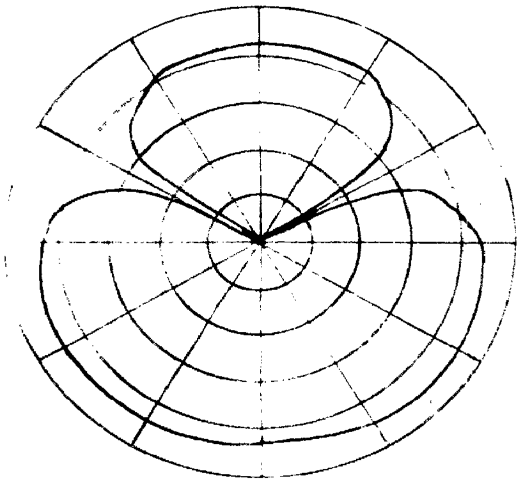
(ii) The amount of acoustical absorption within the room.



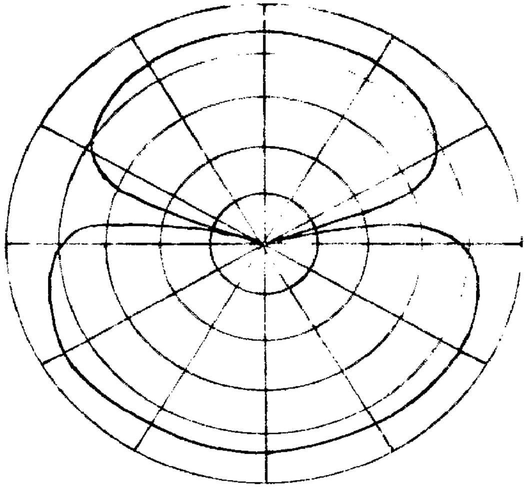
$d = \frac{\lambda}{2}$ $\phi = 0^\circ$

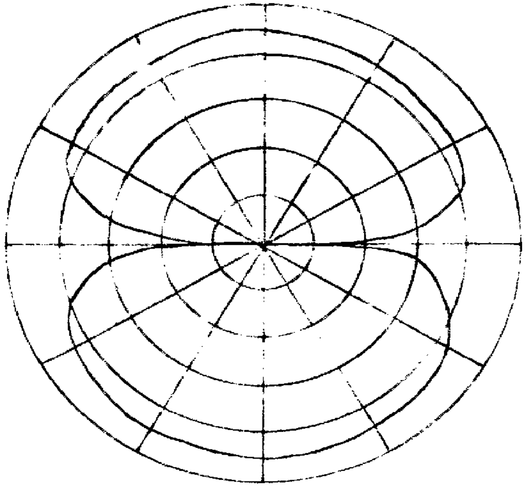


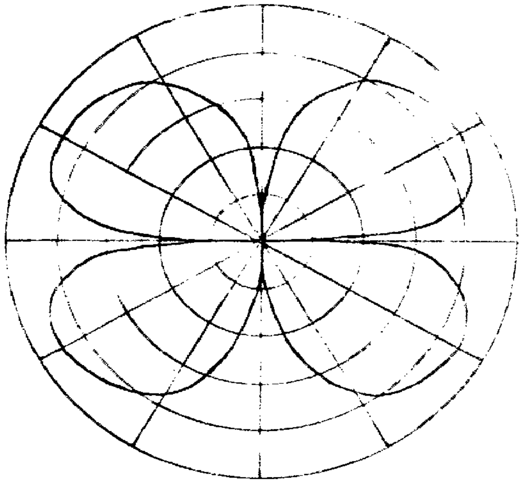
$d = \frac{\lambda}{2}$ $\phi = 45^\circ$

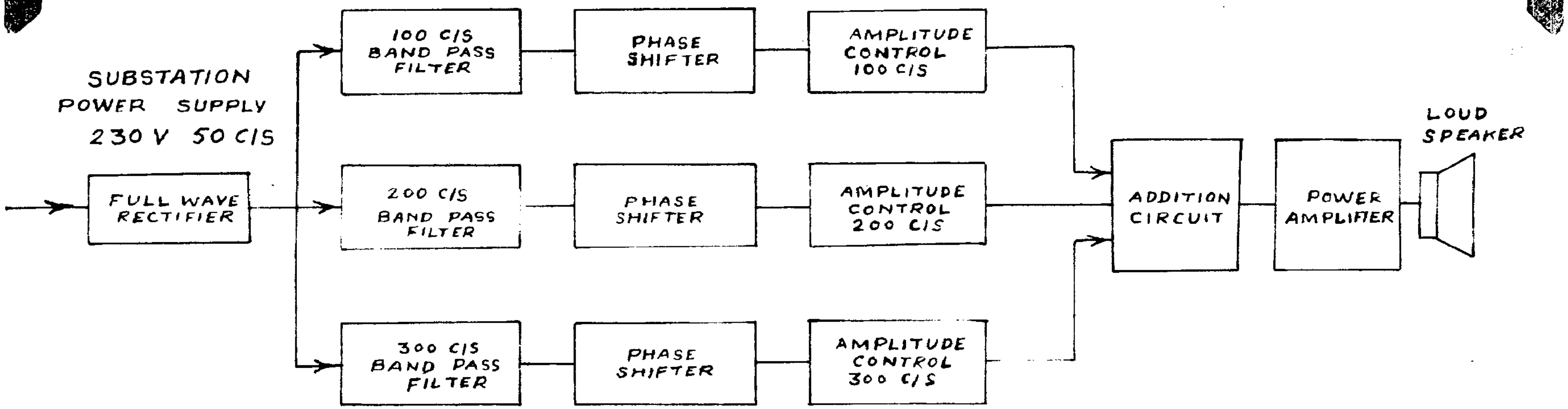


$d = \frac{\lambda}{2}$, $\phi = 90^\circ$









BLOCK DIAGRAM OF SOUND CANCELLATION EQUIPMENT

FIG. No. 5·8

Where the windows are closed; the attenuation depends on

(a) the total window area

(b) the thickness of the glass.

Depending upon the amount of absorption, the window area, attenuations upto 15db are possible. In bed rooms where most attnuation is needed, absorption is greater than in other rooms. An attenuation of 10 db has been found for open windows by experiments[27] and these may be assumed for calculations. For closed windows attenuation may rise upto 15 to 20 db.

### (5.2.7) Psychological Factors in Limiting Transformer Noise.

Some measures which can be adopted in influencing the paychology of the people residing in the houses near the transformer substation will be described. These methods do not reduce the noise as emitted by the transformer but sometimes remove the cause of potential complaint.

(i) Improving the appearance ofthe substation and the property as much as economically justifiable by landscaping, lighting and painting of structures.

(ii) Emergize the transformer two weeks before construction is started and as much as possible during construction in an effort to accustom the neighbourhood to the noise of the transformer and thereby a psychological advantage may be obtained.

# CONCLUSIONS

Heavy load growth and economics necessitate theconstruction of outdoor substations close to the load centres. This requires large transformers to be installed near,residential buildings and makes people more noise conscious. The manufacturers are trying to build smaller and more economical transformers by the use of grain-oriented cold rolled steel. The following are the important conclusions of this study.

## (i) Causes of Transformer Noise:-

(a) The transformer noise originates principally in the magnetorstriction of the core-iron.

(b) Pulsation of the flux in the core-joints also increases the total noise due to vibration of core plates.

(c) The transformer noise may be increased due to resonance at the natural frequency of either core,tank, radiator tubes, junction boxes etc, with the exciting frequency of the core vibrations.

(d) Noise may also increase due to interaction between core and coils.

(e) External cooling equipment(Fans & pumps etc.) of the transformer considerably increases the noise of the transformer.

## (2) Theoretical considerations in determining the Noise Level of Transformers.

(i) The Transformer Noise can be calculated from the design constants using as a base the magnetostriction tests of the core material.

(ii) Sound intensity produced by similar transformers with the same induction in the core varies as the 2/3rd power of the weight.

(iii) The sound intensity produced by a transformer with the core-iron having normal magnetostriction varies as the square of the magnetostriction. This relation can be used to compare the sound intensities produced at various flux-densities or to compare the sound levels of various types of core steels.

(iv) Variation of noise-level due to load variation is of the order of 2 to 3 decibels under the worst conditions of loading and may vary to zero under the best operating conditions.

(v) Theoretically speaking reduction of noise from a transformer is possible by designing it at low flux densities, but from economic considerations this method is impracticable.

(3) Methods of Limiting Transformer Noise.

(Internal Methods)

(a) The core:

(i) Use of special steels with low magnetostriction.

(ii) Reduction of flux density to retain the advantages of low magnetostriction in

(iii) Careful design and construction of the core and coils to avoid resonance and vibration of parts.

(b) Transmission between the core tank walls.

(i) Isolating the core from the tank by paddings to avoid the transmission of vibrations to the tank walls.

(ii) Use of accoustical impedences or noise barriers in the oil.

(c) The tank:

(i) Design and construction of tank to avoid resonance.

(ii) Sound insulation of the tank.

(d) Fitting and Auxiliaries:

Mount them on resilient cushions and avoid resonance.

(External Methods)

(i) Effect of Distance:

Adequate distance between the transformer and the nearest dwellings. The distance itself contributes towards the limitation of transformer noise.

(ii) Use of barriers around the transformer:

The height of the barrier is the most important factor in determining the attenuation of transformer noise. At least the height of the barrier must be 2 or 3ft.more than the height of the transformer tank. The reduction in sound level affected by a wall diminishes as the angular height of observer with respect to the source increases. Single wall barriers are useful when a small attenuation in one direction only is required. However for large reductions in noise and when attenuation in all directions is desired, barriers are uneconomic.

(iii) Enclosures:

Four wall total enclosures are very effective for large noise reductions. Noise reduction of the order of 20 to 25 db is possible by this method; but this method impairs the cooling of the transformer. Attenuation of noise is obtained in all the directions. Total enclosures of brick work and masonry are very popular in U.K. and the continent but in the U.S.A. preassembled enclosures are very popular [illegible] since they have many advantages over brick wall enclosures.

(iv) Noise reduction by sound cancellation Method:

This method gives reduction of transformer noise in an angular space of 30° from the **source** . It is a very cheap method of transformer noise reduction. Maintenance cost is negligibly small. More investigation is needed, in order that this method may given cancellation of noise in a greater angular space.

At the present time, there is not a single satisfactory general solution. Depending upon the importance of a noise problem one or a combination of the methods discussed can be applied.

The transformer noise is trouble some in relatively few cases, but non themselves lend to a general solution. "Each is an economic problem to balance the additional cost of quiet transformer against the cost of providing a suitable enclosure or locating the transformer away for the noise not to be objectionable".

Each case has to be studied individually and the most adequate solution for the reduction of noise consistent with economic considerations has to be adopted. Lower noise level transformer obtained by reducing the flux densities in the core requires more iron, more copper, more insulation , a large tank and more oil. This results in an increase in the cost some times as high as 25% for the desired noise reduction.

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# APPENDIX

## ACOUSTICAL-TERMINOLOGY(23)

Ambient Noise:- General back ground noise in a neighbourhood excluding the source under investigation as well as any temporary or unusual noise which can not be counted on to produce masking of the sound from the source under investigation.

A-Weighted:- A single tone, band of frequencies or total sound which has been modified in accordance with A-weighting is said to be A-weighted.

Weighting:- Weighting is the relative frequency response characteristic of a standard sound level meter. Three standard curves have been adopted A,B,C(Flat)

Harmonic Level:- Weighted sound pressure level, in db, of a single frequency.

Harmonic Index:- The harmonic index, hi, is the difference between the noise level measured by the flat response and the noise level measured by the 40 decibel response curve.

$$hi = db_{(Flat)} - db_{(40)}$$

Loudness:- Intensive attribute of an auditory sensation, in terms of which sounds may be ordered on a scale extending from soft to loud. The Americal unit of loudness is Sone.

Loudness:-(British definition):- It is that subjective quality of a sound which, in general, increases regularly

A true or natural loudness scale is such that when the number of units on the scale is doubled, the magnitude of sensation experienced by normal listeners is also doubled.

The British Unit of Loudness is Phon.

Equivalent loudness(E.L.):- The equivalent loudness of a sound is measured by the intensity level relative to some accepted reference intensity of a standard pure tone of specified frequency, which is judged by the normal observer to be as loud as the sound under consideration. The unit of equivalent loudness is Phon.

The standard tone shall be a sinusoidal sound wave-train coming from a position directly infron of the observer and having a frequency of 1000cps.

Masking:- Amount by which the threshold of audibility of a sound is raised by the presence of another (masking sound). The unit used is the decibel.

Phon:- The Phon is a unit of loudness. By definition a simple tone of requency 1000c/s, 40db above a listerner's threshold, produces a loudness of 1 Phon.

The loudness of any sound that is judged by the listener to be -n- times that of 1 Phon is n-Phons.

Sound Level:- It is the weighted sound pressure level. The frequency weighting network A,B or C should be specified.

<u>Sound Pressure Level</u>:- The sound pressure level, in decibels, of a sound is 20 times the logarthm to the base 10 of the ratio of the pressure of this sound to the reference pressure, which is usually 0.0002 dynes/sqcm.

<u>Threshold of Audibility</u>:- For a specified signal, the threshold of audibility is the minimum r.m.s. sound pressure of the signal, that is capable of evoking an auditory sensation, in a specified fraction of the trials.

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