Measurement of Transformer Noise

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Abstract :

Noise pollution is an important issue in modern societies. Power transformers are a significant contributor to this unwanted ambient noise. Till two decades ago, the noise produced by transformer was not attached any importance in public life. However, of late it is attracting attention as a result of the general public's growing concern about the environmental noise pollution. During normal operation, transformer produces characteristic hum, the magnitude of which increases with increase in its capacity. This paper discussed about influencing factors for noise generation like Flux density, core construction, core construction, Building Factor, Core clamping & Pressure, winding diameter, cooling fans and etc. Standards IEEE, IES & NEMA TR-1 for noise measurement procedure, it depends on the distance between the measuring surface and noise radiating surface by using of noise level meter.

***IndexTerms* – Noise Measurement, Transformer, Magnetostriction, Scale dB(A)**

I. INTRODUCTION

Transformer is the most vital equipment in a power transmission and distribution system. It produces characteristic hum, the magnitude of which increases with increase in transformer capacity. Electricity demand is going to be increase day by day. To meet that increasing public demand, more and larger power transformers must be installed near to the rural, urban and suburban areas. The noise of energized power transformers, which may be heard outside of the station, is "Noise" and must not exceed beyond the prescribed limit by Indian Government.

Different scale like A, B, and C weighted are used for noise level measurement. International standards IEC 60076-10 and IEEE standard C57.12.90-1993 lay down the standard procedure for noise level measurements on transformers.

The sources of transformer noise are the magnetostriction in core vibration, winding vibration,ank walls and cooling equipments. Magnetostriction gives the major contribution in transformer noise, which is change of dimension, due to magnetization, of a magnetic material in a magnetic field. Their frequency is twice that of the power supply system and their magnitude increase with increasing the value of magnetic flux density.

II. METHODS OF NOISE LEVEL MEASUREMENT

Noise pressure level measurements have been developed to quantify pressure variations in air that a human ear can detect. The perceived loudness of a signal is dependent upon the sensitivity of the human ear to its frequency spectrum. Modern measuring instruments process noise signals through electronic networks, the sensitivity of which varies with frequency in a manner similar to the human ear.

Noise power is the parameter, which is used for rating and comparing noise sources. Noise power can be calculated from noise pressure or noise intensity. Noise intensity measurements have the following advantages over noise pressure measurements.

i) An intensity meter responds only to the propagating part of a noise field and ignores any non-propagating part, for example, standing waves and reflections.

ii) The intensity method reduces the influence of external noise sources, as long as their noise level is fairly constant.

The noise pressure method takes the above factors into account through correction for background noise and reflections.

The noise intensity is the time-averaged product of noise pressure 'p' and particle velocity 'v'.

$$I = p \times v \tag{1}$$

Where, I=Intenisty, p=pressure, v=velocity

It is found that when converted in to noise power, the noise intensity measurement leads to values of 2 to 3 dB less in comparison to the noise pressure measurement.

Measurements on 30 transformers in the range from 0.1 to 350 MVA, a mean difference of 3.8dB(A) was established between pressure and intensity measurement values.

III. SCALES FOR NOISE LEVEL MEASURMENT

There are three types of scales for noise level measurement: (1) A-weighting scale (2) B-weighting scale (3) C-weighting scale . The typical frequency response waveforms for the above weighting scales are represented in fig 1.[1].

A-weighting scale

This follows the frequency sensitivity of the human ear at low levels. This is the most commonly used weighting scale, as it also predicts quite well the damage risk of the ear. Noise level meters set to the A-weighting scale will filter out much of the low frequency noise they measure, similar to the response of the human ear. Noise measurements made with the A-weighting scale are designated as dB (A).

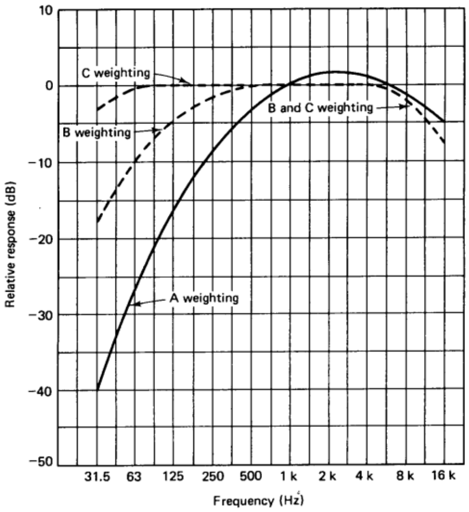

Figure 1: Frequency Response for the A, B and C Weighting Networks

B-weighting scale

Follows the frequency sensitivity of the human ear at moderate levels; used in the past for predicting performance of loudspeakers and stereos, but not industrial noise.

C-weighting scale

Follows the frequency sensitivity of the human ear at very high noise levels. The C-weighting scale is quite flat, and therefore includes much more of the low frequency range of noises than the A and B scales.

Table 1 Noise level Conversion Chart

Frequency (Hz)	Decible (dB)		
	A – Weighting	B - Weighting	C - Weighting
10	-70.4	-38.2	-14.3
12.5	-63.4	-33.2	-11.2
16	-56.7	-28.5	-8.5
20	-50.5	-24.2	-6.2
25	-44.7	-20.4	-4.4
31.5	-39.4	-17.1	-3.0
40	-34.6	-14.2	-2.0
50	-30.2	-11.6	-1.3
63	-26.2	-9.3	-0.8
80	-22.5	-7.4	-0.5
100	-19.1	-5.6	-0.3
125	-16.1	-4.2	-0.2
160	-13.4	-3.0	-0.1
200	-10.9	-2.0	0
250	-8.6	-1.3	0
315	-6-6	-0.8	0
400	-4.8	-0.5	0

500	-3.2	-0.3	0
630	-1.9	-0.1	0
800	-0.8	0	0
1000	0	0	0
1250	+0.6	0	0
1600	+1.0	0	-0.1
2000	+1.2	-0.1	-0.2
2500	+1.3	-0.2	-0.3
3150	+1.2	-0.4	-0.5
4000	+1.0	-0.7	-0.8
5000	+0.5	-1.2	-1.3
6300	-0.1	-1.9	-2.0
8000	-1.1	-2.9	-3.0
10000	-3.5	-4.3	-4.4
12500	-4.3	-6.1	-6.2
16000	-6.6	-8.4	-8.5
20000	-9.3	-11.1	-11.2

IV. CASE STUDY : NOISE LEVEL MEASUREMENT ON DIFFERENT SCALES

There are three scales for noise level measurements. In order to understand the difference and verify the explanation given earlier as to why noise level measurements are specified according to A-weighted scale, a measurements of noise level with A and C-weighted scales were carried out on a 10 MVA, 110/33/11kV, 3-Phase, 50 Hz Power transformer.

Table 2 Noise level Measurement on Different Scales

Test	**Measured Noise level (Corrected)**
Background	60.8 dB(A)
No-load Condition	63.4 dB(A)
No-load Condition	72.4 dB(C)
Load Condition	61.8 dB(A)

From the above experimentation, it is inferred that, (a) noise level is high on C-weighted scale as compared to that on A-weighted scale, because C-weighted scale includes noise at lower frequency, which can not be sensed by the human ear. (b) A-weighted scale is generally accepted for measurement of transformer noise because the purpose is to measure the noise level frequency within the band, which can be sensed by the human ear. (c) The noise level under load when excited at impedance voltage during works testing is significantly lower than no-load noise level.

V. NOISE LEVEL MEASUREMENT PROCEDURE AS PER STANDARDS

International standards IEC 60076-10 and IEEE standard C57.12.90-1993 lay down the standard procedure for noise level measurements on transformers. Some of the salient points are extracted from the standards and presented here to introduce the subject [2], [3], [4].

Ambient Noise Pressure Level

The ambient noise pressure levels are measured immediately preceding and immediately following the noise measurements with the transformer energized. The ambient noise shall be measured at minimum four locations. Additional measurement may be made if the ambient measurements vary by more than 3 dB around the transformer.

At least one of the locations for measuring ambient noise pressure levels shall be on the center of each face of the measurement surface.

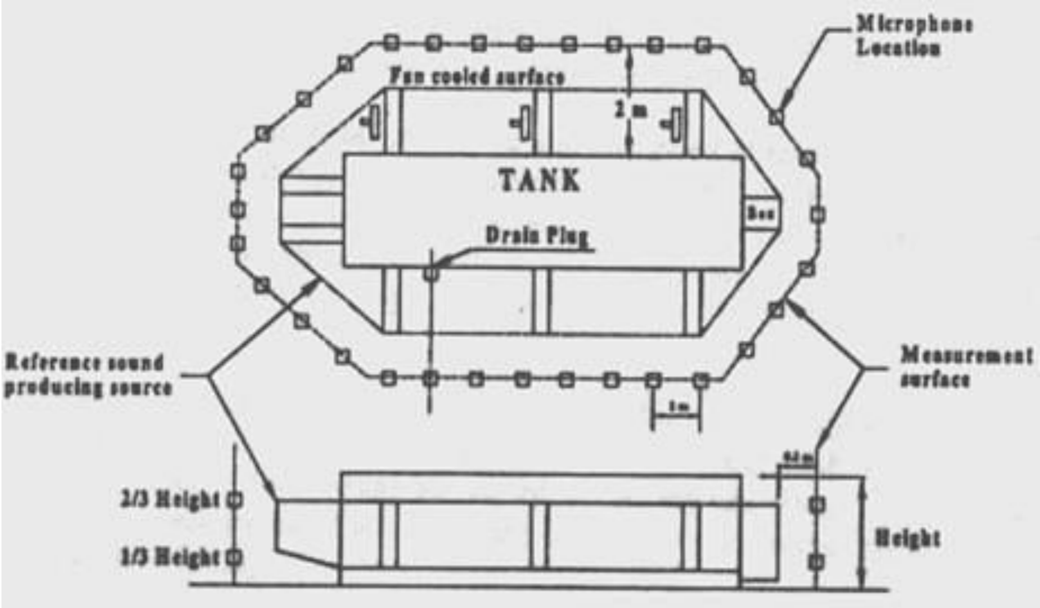

Figure 2. Microphone Location for Measuring Audible noise on Transformers

Reference Noise-Producing Surface

The reference noise-producing surface of a transformer is a vertical surface that follows the contour of a string stretched around the periphery of the transformer or integral enclosure. The contour shall include radiators, coolers, tubes, switch components, and terminal chambers, but exclude bushings and minor extensions, such as valves, oil gauges, thermometers, terminal boxes, and projections at or above cover height.

First Measurement Position

The first microphone location shall coincide with the main drain valve. Additional microphone locations shall be at 1m intervals in a horizontal direction, proceeding clockwise on the measuring surface.

Locations of Microphones from Noise-Producing Surface

The microphone shall be located on the measurement surface. As per IEEE Standard C57.12.90-1993, the microphone shall be spaced 0.3m away from the reference noise producing surface (principle noise radiating surface). When fans are in operation, the microphone shall be located 2m away from any portion of the radiator, coolers, or cooling tubes cooled by forced air. As per IEC 60076-10, for measurements made with forced air cooling with auxiliaries out of service, the prescribed contour shall be spaced 0.3m away from the principle radiating surface and when these in service, the prescribed contour shall be spaced 2m away from the principle radiating surface. There shall be a minimum of six microphone positions.

Generally, noise level is measured from noise-producing surface, apart at 0.3m for ONAN and 2m for remaining cooling scheme. When the distance of microphone becomes double, the drop in noise pressure level will be 6 dB [12]. Following formula is used for calculation of noise level at different distances from the noise emitting surface.

$$L_P\,(d1) = L_P\,(d) - 20\log(d1/d) \qquad (2)$$

where, d=reference measurement distance (m), d1=desired measurement distance (m)

Height of Microphone Locations

As per IEEE Standard C57.12.90 -1993, and IEC-60076-10, for transformers having an overall tank or enclosure height of less than 2.4m and 2.5m respectively, measurements shall be made at half height. For transformers having an overall tank or enclosure height of 2.4m or more, measurements shall be made at one-third and at two-thirds height. Noise measurement of cooling system shall be made at locations only at one-half height.

VI. CORRECTION FACTORS

Measurement should be made in an environment having an ambient noise pressure level at least 5 dB (as per IEEE standard) or 3 dB (as per IEC-551 and CBIP manual) below the measured noise pressure level of the transformer. When the ambient noise pressure level is 3 dB or more below the measured transformer noise level, the corrections shall be applied to the combined transformer and ambient pressure level to obtain the transformer noise pressure level. The various correction factors as defined in IEEE, IEC-551 and CBIP manual are reproduced below in Table 3. The measurements carried out on transformer with ambient noise level difference of less than 3 dB are invalid.

Table 3 Noise level Correction Factors as per IEEE C57.12.90, IEC-551 & CBIP Manuals

IEEE		**IEC 551**		**CBIP**	
Difference between combined & Background Noise (dB)	**Correction to be subtracted (dB)**	**Difference between combined & Background Noise (dB)**	**Correction to be subtracted (dB)**	**Difference between combined & Background Noise (dB)**	**Correction to be subtracted (dB)**
5	1.6	3	3	3	3
6	1.3	4-5	2	4-5	2
7	1.0	6-8	1	6-8	1
8	0.8	9-10	0.5	-	-
9	0.6	-	-	-	-
10	0.4	-	-	-	-
Above 10	0.0	-	-	-	-

VII. INFLUENCING FACTORS IN TRANSFORMER NOISE ESTIMATION

Here, discussed about influencing factors in noise calculation like Flux density, core construction, Building Factor, Core clamping & Pressure, winding diameter, cooling fans and etc. Core vibration is the main factor in the no-load noise level. Noise level also depends on magnetic property of transformer core material. Factors such as sheet thickness, stress, coatings, induction level and frequency of magnetization affect the magnetic properties of the core material [5], [6].

A. Core Joints/Core Construction

There are many types of core configurations. However, there are some common features in terms of core corner joints. The three most commonly used types of corner joints are (a) Interleaved joints; (b) Mitred joints; and (c)Step-lap joints.

Normally, we tend to relate type of core joints with the core losses. However, magnetostriction changes in length and magnetic forces arising at the joint regions of the core excite vibrations in the core, giving rise to noise. Therefore it is relevant to discuss here the types of core joints and their influence on noise.

The interleaved joints, as shown in Figure 3, are the simplest ones and are usually preferred only for small rating transformers, where the total core loss itself is very small.

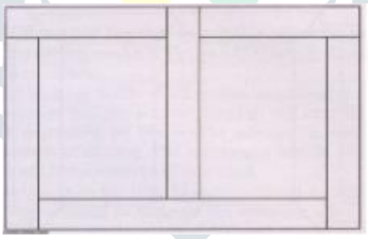

Figure 3. Interleaved Joints

Mitred joints or single steplap core joints consists of 45degree overlap arrangements at the corners as shown in Figure 4. In such arrangement, the magnetic flux leaving/entering the joints finds a smooth path for its permeance. This is most commonly used type of joint.

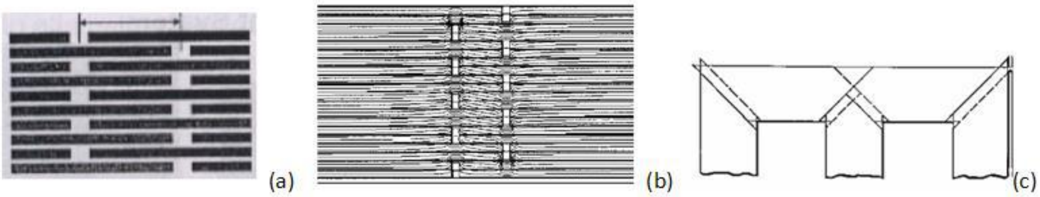

Figure 4. Mitred Joints: (a) Cross-sectional view (b) Flux distribution (c) Front view

Steplap cores comprise several laminations cut to different lengths. Steplap core configurations comprises, say in case of a 5 step lap core, 5 laminations of different lengths, each successive lamination being slightly longer than the previous one by a specific step overlap of, for example 2, 4 or 6 mm. Such arrangement, as shown in Figure 5 generally leads to much better magnetic and noise performance than the mitred overlap joints, considered to arise due to fewer inter-laminar forces arising in the multi steplap cores. This type of core with 5 or 7 steplap is finding increasing acceptability due to reduction in core loss and noise. It is reported to effect noise reduction on an average to the tune of 4dB.

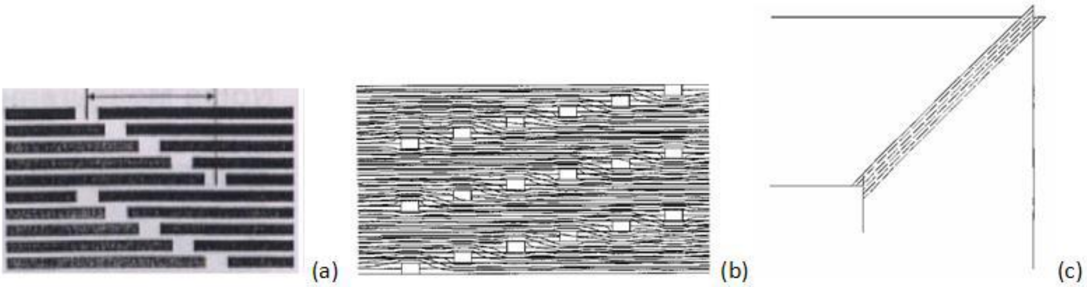

Figure 5. Step-lap Joints: (a) Cross-sectional view (b) Flux distribution (c) Front view

B. Core Grade

Desirable magnetic properties of electrical steels are (i) Low loss, to minimize energy loss due to magnetization of the core; (ii) High permeability to minimize the applied current (magnetizing current) required to achieve a particular induction level; (iii) Low noise generation from the core. The popular grades of CRGO (Cold Rolled Grain Orientation) are M4, MOH and HI-B (ZDKH). The HI-B grade core material offers 2-3dB reduction of noise level as compared to normal grade CRGO because of comparatively less magnetostriction amplitude (Refer Figure 6). The increase in lamination sheet thickness could result in lower noise level due to damping of core vibration. This however increases the overall no-load loss.

In practice, electrical steels are classified in to many categories. These have been generally used in the industry, that an understanding of them is required. They are made on the basis of the primary magnetic property of the material, the form, the difference from the majority of grades, or the method by which the material is produced. Following, description of four general classes are given below

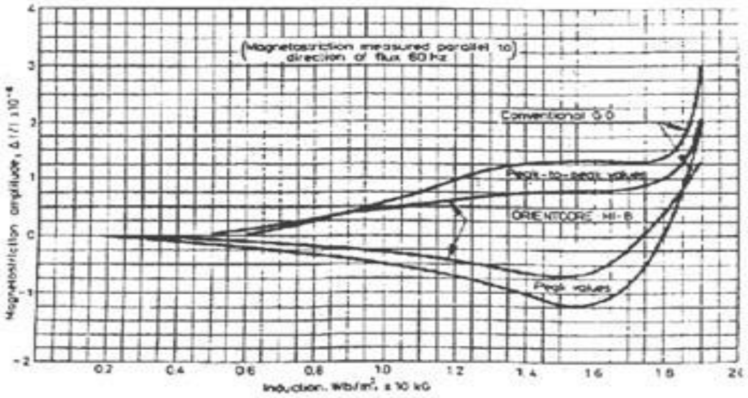

Figure 6. Amplitude of Magnetostriction as a Function of Flux Density

Non-oriented: This type of electrical steels, in which the magnetic properties are practically the same in any direction of magnetization in the plane of the material. The term "nonoriented" is used to differentiate these materials from those produced by processes that create a definite orientation or directionality of magnetic properties.

Grain-Oriented: This term is used to designate electrical steels that possess magnetic properties which are strongly oriented with respect to the direction of rolling. By a process of rolling and annealing, alloys of suitable composition can be produced with a metallic crystal structure in which the grains are aligned so that magnetic properties are vastly superior in the direction of rolling. This results in inferior properties in other directions, however.

Fully Processed: This type of electrical steels in which the magnetic properties are completely developed by the steel producer. The name is derived from the fact that the materials are completely processed, ready for use without any additional processing required to achieve the desired magnetic quality. However, a low temperature heat treatment may be employed by the user to eliminate stresses introduced by fabrication of the material into cores.

Semi-Processed: This type of electrical steels in which finished to final thickness and physical form (sheets* or coils) by the producer but are not fully annealed to develop final magnetic quality. With these materials, the achievement of magnetic properties by the annealing treatment becomes the responsibility of the user. Due to the intricacies of developing adequate magnetic properties, grain-oriented steels are produced fully processed.

C. Flux Density

It is given that a variation of 10 percent in the flux density relative to the rated value produces on average a difference of about 2 to 3 dB(A). The noise level is closely related to the operating peak flux density and core weight. The change in noise level as a function of these two factors can be expressed as below.

$$\Delta p = 10 \log \left[\left[\frac{B2}{B1} \right]^{8} \times \left[\frac{W2}{W1} \right]^{1.6} \right] \quad (3)$$

Where, B = Flux density (T), W = Core weight (kg)

In the above formula, core weight is assumed to change with flux density approximately in inverse proportion. It is observed that for a flux density reduction of 0.1 T, the noise level reduction of about 2dB is obtained. However, this results in increase of material content (copper and core) and hence it is advantageous only if the no-load loss capitalization rate is high. An alternative way of reducing flux density in transformer core without affecting winding weight is to increase top and bottom yoke diameter, keeping limb diameter fixed.

D. Cooling Scheme (ONAN/ONAF/OFAF/ODAF/OFWF)

As a part of cooling equipment, standard size of 18 & 24 inch fans with speed of 900-950 rpm are used & their noise level is in the range of 64-65dB(A). The fan noise is a function of its speed and circumferential velocity, a low speed fan (say 750 rpm) has smaller noise level. As the speed is lowered, air delivery also reduces necessitating an increase in number of fans. Many a times, the specified noise level specified is so low that it may not be possible to get matching low noise fans. In such cases, ONAN cooling should be preferred to mixed ONAN/ONAF cooling for small and medium rating power transformers, even if it results in increase of number of radiators. When cooling pumps are required, pumps with low noise emission should be adopted.

E. Building Factor for Different Core Materials

Core steel grade cab be classified in to three major material types: Regular grain orientated (RGO), highly Grain oriented (HI-B) and Domain Refined (DR). All three types were used in the model cores. Measured values of the building factor are shown Figure 7. for the three phase model cores and Figure 8 for the single phase model cores.

It can be seen from the figure that the building factor generally increase with the degree of orientation of the material type where DR material has both the highest building factor and the greatest degree of orientation of all the material types shown for both three phase and single phase results. The building factor for the three phase cores is between 1.04 and 1.18; whereas magnitudes of the single phase building factor were close to, or slightly below, 1.00. The lightly loaded corners of single phase 2-limb core and slight spatial redistribution of flux in the limbs and the yokes across the width of laminations contributes to low values of the building factor in single-phase, 2-limb cores, especially those made of regular grain oriented steels.

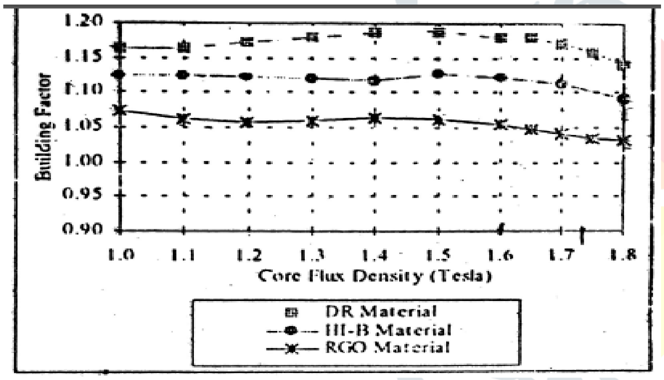

Figure 7. Reference Building Factors – Three Phase Cores

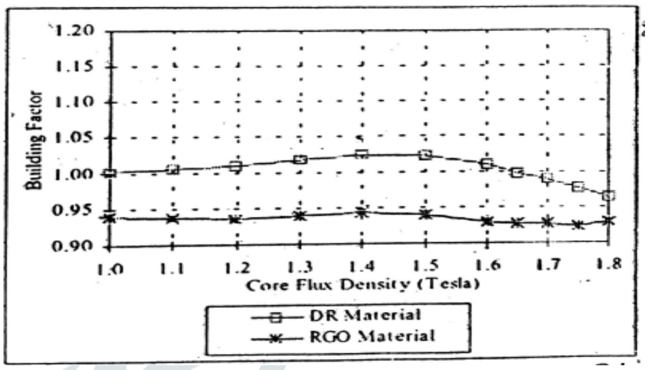

Figure 8. Reference Building Factors – Single Phase Cores

F. Core Clamping

For reducing the transformer noise, the laminations are clamped together. For effective clamping of the core leg laminations, Flitch plates made up of steel are used on either side of each leg. These plates are mechanically strong enough to prevent buckling, bending of laminations and are able to withstand the lifting load of core and windings. Over the clamp plates, 50 mm wide fiberglass tapes are tightly would around the legs.

For effective clamping of the yoke laminations, bolted yoke or boltless yoke clamping arrangement is used. In bolted yoke clamping arrangement, yoke clamping frames made of steel are used on either side of top and bottom yokes and entire core and frame structure is properly secured through yoke bolts at a number of positions. While in boltless yoke clamping arrangement, top and bottom yokes are bound through end frames with the help of 40 mm wide resiglass tapes at a number ofpositions [12].

The clamping pressure on the core should be uniformly distributed. If limbs/yokes are clamped with resinglass or fiber-glass tapes, the pitch (distance between two tapes) should be small so that adequate uniform pressure is applied.

The effect of clamping pressure on transformer noise has been evaluated for a three phase, 5step lap core with 6mm step overlap comprising 27M3 grade CGO material. It is observed that excessive pressure result in an increase in noise level [8], as shown in Figure 9.

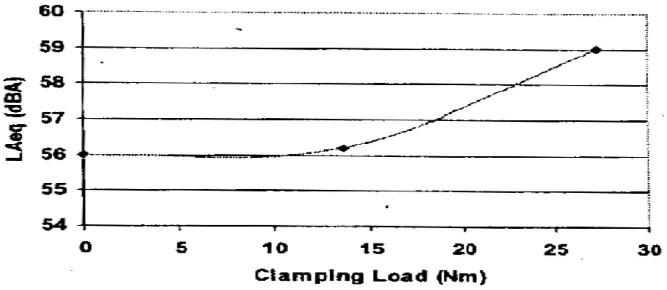

Figure 9. Effect of Clamping Pressure on Noise level

VIII. CONCLUSION

It can be concluded that, A-weighted scale(dB(A)) is generally accepted for measurement of transformer noise because the purpose is to measure the noise level frequency within the band, which can be sensed by the human ear. Magnetostriction gives the major contribution in the transformer noise level and it is directly proportional to the flux density. Reduction of sound level to the tune of 2-3 dB(A) with reduction of 0.1T flux density in the region close to rated operating flux density

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