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RECENT FEATURES OF FUJI LOW-SOUND-LEVEL TRANSFORMERS (2)

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V. BASIC POINTS CONCERNING SOUND

1. Sound Pressure Level, Intensity Level, Loudness level, Noise Level

When sound waves move through a medium, small periodic pressure changes arise which accumulate as static pressure. The effective value of this change in pressure is known as sound pressure and it is expressed in dyne/cm^2=μ bar since the atmospheric pressure change due to sound is about one part in one hundred. Absolute values of the sound pressure level are expressed by the decibel scale (logarithmic scale). The sound pressure level L_p of sound pressure p is related to the basic sound pressure $P_0=2\times10^{-4}$ μ bar (with no reference to frequency) as follows:

$$L_p=20\log_{10}\frac{p}{p_0}=20\log_{10}\frac{p}{2\times10^{-4}}[\text{dB}]\cdots\cdots(12)$$

The sound intensity level L is expressed as absolute values of sound intensity by the decibel scale. The sound intensity level L of intensity I (watt/m^2) is related to the basic intensity $I_0=10^{-12}$ watt/m^2 (with no reference to frequency) as follows :

$$L=10\log_{10}\frac{I}{I_0}=10\log_{10}\frac{I}{10^{-12}}[\text{dB}]\cdots\cdots\cdots\cdots(13)$$

The sound intensity in relation to the senses is known as loudness. The loudness level of a sound is expressed as a numerical value which is the same as the 1000 c/s pure sound intensity level which can be heard at the same loudness as the sound in question.

Phon is used internationally as the units for loudness level. For example, at 1000 c/s, a sound with an intensity level of 80 dB and the sound which can be heard at the same loudness is said to have a loudness level of 80 phon without any reference to the sound intensity level.

The mutual relationship between the frequency, intensity level and loudness of pure sound is shown in widely used curves known as the Fletcher-Munson's Equal Loudness contour based on the work of scientists of the same name. These curves are based on average statistical values obtained in relation to young people with healthy ears. The 0 phon curve indicates the minimum value which can be heard at each of the frequencies. Since these values become 10^{-12} watt/m^2 at 1000 c/s, this value can be considered as the basic sound intensity level. These curves were derived in the following way. At 1000 c/s, the sound intensity scales of 10^{-12} watt/m^2, 10^{-11} watt/m^2, 10^{-10} watt/m$^2\cdots$are expressed logarithmically; while for sounds at frequencies other

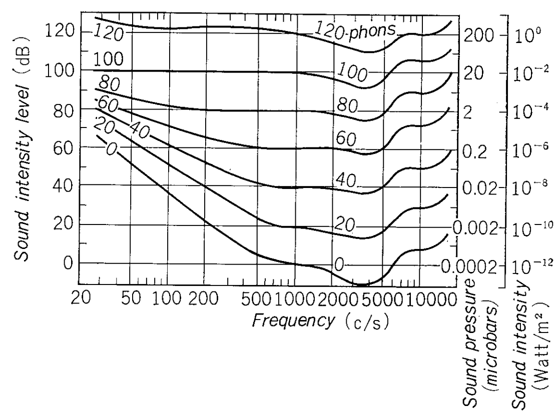


Fig. 22 Fletcher-Munsion's equal loudness contour

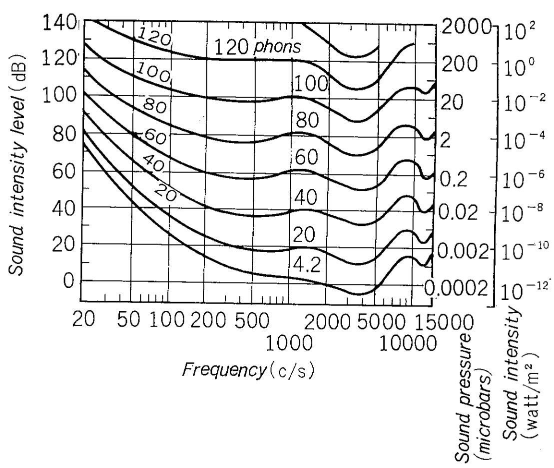


Fig. 23 Robinson-Dadson's equal loudness contour

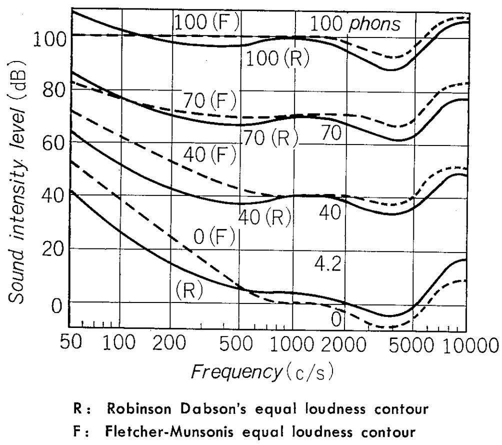


Fig. 24 Comparison between the old and new equal loudness contour

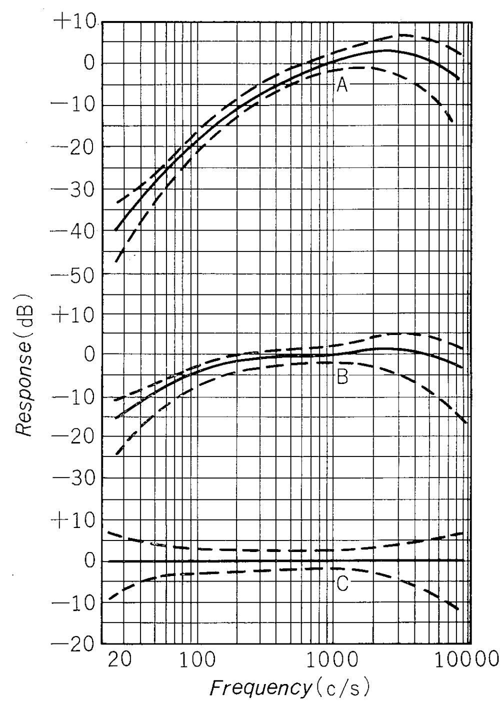


Fig. 25 Frequency response characteristics and tolerances of sound level meter

than 1000 c/s points were plotted in respect to sound intensity levels which could be heard at the same loudness as the 1000 c/s sound. For example, the curve which corresponds to a sound intensity level of 80 dB at 1000 c/s indicates the relationship between the frequency and intensity level of the sound which can be heard at the same loudness. In other words, the sounds on these curves are all sounds with a loudness of 80 phon.

British scientists Robinson and Dadson devised their own equal loudness contour in opposition to the Fletcher-Munson's equal loudness contour and these Robinson-Dadson's equal loudness contour are recommended by the International Organization for Standardization (ISO) which insures their wide acceptance.

These curves indicate sound level at 20 phon intervals and are based on data from healthy young people, 18～25 years old, with normal hearing powers (with both ears) a plane progressive sine wave from a sound source. *Fig. 26* shows a comparison between the Robinson-Dadson's and Fletcher-Munson's equal loudness contours.

The sound level meter specified in Japanese as shown in *Fig. 27* for the *A* scale (40 phon of the Fletcher-Munson's equal loudness contour), *B* scale (70 phon) and *C* scale (flat characteristics). The numerical values measured by this meter are in the form of noise level values which are expressed in both phons and decibels.

2. Acoustic Power and Power Level

The noise energy developed from a noise source in a unit time is known as the acoustic power *P* and when this is expressed in decibels it is referred to as the power level L_W. The acoustic power is a quantity required when estimating the noise surrounding the source or in the room in which the source is located. In many cases it is indicated as the band level and the same frequency band range. The acoustic power units are watts, but 1/1000 of milliwatts (10^{-3}) or μ watts (10^{-6}) are also used. The power level can be expressed by the following equation, using $P_0=10^{-12}$ watt as the basic acoustic power.

$$L_W = 10 \log_{10}\frac{P}{P_0} = 10 \log_{10}\frac{P}{10^{-12}} \text{ [dB]} \quad \cdots\cdots\cdots (14)$$

3. Relationship Between Power Level and Sound Pressure Level

When sound waves are propagated in the from of spherical waves, the sound intensity *Ir* (watt/m²) at a distance *r* (m) from a point source of acoustic power *P* (watt) can be expressed as:

$$I_r = \frac{P}{4\pi r^2} \text{ (watt/m}^2\text{)} \quad \cdots\cdots\cdots (15)$$

And from this

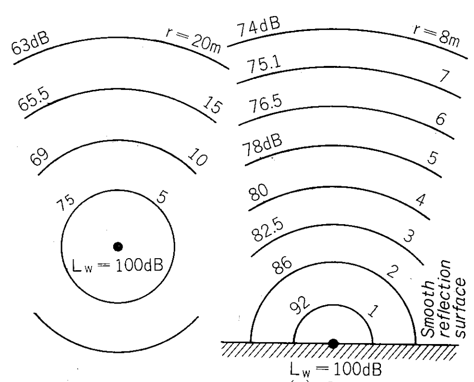


Fig. 26 Sound distribution caused by a point noise source of 10 mw (L_W=100 dB)

$$10\ \log_{10}\frac{P}{10^{-12}}=10\ \log_{10}\frac{I_r}{10^{-12}}+10\ \log_{10}4\pi r^2 \quad \cdots\cdots(16)$$

Therefore, when there is spherical wave propagation as shown in *Fig. 28 (a)*; the following relation exists:

$$L_W=L_n+20\ \log_{10}r+11\ (\text{dB}) \quad \cdots\cdots(17)$$

When there is half spherical wave propagation as in *Fig. 28 (b)*, the following relation exists:

$$L_W=L_p+20\ \log_{10}r+8\ (\text{dB}) \quad \cdots\cdots(18)$$

4. Effect of Distance from the Sound Source

At a sufficiently far distance from the sound source (considered as a point source), the sound waves diffuse during half spherical propagation. The sound intensity I_r at a distance r and a source acoustic power P is as follows:

$$I_r=\frac{P}{2\pi r^2} \quad \cdots\cdots(19)$$

Therefore, the sound intensity levels at distances r_1 and r_2 are as follows:

$$L_{r1}=10\ \log_{10}\frac{I_{r1}}{I_0} \quad \cdots\cdots(20)$$

$$L_{r2}=10\ \log_{10}\frac{I_{r2}}{I_0} \quad \cdots\cdots(21)$$

The difference in intensity level between the two points, from equations (20) and (21) becomes:

$$L_{r1}-L_{r2}=20\ \log_{10}\frac{r_2}{r_1} \quad \cdots\cdots(22)$$

For example, $r_2=2\ r_1$

$$L_{r1}-L_{r2}=20\ \log_{10}2=6\ [\text{dB}]$$

In other words, when the distance is increased by twice, the attenuation becomes 6 dB. Attenuation at 3× the distance is 9.5 db, 14 dB at 5× and 20 dB at 10×.

5. Influence of Increasing the Number of Sources

When a device sending out A (dB) of sound is joined by one more of the same device nearby, the total noise does not become $2\times A$ (dB), but becomes $(A+3)$ db. When devices generating sound are increased by some number of the same such devices in the near vicinty, it is convenient to know beforehand just how much the total noise will increase. Considering N units of sound sources, with sound intensities of I_A, $I_B\cdots\cdots$, the intensity level of each source will be:

$$L_A=10\log_{10}\frac{I_A}{I_0}(\text{dB}),\ L_B=10\ \log_{10}\frac{I_B}{I_0}(\text{dB})\cdots\cdots$$

Therefore, the total intensity level ΣL can be expressed by the following equation:

$$\Sigma L=10\ \log_{10}\frac{I_A+I_B}{I_0}\ (\text{dB}) \quad \cdots\cdots(23)$$

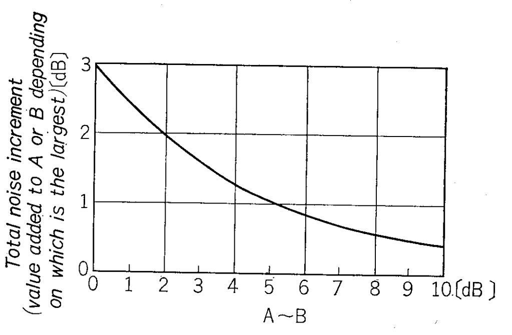


Fig. 27 Increment of sound level due to noise source B added to noise source A

If the N units are all of the same type,

$$A=B=C=\cdots\cdots$$

and the total intensity level then beeomcs:

Table 3 **Correction of Sound Level with Regard to Ambient Noise Level**

Difference of indication when the sound in question exists and when it doesn't exists	3	4	5	6	7	8	9
Correction values	−3	−2		−1			

$$\Sigma L=A+10\ \log_{10}\ (\text{bB}) \quad \cdots\cdots(24)$$

In other words, the amount of increase in the noise is 10 $\log_{10}$ N (dB).

As a point of reference, when a device of sound B (dB) is placed near an existing device of sound A (dB), the total sound magnitude is the sum of A or B (learger value is used) and the increase shown in *Fig. 29.* For example, when the actual sound generated from a device must be determined among all factory noise sources, it is necessary to subtract the correction values in *Table 3* from the factory noise. These values are as specified in JIS Z 8731 1968 (different from JEM 1117).

6. Influence of Climatic Conditions

When sound is propagated in the atmosphere, it is influenced by climatic conditions.

1) Influence of rainfall etc.

When mist, rain, snow etc. is present with no wind, it is known that sound waves can traverse longer distances than on fine days. This is not due to the accoustic characteristics of the mist, rain or snow particles, but is caused mainly by the small temperature gradient in the atmosphere at the earth's surface. Attenuation of sound waves can not be confirmed from investigations in the mist and rain: Such influences can in fact be disregarded. However, when the earth's surface is covered with snow, noise tends to be absorbed so that sound waves propagated near the earth's surface are attenuated and the area becomes still. When rain is falling, the ambient noise increases due to the noise arising from the impact of the rain drops.

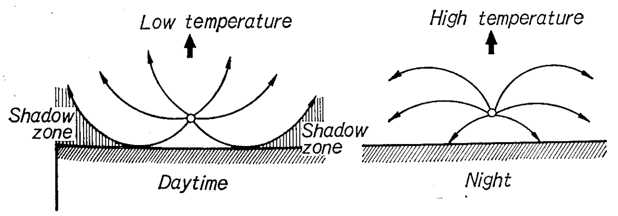


Fig. 28 Noise refraction due to vertical temperature distribution

2) Influence of temperature changes.

During the day, the surface of the earth is warmed by the sun so that the temperature of the air in contact with the earth rises and a countercurrent develops. This rising air current expands adiabatically and the temperature drops, so that a temperature gradient develops in which the upper air is at a low temperature and the lower air is at a higher temperature. During the night, the earth's surface cools down because of radiation so that the temperature of the air in contact with the earth's surface drops, the air becomes heavier and no counter-current develops. Therefore, when the wind is week, a temperature gradient develops such that the upper air is at a high temperature and the lower air is at a lower temperature. This means that the air temperature reverses. Since the speed of sound wave propagation is proportional to the air temperature, sound rays which indicate the direction of sound wave propagation are refracted as shown in *Fig. 30* and shadow zones occur at certain distances from the sound source where sound waves are not propagated. The shadow zone is not well defined in cases when there are light rays, and the sound is transmitted also to a certain degree into the shadow zone due to refraction, but the attenuation is extremely high. In other words, during the day, it is difficult to propagate sound to remote receiving points, but during the night, the sound waves are refracted downwards so that no shadow zone develops and it is easy to supply sound to relatively distant points.

3) Influence of wind.

When the wind is blowing, the wind velocity is low near the surface of the earth due to frictional resistance, no matter how high the wind velocity is in the upper atmosphere. The speed of sound propagation makes a vector total with the wind velocity so that the sound rays are refracted upwards in the

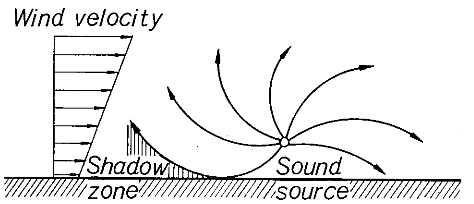


Fig. 29 Noise refraction due to wind

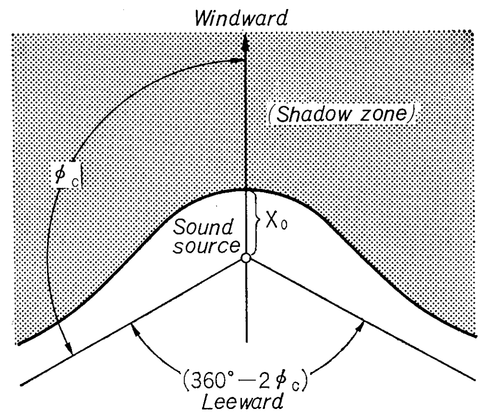


Fig. 30 Shadow zone in the windward from the noise source (plan)

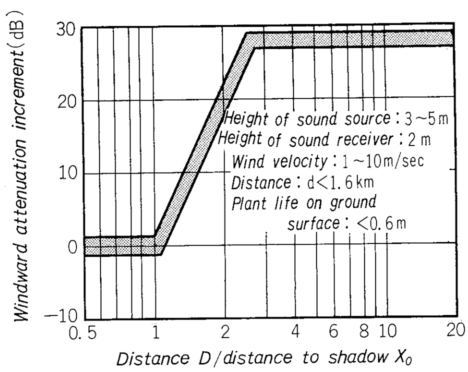


Fig. 31 Increment of attenuation in the windward direction

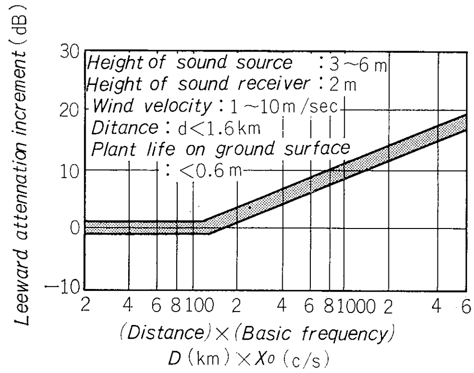


Fig. 32 Increment of attenuation in the leeward direction

windward direction and downward in the leeward direction as shown in *Fig. 31*. Therefore, in the windward direction there is a shadow zone where sound waves can not be propagated but in the leeward direction, there is no such shadow zone and sound can be easily propagated over long distances.

4) Attenuation increases due to wind/temperature gradients.

Generally the conditions shown in *Fig. 30* and *31* overlap and the refraction conditions can be calculated theoretically by totalling the temperature and wind

***Table 4* Distance X_0 from Noise Source to Shadow Zone in the Windward Direction**

	Weather	Temperature Distribution	Wind Velocity (m/sec)	X_0
Daytime	Fair	Low temperature in upper air	5～9	80m
Daytime	Cloudy	Normal	5～7	130m
Night	Fair	High temperature in upper air	1～2	670m

velocity gradients. During the day, the sound rays which all curve upward by temperature gradients, and downwards in the leeward direction so that, in some range of angle ϕc the two influences cancel each other out and there is no shadow zone. In the windward direction there are $2\phi c$ sectors and one $360°-2\phi c$ sector in the leeward direction. The attenuation increases differ considerably on the windward and leeward sides; at the same distance, it is 20～30 dB larger in the windward than in the leeward direction. The pattern shown in *Fig. 32* was devised in accordance with various climatic conditions in the course of finding a method of treating this problem when devising noise countermeasures. The wind direction and wind velocity as well as temperature gradients throughout the year were processed statistically and attenuation increases outside windward ($\phi=0°$) and leeward ($\phi=180°$) in respect to the main wind directions at those points on the ground were disregarded. Under these two conditions, *Fig. 33* and *34* which show attenuation increments for $\phi=0°$ and $\phi=180°$ resp. were obtained from actual experiments. Naturally these figures do not apply when the height of the land between the source and receiving point differs considerably. Especially in respect to the windward, the distance to the shadow zone X_0 increases as the land elevation increases (see *Table 4*). When the wind velocity is below 1～1.5 m/sec, the temperature gradient tends to become dominant, which must be considered in the planning.

VI. SOURCES OF TRANSFORMER NOISE AND THEIR NOISE LEVELS

1. Causes of Noise in Transformers

Causes of transformer noise can be classified as follows.

1) Primary causes

(1) Basic changes in magnetostriction of silicon steel sheet

In transformer cores, maximum magnetostriction develops during every half cycle of magnetization as shown in *Fig. 35*. Therefore, magnetostriction vibrations are based on a vibration frequency twice the excitation frequency and many harmonic vibra-

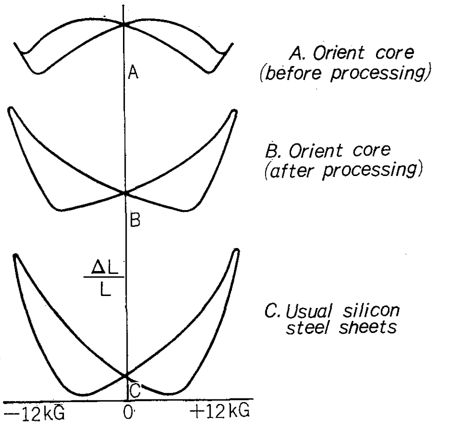


Fig. 33 Magnetostriction characteristics of electrical sheet steel excited at a maximum fluxdensity of 12 kilogauss

tions (integer multiples) are included so that the magnetostriction characteristics are non-linear. In other words, a 50 Hz transformer will include the basic 100 c/s sound and also 200, 300, and 400 c/s··· sounds. The influence of high frequency components is small.

(2) Vibrations in electromagnetic force between core joints and laminations.

Genenerally, these components can be disregarded in assembled cores. This phenomenon can be explained qualitatively as follows. It is very difficult to contact the core joints perfectly during manufacture. Therefore, in the joints, the ratio of the magnetic flux which penetrates into the silicon steel sheets and the magnetic flux in the air gap changes because of variations in permeability due to the silicon steel sheet's flux density. Since the permeability changes and non-linear, vibrations which are based on a vibration frequency twice the excitation voltage freqency as well as the mutual absorption power between the pull-out plate layers, with their harmonic vibrations develop.

(3) Vibrations in electromagnetic force between conductors and between windings.

Vibrations will arise by appling electromagnetic

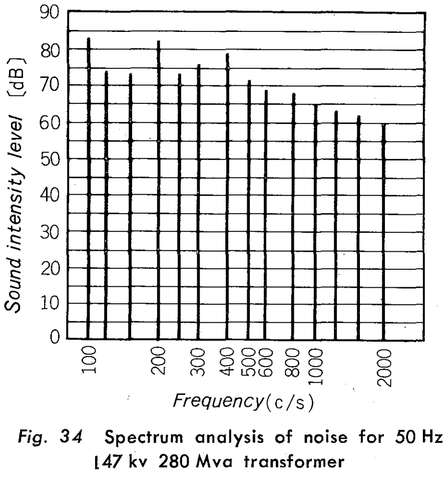


Fig. 34 Spectrum analysis of noise for 50 Hz 147 kv 280 Mva transformer

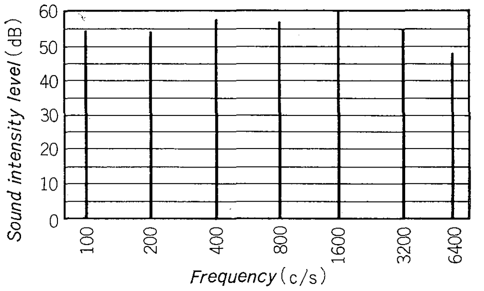


Fig. 35 Spectrum analysis of noise for 50 Hz cooling fan

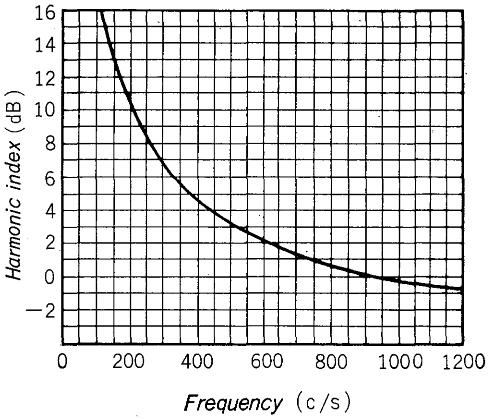
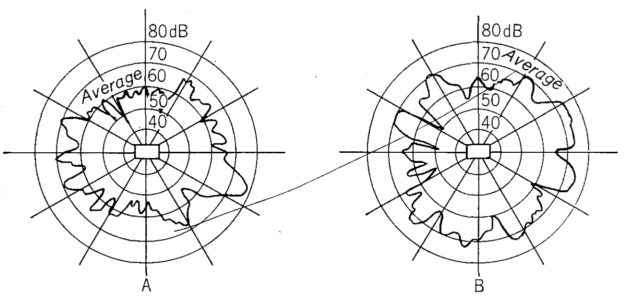


Fig. 36 Harmonic index of pure tone



(A at 1/3 and B at 2/3 of the height of the tank)

Fig. 37 Directional characteristics of noise for 125 Mva model transformer

force to the coils etc. but since the windings are usually tightened sufficiently, no problem arises quantitatively.

2) Secondary causes

(1) Noise generated from auxiliary equipment such as cooling fans and oil pumps, etc.

(2) Noise from resonance in the tank and radiator.

(3) Chattering due to insufficient tightening or incomplete contact of metal fixtures

(4) Noise due to resonance and reflection in the building.

2. Transformer Noise Characteristics

1) Spectrum analysis

Iron core magnetostriction vibration consists of a fundamental wave with a vibration frequency twice that of the excitation frequency with many integer multiple harmonics. For example, the noise of a 50 Hz transformer can be analysed into several frequencies from 100 c/s up to several thousand c/s. *Fig. 36* shows a spectrum analysis of the main noise components in the low frequency range (100∼400 c/s) based on actual tests with a 50 Hz 147 kv 280 Mva transformer. *Fig. 37* shows the noise spectrum analysis for a 50 Hz cooling fan. Although there is a wide band from the low frequency range to middle and high frequency range, this spectrum shows a uniform intensity in all cases.

It is necessary to know the noise frequency components in order to solve the noise problem and devise countermeasures. The response characteristics of a sound level meter are employed to roughly estimate these components. The difference between the level measured with the *C* scale and that measured by the *A* scale is called the harmonic index. If this is larger, the low frequency components can be considered predominate. If the harmonic index of sound is compared with the harmonic index of pure tone as shown in *Fig. 38*, a ferquency standard for the main component can be obtained. Usually, the difference between the *A* and *C* scales is about 8∼14 db for medium and large transformers. When measuring the transformer noise, there is no need to be limited to the *A* scale. By using the *C* scale as well, the number of values which can be utilized increases, and the *B* scale is also suitable for measuring purposes.

2) Directivity

Transformer sound like that from any ordinary sounding body does not radiate uniformly into the surroundings, but exhibits a complex directivity. It has been reported that in general power transformers, the lowest intrinsic vibration frequency of the full oil tank is about 20 c/s. Since the tank also possesses many higher effective vibration frequencies, there are many possibilities for some of the transformer vibration frequency components to resonate. Therefore, the actual conditions of tank vibrations are very complex and even with symmetrical type tanks, the intensity components of radiated noise are generally not symmetrical. In other words, the directivity is considerable and is exhibited in many directions. In actual transformers, directional requirements need a great deal of planning.

Since ambient noise also has some influence, it is difficult to ascertain the actual conditions since the noise is continuously changing at all points. The directional characteristics for the 125 Mva model transformer are shown in *Fig. 39*. This drawing illustrates intensity distribution of the basic frequency sound at a fixed radius from the center of the tank. *A* shows the results at 1/3 the height of the tank while *B* shows them for 2/3 the height of the tank. The noticable differences due to the vertical and horizontal changes are evident. Naturally, harmonic

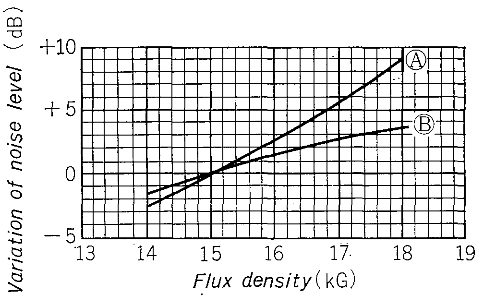


Fig. 38 **Variation of noise level with flux density**

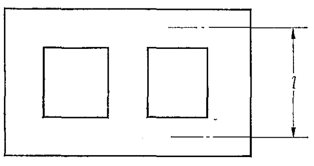


Fig. 39 **Effective length of the iron core**

wave sound also has the same type of complex directivity. From these considerations, the transformer noise level is decided generally by using the arithmetic average of levels taken at various measuring points.

3) Noise level

The requirements for measuring transformer noise level according to JEM standard 1117 will be given below.

With noise level at a flux density of 15 kG as standard, noise level changes in respect to flux density are as shown in *Fig. 40*. The Ⓐ line in the drawing shows the actually measured average of the 50∼300 Mva transformer which employs Fuji Electric's silicon steel sheets with cold rolling directional characteristics. The Ⓑ line shows the noise level values as calculated from the equation in 3 for a tranformer employing silicon steel sheets with hot rolling characteristics as developed by Rothert and Jordan.

If the magnetostriction characteristics of the material of the core are almost constant and the frequency is constant (50 Hz), the noise is measured according to the flux density and effective length of the iron core by the following equation. In other words, the noise is determined theoretically by introducing various assumptions from the vibration amplitude due to magnetostriction of the iron core.

$$L = k_1 + k_2 \log_{10} l + k_3 \log_{10} (k_4 B - k_5) \qquad (25)$$

where l: Effective length of core (see *Fig. 41*)

B: Flux density (Gauss)

L: Sound intensity level (dB)

The above type of calculation has been widely used up to now to determine noise generated by transformers, but the conditions of transformer noise generation are extremely complicated and can not be explained merely by simple theory. Fuji Electric has developed a method for estimating the noise generated by a transformer using statistics and based on actual results obtained to the present.

An example will be given below in which the noise level generated by a transformer over 40 Mva is estimated according to this method.

(1) Relation between noise level L (phon) and magnetic flux density B (kG)

The relation between the noise level L (phon) and the magnetic flux density B (kG) is shown in *Fig. 42*. For each of the straight lines *A, B, C* and *D* in the drawing, the level of significance was 5%.

(2) Relation between noise level L (phon) and core weight W (ton)

This relation is shown in *Fig. 43*. For each of the straight lines *A, B, C* and *D* in the drawing the level of significance was 5%. When the magnetic flux density is not 17 kg, compensation is performed in accordance with *Fig. 40*.

(3) Relation between noise level L (phon) and equivalent transformer output P (Mva)

This relation is as shown in *Fig. 44*. Again the level of significance is 5% for each of the straight lines *A, B, C* and *D*.

(4) Attenuation of noise level in respect to distance.

The attenuation characteristics of noise level in respect to distance are shown in *Figs. 45* and *46*. The *A* line in *Fig. 45* shows the theorectical attenuation curve of $-20 \log_{10} D$ (D: distance operating

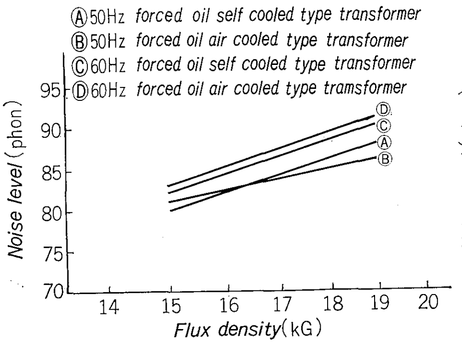


Fig. 40 **Relation between noise level and flux density**

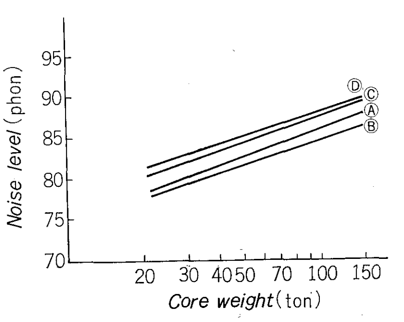


Fig. 41 **Relation between noise level and core weight**

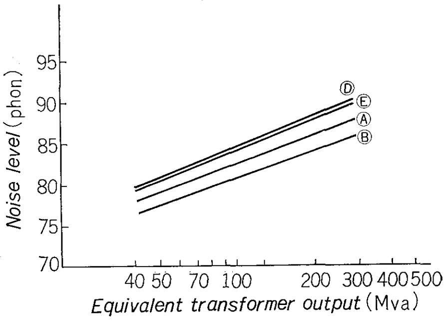


Fig. 42 **Relation between noise level and equivalent transformer output**

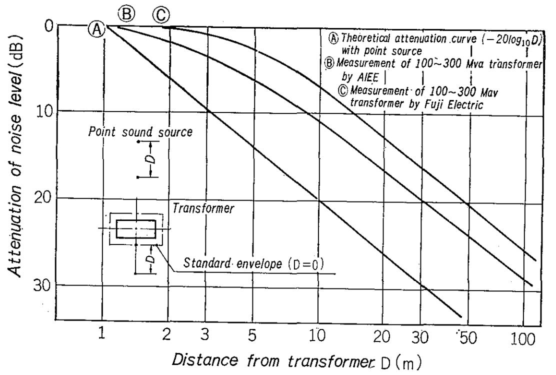


Fig. 43 **Attenuation characteristics of nois vs. distance**

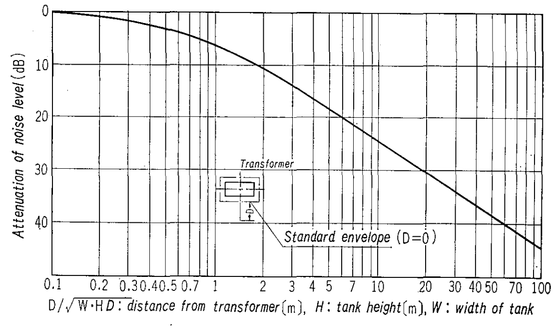


Fig. 44 **Attenuation characteristic of noise vs. distance**

in meters) in respect to a point sound source. The *B* line shows actual operating results using a AIEE 50~100 Mva transformer. The *C* line shows actual results using a Fuji Electric transformer over 100 Mva. The attenuation up to about 20 m from the transformer is smaller in the *B* and *C* lines than the *A* line because a point sound source does not exist in practice with larger capacity transformers. However, for distances over 20 m, the slopes of all three attenuation curves (*A, B* and *C*) are the same. Therefore, the relation of the noise value of the noise source has to be considered and *Fig. 46* shows the results obtained from experiments of noise attenuation versus distance using a rectangular surface instead of a point source. These values agree well with the actually measured values. From the above information it is evident that if the distance from the transformer to the areas where noise must be prevented and the transformer size are known, the sound level at the area in question can usually be estimated.

VII. REGULATIONS AND TOLERANCES CONCERNING TRANSFORMER NOISE

The intensity and loudness of sound were discussed in section V but there are more points which must be considered when considering sound as noise. For example, it is improtant to employ a scale established in actual practice in respect to annoyance. Naturally this is not a simple problem and up to the present no universally applicable scale has been established.

When installing transformers, it is easier and more economical to estimate pre-determined noise level tolerances and devise countermeasures than to be faced with future problems, and therefore these matters can not be disredarded.

The sensation of annoyance in relation to noise is closely related to the following factors.

(1) The loudness of the noise in question.
(2) The loudness of ambient noise.
(3) Time characteristics and generation characteristics of the noise.
(4) Purity and impact of the noise.
(5) Whether or not the residents have experienced the noise before.

In addition to the above, there are many factors which can not be given actual values (physchological factors) such as the residents' emotions and prejudices, and these will often cause discrepancies in evaluation of annoyance.

1. Noise Prevention Ordinances

As shown in *Table 5*, many communities have enacted noise prevention ordinances in order to eliminate public noise hazards, and it is thus essential to correlate noise prevention with these ordinances. As an example, some specified noise values extracted from the Tokyo Metropolitan Area's noise prevention ordinances according to readings of a sound level meter.

Table 5 **Extract from the Tokyo Noise Prevention Ordinance**

Type of area	Area	Time 8.00~19.00	Time 6.00~ 8.00 19.00~23.00	Time 23.00~6.00
Area of first type	Special residential areas and No. 1 type school areas	50 phons	45 phons	All noises which can be heard clearly are prohibited
Area of second type	Residential areas and green areas	55 phons	50 phons	
Area of third type	Business area, semi industrial areas and industrial areas	60 phons	55 phons	
Area of fourth type	Areas of third type which are roads more than 11 m wide and areas within 10 m from the boundaries of open spaces	65 phons	60 phons	
Area fifth type	Ommitted (near busy areas)	70 phons	65 phons	

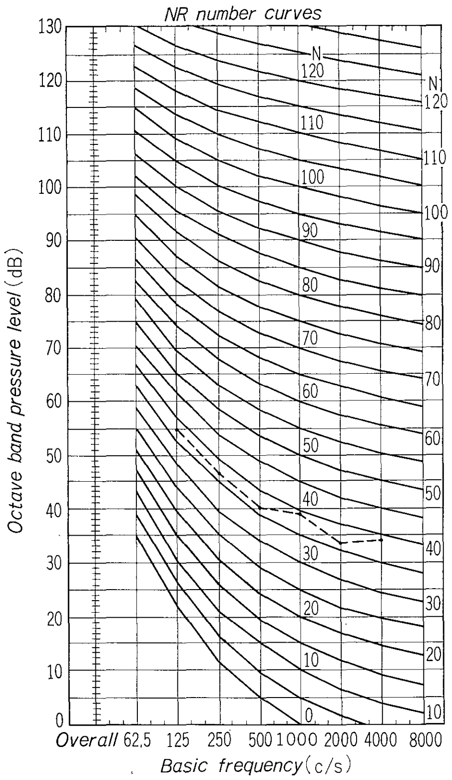


Fig. 45 Noise rating number contour

***Table 6 (1)* Correction of Noise Rating Numbers with Regard to Noise Characteristics**

	Conditions	NR number correction value
Spectrum	Pure tone Noise of wide band	+ 5 0
Waveform factor	Impact type Non-impact type	+ 5 0
Estimated when noise is repeated continuously for about 0.5 min.	Every minute 1 time Every hour 10～60 times Every hour 1～10 times Every day 4～20 times Every day 1～ 4 times Every day 1 time	0 − 5 −10 −15 −20 −20
Past experience	None Some Considerable	0 − 5 −10
Time which sound is heard	Only daytime Only night Cold season Summer season	− 5 + 5 − 5 0
Area conditions	Farming village Suburbs Residential area (large city) Light industrial area near city Heavy industrial area	+ 5 0 − 5 −10 −15

2. Noise Rating Values (NR Numbers)

The ISO Conference in Helsinki in 1961 adopted the NR (noise rating) numbers for noise rating and countermeasure standards.

***Table 6 (2)* Noise Rating Number in the Open Air in Residential Areas and Public Reaction Against the Number**

Corrected NR Numbers	Estimated Reaction
And under 40	No reaction
40 ～ 50	Scattered complaints
45 ～ 55	Wide range of complaints
50 ～ 60	Indications of area activity
And over 60	Powerful area activity

***Table 6 (3)* Recommendations of NR Numbers to Suit Purposes of Building**

NR Number	Example of suitable rooms
20～30	Bedrooms, sick rooms, TV studios, living rooms, theaters, churches, movie theaters, concert halls, small offices, reading rooms, conference rooms, class rooms
30～40	Large offices, stores, department stores, reception rooms, quiet restaurants
40～50	Large restaurants, secretarial rooms with typewriters, Gymnasiums
50～60	Large typing areas
60～70	Factories

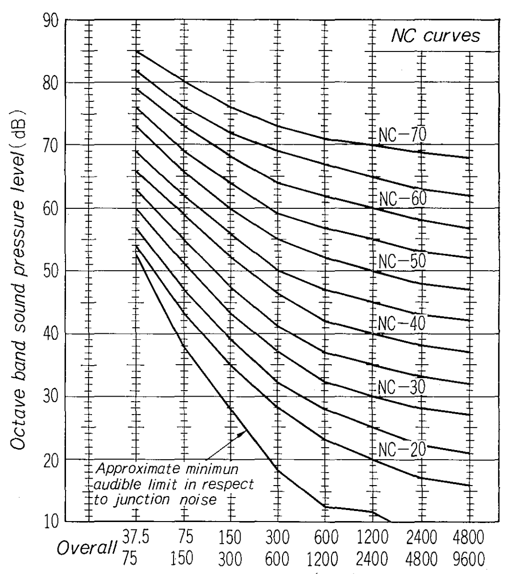


Fig. 46 Noise criteria contour

First, a frequency analysis of the sound in question is carried out at the octave band according to the *C* scale. From the results of this, the *C* scale sound pressure levels within each of these bandwidths are entered on a graph as shown in *Fig. 47*, and the NR values of the curves which contact these values from above are the NR numbers. For example, when the *C* scale noise spectrum of a transformer with a composite noise level of 39 phons according to the *A* scale is as shown by the dotted line in *Fig. 47*, the NR number is slightly less than 40.

This NR number is an objective expression of annoyance and these numbers differ according to the subjective qualities of the sound and the ambient conditions. Since the sensation of annoyance for humans in respect to noise is a purely subjective matter, it is necessary to make appropriate corrections of NR numbers according to the conditions shown in *Table 6* (1).

For example, the following correction are required in this case : the spectrum is near that of pure sound +5 ; a percentage of the waveform does not make impact 0 ; there is some past experience −5, there is continuous sound night and day all year around +5, the equipment is installed in the suburbs 0. Therefore a total correction of +5 must be made, so that the NR value will become 45 and from *Table 6* (2) it can be seen that this will cause almost no complaints. *Table 6* (2) and *6* (3) give decisive factors concerning corrected NR numbers.

3. NC Curves

NC (noise critieria) curves (shown in *3 Fig. 48*) developed by Berank in 1957 from the results of investigations using 300 industrial workers are widely used along with loudness for rating noise loudness determined by the frequency characteristics in the octave band. In this case, the NC values are given by the values on the curves approach from the lower part as near as possible the actual measured values plotted as in the figure. The deciding factors concerning NC values are omitted here.

VIII. CONCLUSION

This paper began with the features of Fuji Electric's low sound level transformers and continued with general aspects of transformer sound and basic matters concerning accoustics.

Recently there have been pronouced trends towards the installation of large capacity transformers near residental areas so that transformer noise problems have become more and more important. Under these circumstances, it is hoped that this article will be of some use when planning substations and investigating problems concerning transformer noise.

The way in which transformer noise is generated is so complex that it is very difficult to deal with it purely by theory and therefore to deal with the problem of transformer noise adequately, practical considerations are extremely important. From now on more efforts will be devoted to the investigation of unsolved matters as well as the accumulation of practical experience data.

The writers wish to express their most sincere thanks to all those both inside and outside of the company who rendered them assistance in the form of data or pretinent advice.